Pilot Study:
Implementation of a Periphyton Monitoring Network for the Non-Tidal Delaware River

Delaware River Biomonitoring Program
Delaware River Basin Commission
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SUMMARY and RECOMMENDATIONS

This pilot study at five middle and lower non-tidal Delaware River sites indicates that:

1. The Delaware River generally possesses a diatom community characteristic of high water quality and high biological integrity.
2. The diatom community of the northern Delaware River appears to be less rich, less diverse, less pollution tolerant, and more indicative of oligotrophic conditions than that of the lower non-tidal Delaware River.
3. The lower non-tidal Delaware River contains high relative abundance of diatom taxa indicative of high nutrient concentrations.
4. Two of the five sites, at Portland and Washington Crossing, exhibited high abundance of diatom taxa that are tolerant of siltation or substrate instability.
5. Results are based upon only five samples, so further investigation is required to verify these conclusions.

Recommendations:

1. Additional Delaware River periphyton monitoring should be conducted as an annual survey from Hancock, New York to Trenton, New Jersey (see Appendix C for Current Site List). Over time, representative baseline conditions should be established for analyses of spatial and temporal trends in Delaware River biological conditions.

2. Periphyton data should be used to establish water quality biocriteria; nutrient criteria; and eutrophication criteria for the Delaware River. These data should be used alongside those generated by parallel DRBC nutrient assimilation studies to determine nutrient thresholds.

3. Resources should be allocated for additional Delaware River investigations related to primary producers, nutrients and trophic state, including description of the relationships between periphyton, phytoplankton, submerged aquatic vegetation in these processes. In addition, the relationships between primary producers and higher trophic levels, such as macroinvertebrates and fish, should be further explored.

4. Over time, it is expected that more data will become available from the DRBC, State monitoring programs, and the USGS NAWQA program. Using these local data, DRBC should determine Delaware River specific optima and tolerance values of physical and chemical determinants of periphyton community structure. These can be included in water quality and flow models for prediction of water quality changes and eutrophication events.

Introduction

The Delaware River Basin Commission (DRBC) is responsible for water quality regulation and assessment of the main stem Delaware River. In order to fulfill goals and objectives defined in the Water Resources Plan for the Delaware River Basin (DRBC 2004a), the Delaware River Biomonitoring Program aims to improve DRBC's capacity to manage the river as an ecological resource.

Assessment of aquatic life use in the Delaware River and understanding the relationships between water quality and aquatic life requires examination of multiple biological assemblages (Barbour et. al 1999; Karr and Chu 1999). This document represents an expansion of DRBC's biological monitoring and assessment program. Beginning in August 2001, DRBC began to implement annual benthic macroinvertebrate surveys to begin using biological data for determination of existing biological quality targets under the DRBC Special Protection Waters rules, and eventually for assessment of Aquatic Life Use attainment as described in section 305(b) of the Clean Water Act. As of Summer 2006, 4 full sets of benthic macroinvertebrate samples have been collected and will be analyzed for development of biocriteria for the main stem Delaware River. Although macroinvertebrate data are useful, it is necessary to widen programmatic focus to also include periphyton, fish, mussels, aquatic plants, instream habitat and riparian conditions for determination of the effects of water quality and various stressors on the biota.

Periphyton are diatoms and algae that live attached to aquatic substrate (Moulton et. al 2002). Periphyton monitoring programs have grown in popularity in recent years, and are used as regulatory tools in the UK, Australia, and several U.S. states. Periphyton are characteristically non-mobile, taxonomically rich, excellent indicator organisms of specific environmental conditions, and accurately reflective of the physical, chemical, and biological disturbances that occur at a site over a short period of time. Based on their relatively short life cycles (3-4 weeks), they best characterize episodic impairments within a relatively short time frame. When the periphyton assemblage is used in conjunction with invertebrate data, analysis of short lived organisms (periphyton) and longer lived organisms (invertebrates) can capture a wide range of environmental stressors and biological responses for accurate assessment of water quality and ecological integrity of the Delaware River. Various environmental stressors expected to be assessed through periphyton monitoring include nutrient pollution, eutrophication, habitat instability, fine sediment pollution, and flow changes (Stevenson et. al 1996; Barbour et. al 1999; Kentucky DEP 2002; Potapova et. al 2004).

Among the environmental stressors mentioned above, nutrient pollution and eutrophication are immediate concerns in parts of the Delaware River. In recent years, chemical monitoring has revealed high nitrogen and phosphorus concentrations, very high pH, and wide daily variation of dissolved oxygen concentrations. During extended periods of low flow conditions, there were also many observations of nuisance aquatic plant and nuisance algae growth and activity (DRBC 2004b). An important part of this study is to use the periphyton assemblage to provide biological evidence of potentially eutrophic conditions in the Delaware River.

Depending upon variability of data, sufficient information may be available within 3 to 5 years to develop periphyton-based biological criteria or nutrient criteria for the non-tidal Delaware River. Such criteria may be applied using annual periphyton surveys (concurrent with annual macroinvertebrate surveys) to provide an integrated assessment of Delaware River water quality under sections 305(b) and 303(d) of the Clean Water Act.

The purposes of this pilot study were to:

- Use various metrics of biotic integrity to generally assess the Delaware River periphyton community;
- Examine biological response to increased nutrient concentration along the river;
- Apply various eutrophication measures (New Jersey DEP, Kentucky DEP; UK Environment Agency) to explore effects of increased nutrient concentrations in the Non-Tidal Delaware River; and to
- Develop a practical, economical and logistically viable algae monitoring component to an existing biological monitoring program, starting with five (5) sites in 2005 and expanding to twenty-five (25) sites in 2006 and beyond.

Methods

In 2005, the pilot periphyton study was conducted at 5 Delaware River sites between Port Jervis, New York and Washington Crossing, New Jersey (Figure 1). Figure 2 shows Delaware River hydrologic conditions surrounding the study period.

Periphyton Collection for Taxonomic Analyses

All samples were collected concurrently with the annual invertebrate sample collections on the main stem Delaware River. Similar to DRBC's benthic macroinvertebrate monitoring strategy, periphyton samples were collected from a single habitat to accurately reflect water quality changes from year to year and from site to site along the river. Samples were collected in riffle areas as described in the Richest Targeted Habitat approach used by the USGS National Water Quality Assessment (NAWQA) program (Moulton et. al 2002). Taxonomic data were used to calculate common community metrics listed below for assessment of biotic integrity (Hill et. al 2000; Potapova and Charles 2005; Ponader et. al 2005; Bahls 1993; Kentucky DEP 2002; Kelly et. al 2001; Barbour et. al 1999):

% Diatoms
% Cyanobacteria
% Dominant Diatom
% Acidophilic Diatoms
% Eutraphentic Diatoms
% Motile Diatoms
Chlorophyll *a*
Ash-Free Dry Mass (AFDM)
Autotrophic Index

Total Number of Diatom Genera
Shannon Diversity of diatoms
KY Diatom Pollution Tolerance Index
US Diatom TP and TN metrics
NJ Diatom TP and TN Indices
MT Diatom Pollution Tolerance Index
UK Trophic Diatom Index
Siltation Index
Fragilaria & Cymbella Group Richness

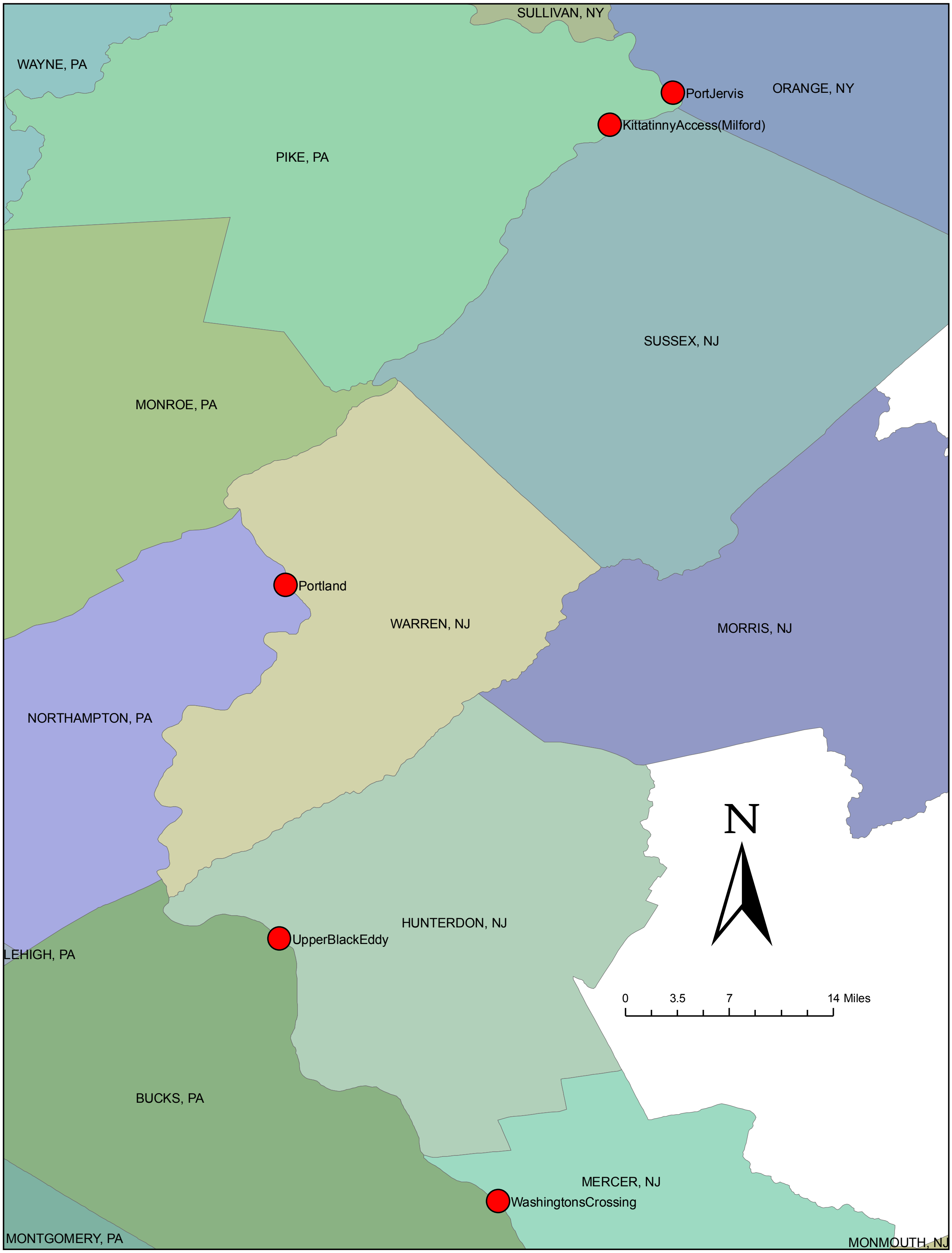

Figure 1. Location of DRBC Periphyton Monitoring Sites 2005. From north to south, sites were located at Port Jervis, Kittatinny Access, Portland, Upper Black Eddy and Washington Crossing.

Density specific analyses (Chlorophyll a and Ash Free Dry Mass) were also evaluated, and the resulting data are also expected to be used to aid in development of nutrient criteria for the main stem Delaware River as well as to support QUAL2K model simulations in various river reaches.

Field procedures generally followed those of the NJDEP Algal Indicators Project (Charles et. al 2000; Ponader and Charles 2003; Ponader et. al 2005). The following standard procedures, taken from the Delaware River Biomonitoring Program 2006 Quality Assurance Project Plan (DRBC 2006) were developed and employed to gather information.

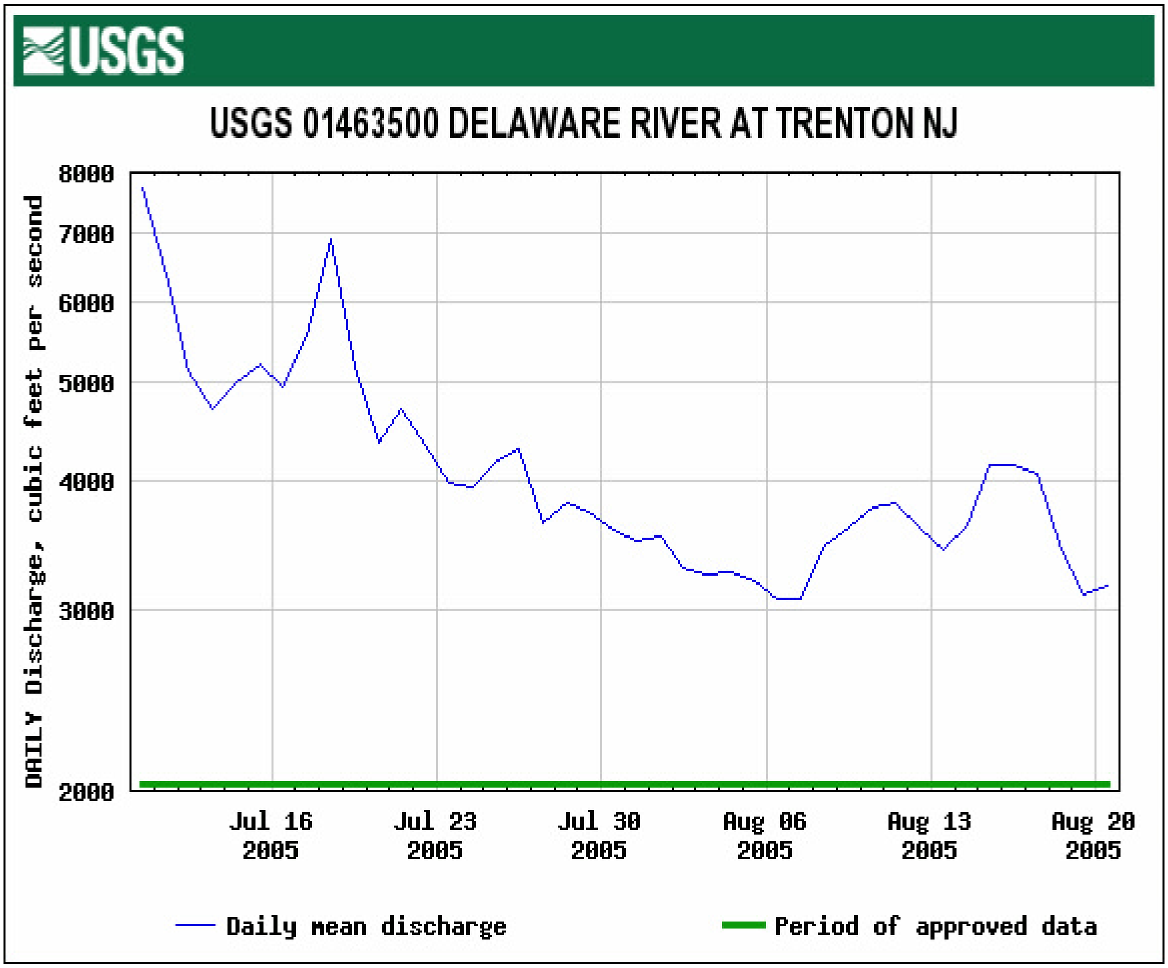

Figure 2. Delaware River at Trenton, NJ, daily mean discharge during study period. Arrow shows sampling period.

DRBC Standard River Biology Procedure – Periphyton

The periphyton sample collection method gathers periphyton from Richest Targeted Habitat, just like the macroinvertebrate method used by DRBC. Periphyton are sampled at the same time as invertebrates and at the same locations (upstream and parallel to the macroinvertebrate sampling transect). Collection methods were adapted from Field Sampling Procedures for the New Jersey Algae Indicators Project (ANSP Procedure No. P-13-64, Charles et. al 2000).

After taking macroinvertebrate samples, an algae transect is established in RTH parallel to the macroinvertebrate sampling transect. From this transect (approximately 30 m long), three (3) representative cobbles are taken and placed into a white plastic pan for Chlorophyll A and AFDM sampling. Locations where each cobble was taken are flagged. These rocks are photographed with a measurement scale. Using the top-rock scrape method described in the RBP (Barbour et. al 1999), a composite sample is scraped, rinsed and transferred into a pre-weighed and numbered 250 ml plastic bottle. The area of each cobble that was scraped is covered by aluminum foil and cut to shape for later area measurement in the office. The 3 foil cutouts are placed in a Ziploc bag and labeled. The sample is iced, with no preservative, and shipped within 24 hours to the environmental geochemistry laboratory at the Academy of Natural Sciences of Philadelphia, PA. Once received by ANSP, the samples are analyzed under the following standard procedures, and results reported to DRBC:

1. Benthic Algae and Sediment Chlorophyll A Preparation and Analysis (ANSP Procedure No. P-16-117, Velinsky and DeAlteris, 2002)

2. Determination of Dry Weight and Percent Organic Matter for Sediments, Tissues and Benthic Algae (ANSP Procedure No. P-16-113, Kiry et. al. 2000).

An additional five (5) cobbles, preferably without large growths of filamentous algae, yet representative of cobbles found throughout RTH, are collected from the transect and placed in a white plastic pan. Flags are placed to indicate locations where cobbles were taken. Cobbles are photographed, scraped, and rinsed with river water into a 500 ml plastic bottle and preserved with buffered formalin (constituting 3 to 5% of total sample volume). The aluminum foil area measurement procedure described above is repeated for each cobble. Samples are labeled and stored for later analysis of diatom taxonomy. Diatom taxonomy follows the ANSP Standard Procedure:

1. Procedure for Semi-Quantitative Analysis of Soft Algae and Diatoms (ANSP Procedure No. P-13-65, Ponader and Winter, 2002).

Once the samples are taken, additional site measurements are taken and recorded on the Quantitative Targeted Habitat Periphyton Sample Field Data Sheet. Measurements include:

- Particle size class of each cobble sampled (using gravelometer template)
- At each flag, record depth (which should be a minimum of one foot), velocity, shading, percent canopy (densiometer), and macroalgae color/type.
- At upstream end, middle, and downstream end of transect, measure PAR 400-700 nm light intensity at 6 depths: top, 1/5, 2/5, 3/5, 4/5 and bottom depth.
- Record weather, precipitation, water quality, clarity and color characteristics.

In the office, copy a full scale image of each piece of foil to an 8.5x11 sheet and record label information on each sheet. Use a Sharpie to make bold the outline of each piece of foil. Create an Adobe® document of sheets, and open the document at full scale in ARC MAP®. Digitize and measure the area of each piece of foil, so that Chlorophyll a, AFDM, and algal densities can be expressed.

DRBC Standard River Biology Procedure - Quantitative Instream Habitat

Pebble counts, depth profiles and flow measurements are conducted to quantitatively characterize the microhabitat of the samples taken to eliminate the subjectivity of the site selection process.

Pebble Count: A 100-particle pebble count is conducted at the each of the sampling sites to numerically characterize the particle size of each of the sampled areas (Wolman, 1954). 100 particles are gathered along the sampled transect and measured using an AL-SCI Field Sieve from Albert Scientific. Particles are selected by stepping along the transect line, bending without looking at the substrate and selecting the first particle touched. The transect should be sampled as evenly and representatively as possible, without concentrating on any particular portion of the transect. Particles are placed in the sieve to determine the size class of each particle and the data recorded using a #2 pencil on the brushed aluminum surface of the sieve until data can be transferred to a field sheet. Measurements are analyzed in the field for completeness, and to determine the median particle size (D50) and class of substrate present. These measurements are used to validate the comparability of the benthic community collected with each sample. The median particle size (D_{50}) should fall in the range between 40 and 70 mm. Outliers are noted in statistical analysis of results.

Velocity Measurement: Velocity and depth are measured with a digital Pygmy meter and wading rod at the left, center, and right edge of each of the 2x2 ft kicks sampled for macroinvertebrates and once at each location where a cobble was taken for periphyton. Each velocity measurement should be taken at 6/10 of the depth wherever the depth is less than 3 feet. Locations greater than 3 feet deep should not be sampled. The average velocity and depth validates the comparability of samples. The average velocity at each site should fall in the range of 1.0 and 3.0 cfs. Any samples falling outside this range will be noted in statistical analysis. Depth of samples collected should range between 0.5 and 1.5 ft. Outliers are noted in statistical analysis.

DRBC Standard River Biology Procedure - Water Quality

Instantaneous water quality measurements are taken once at each sampling site. The RBP Physical Characterization / Water Quality Field Sheet is completed once per site. A YSI or Hydrolab multi-parameter meter is used to collect data for the following parameters:

- Dissolved Oxygen (mg/L)
- Temperature (^{o}C)
- Conductivity (mS/cm)
- pH
- Turbidity (NTU) – if available

Instrumentation is calibrated for all parameters on a daily basis with the exception of Dissolved Oxygen Percent Saturation (DO %), which is calibrated at each site, and Turbidity, which requires Formazin calibration that is not safe for field calibration and disposal. The calibrations are recorded in a logbook for analysis following completion of sampling. Meter calibration is verified prior to measurements at each site.

DRBC Standard River Biology Procedure - Qualitative Habitat Assessment

Habitat conditions are qualitatively assessed using the high-gradient RBP (Barbour et. al 1999) habitat assessment once at each site. This habitat assessment system uses the following parameters to approximate the instream health of the system:

- Epifaunal Subtrate/ Available Cover
- Embeddedness

- Velocity Depth Regime
- Sediment Deposition
- Channel Flow Status
- Channel Alterations
- Frequency of Riffles (or Meanders)
- Bank Stablility
- Vegetative Protection
- Riparian Vegetative Zone Width

These measurements, once analyzed, are used to describe habitat conditions and identify factors attributing to biological changes.

DRBC Standard River Biology Procedure - Location Information

Location information is collected at each site using a hand-held Magellan GPS unit. The positioning information is used for Geographic Information System (GIS) presentation and analysis of data. Location information and notes are reported on a set of DRBC "River Recreational Maps" and in log books. Field notes are combined with field sheets for later data entry. Digital photographs are taken in the following order at each site:

- Directly upstream (1)
- Upstream toward right shore (2) and left shore (3)
- Directly toward right shore (4) and left shore (5)
- Downstream toward right shore (6) and left shore (7)
- Directly downstream (8)
- Substrate photo of macroinvertebrate station A (downstream end of transect) (9)
- Substrate photo of macroinvertebrate station B (mid-transect) (10)
- Substrate photo of macroinvertebrate station C (upstream end of transect) (11)
- Photos of white pan containing mussels from A (12), B (13), and C (14). ID and count mussels.
- Photo of white pan, with measurement scale, containing 3 Chlorophyll a / AFDM cobbles (15)
- Photo of white pan, with measurement scale, containing 5 Diatom Taxonomy cobbles (16)
- Other photos as needed (NOTE in field notes, starting with #17 per site no.)

Ambient Nutrient Sample Collection

In order to best characterize nutrient versus periphyton relationships and interpret periphyton data, nutrient samples were collected weekly at each of the sampling locations for a period of one month prior to periphyton sample collection. For the pilot study, 5 sites were chosen based on the presence of both a periphyton sampling location and an established ambient nutrient sampling location within very close proximity of one another (Table 1). Nutrient Results are shown in Appendix B.

River Mile	Site Number	Site Name	Project	Parameter	Latitude	Longitude
254.75	*NA*	Delaware R. at Port Jervis	Tri-State	Nutrients	41.37173	-74.69723
255.00	DRBC2550	Delaware R. at Port Jervis	Biomonitoring	Periphyton	41.37229	-74.69813
250.00	*NA*	Delaware R. at Bdy of DWGNRA	Tri-State	Nutrients	41.32280	-74.75774
249.89	DRBC2499	Delaware R. at Kittatinny Access	Biomonitoring	Periphyton	41.34134	-74.75964
207.40	NJPAC11	Delaware R. at Portland	L. Delaware	Nutrients	40.92417	-75.09611
207.20	DRBC2073	Delaware R. at Portland	Biomonitoring	Periphyton	40.89449	-75.07563
167.70	NJPAC06	Delaware R. at Milford	L. Delaware	Nutrients	40.56639	-75.09889
166.60	DRBC1666	Delaware R. at Upper Black Eddy	Biomonitoring	Periphyton	40.55148	-75.08178
141.80	NJPAC02	Delaware R. at Washington Crossing	L. Delaware	Nutrients	40.29528	-74.86889
141.98	DRBC1418	Delaware R. at Washingtons Crossing	Biomonitoring	Periphyton	40.29657	-74.86853

Table 1. Delaware River Sites for Periphyton and Nutrient Samples – 2005 Pilot Study.

Results and Discussion

The taxonomic list (Appendix A), autoecological information derived from various sources (Appendix B) and relative abundance data were used to express results in terms of various commonly applied community metrics (see Table 2). These metrics can be used to describe the biotic response by the periphyton assemblage to physical and chemical conditions in the Delaware River. Since so few samples were taken (n=5), it is possible only to draw very general conclusions. The data set was very useful, however, for exploring metrics and their potential uses. Metrics are described in Appendix C.

	Delaware River Mile					
Metric	**141.9**	**166.6**	**207.2**	**249.9**	**255.0**	**Source of Info.**
% Diatoms	62	86	15	68	71	Hill et al.2000
% Cyanobacteria	38	13	49	25	24	Hill et al.2000
% Dominant Diatom	22	29	15	21	26	Hill et al.2000
% Acidophilic Diatoms	0	0.3	0	0	0.3	Hill et al.2000
% Eutraphentic Diatoms	39	50	54	26	27	Hill et al.2000
% Motile Diatoms (Siltation Index, %NNS)	55	37	54	38	36	KYDEP 2002
Chlorophyll *a* concentration (mg/m^2)	0.72	0.93	2.74	6.44	2.28	KYDEP 2002
Ash Free Dry weight (AFDW, mg/m^2)	660	2972	875	1106	342	KYDEP 2002
Autotrophic Index (AI)	917	3196	319	172	150	KYDEP 2002
Total Number of Diatom Taxa	23	23	15	15	14	KYDEP 2002
H'=Shannon Diversity of Diatoms (Base 10)	1.30	1.32	1.24	0.95	0.99	KYDEP 2002
Shannon Diversity of Diatoms (Base e)	2.99	3.03	2.84	2.18	2.29	KYDEP 2002
KY Diatom PTI (1=tolerant, 4=sensitive)	2.28	2.37	2.51	3.22	2.98	KYDEP 2002
US Diatom TP (low TP % abundance)	9.7	12.3	17.2	34.0	41.2	Potapova & Charles 2005
US Diatom TP (high TP % abundance)	52.8	19.7	14.2	2.3	4.0	Potapova & Charles 2005
US Diatom TN (low TN % abundance)	6.3	9.7	18.2	54.3	65.5	Potapova & Charles 2005
US Diatom TN (high TN % abundance)	63.8	44.2	29.7	5.3	10.0	Potapova & Charles 2005
US Diatom TP Index (high/low optima ratio)	8.4	6.2	4.5	0.6	0.9	Potapova & Charles 2005
US Diatom TN Index (high/low optima ratio)	9.1	8.2	6.2	0.9	1.3	Potapova & Charles 2005
MT Diatom PTI (1=tolerant, 3=sensitive)	2.38	2.60	2.45	2.62	2.64	Bahls 1993
UK Trophic Diatom Index (1-100)	68	60	50	65	53	Kelly et. al 2001
UK WMS (1=very low nutrients,5=very high)	3.72	3.39	2.98	3.59	3.11	Kelly et. al 2001
Fragilaria + Cymbella Group Richness (%max)	86	57	100	86	86	KYDEP 2002
Kentucky DBI (modified)	85	85	82	84	83	KYDEP 2002

Table 2. Commonly applied algal community metrics applied to Delaware River samples. Caution: as N = only 5, no major conclusions can be drawn from these results.

	Delaware River Mile				
Parameter	1418B mean (min-max)	1666B mean (min-max)	2073B mean (min-max)	2499B mean (min-max)	2550B mean (min-max)
NH3-N mg/l, n=6	0.08 (0.03 – 0.13)	0.13 (0.07 – 0.16)	0.14 (0.04 – 0.29)	0.09 (0.06 – 0.11)	0.08 (0.06 – 0.10)
TKN mg/l, n=6	0.49 (0.27 – 0.67)	0.37 (0.32 – 0.44)	0.31 (0.21 – 0.39)	0.71 (0.40 – 1.00)	0.72 (0.40 – 1.00)
NO3-N mg/l, n=6	0.95 (0.94 – 0.97)	1.06 (1.02 – 1.10)	0.3 (0.02 – 1.08)	0.12 (0.04 – 0.22)	0.14 (0.06 – 0.21)
TN mg/l, n=6	1.4 (1.20 – 1.60)	1.4 (1.40 – 1.50)	0.6 (0.20 – 1.40)	0.8 (0.50 – 1.10)	0.9 (0.50 – 1.20)
TP mg/l, n=6	0.08 (0.03 – 0.11)	0.11 (0.05 – 0.16)	0.09 (0.02 – 0.18)	0.04 (0.03 – 0.05)	0.05 (0.05 – 0.05)
TN:TP ratio, n=6	18 (15 – 40)	13 (9 – 28)	7 (8 – 10)	20 (17 – 22)	18 (10 – 24)
Depth (ft), n=9	1.29 (1.2 – 1.4)	0.91 (0.75 – 1.0)	1.04 (0.8 – 1.2)	1.34 (1.05 – 1.5)	0.93 (0.5 – 1.2)
Velocity ft/sec mean, n=9	2.52 (1.8 – 3.1)	1.97 (1.4 – 2.4)	1.49 (1.2 – 1.8)	2 (1.6 – 2.2)	1.18 (1.0 – 1.5)
Particle Size (mm) D16, n=100	32	8	32	30	35
Particle Size (mm) D35, n=100	48	27	65	43	57
Particle Size (mm) D50, n=100	66	40	87	52	78
Particle Size (mm) D84, n=100	123	94	197	86	174
Particle Size (mm) D95, n=100	207	180	287	128	241
Dissolved Oxygen mg/l, n=1	6.32	7.15	7.86	7.83	7.96
Dissolved Oxygen % saturation, n=1	0.928	1.046	0.964	1.144	1.174
Air Temperature, n=1	23	22	23	24	26
Water Temperature, n=1	25.48	25.47	26.43	25.32	25.67
Specific Conductance umhos/cm, n=1	225	225	95	78	78
pH, n=1	7.55	7.83	7.87	7.58	7.97
Turbidity NTU, n=1	3.9	3.5	0.3	1.4	0.9

Table 3. Physical and Chemical Results, July-August 2005

Results Related to Nutrient Concentrations and Eutrophication

Biological measures of nutrient conditions included % Eutraphentic Diatoms, Chlorophyll A, Autotrophic Index, US Diatom TP and TN optima (% abundance and ratios), the UK Trophic Diatom Index, and the UK Weighted Mean Sensitivity score. Some of these measures displayed very clear responses to increased nutrients, others less so as shown in Table 2. Weighted Mean Sensitivity (WMS) is a measure used within the Trophic Diatom Index (Kelly et. al 2001) based upon species-specific nutrient optima. The range shown in Table 2, of about 3 to 3.7, places Delaware River sites in the intermediate to high nutrient range as calculated using historical European diatom autoecology data that may not translate well to U.S. algal communities. Due to small sample size, the Trophic Diatom Index has relatively little meaning, and more intensive sampling is required to distinguish changes. The Autotrophic Index is not directly related to nutrient conditions and tends to vary significantly with the amount of other organic matter in each sample. Other nutrient-related measurements produced ambiguous results.

The U.S. TP and TN indices shown in Figure 3 were developed from U.S. NAWQA data and may be the most relevant metrics as applied to Delaware River sample information. They produced results showing a strong longitudinal shift in the periphyton community. Northern sites Port Jervis and Kittatinny Access are dominated by low nutrient indicator species, and lower non-tidal sites Portland, Upper Black Eddy and Washington Crossing are increasingly represented by high nutrient indicator species. Using nutrient optima determined from NAWQA samples (Potapova and Charles 2005), abundance of species preferring high nutrients were compared to those preferring low nutrients. Figure 3 shows results at the 5 sample sites.

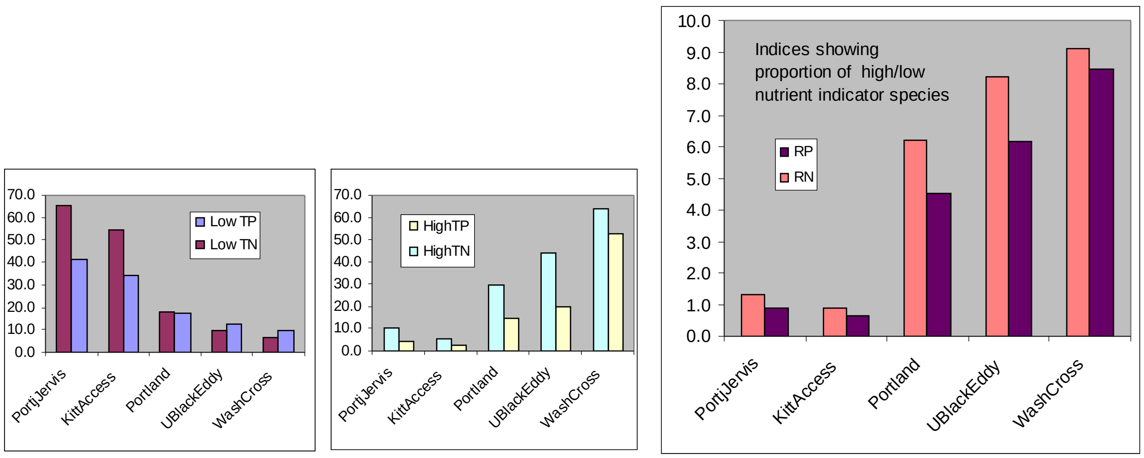

Figure 3. Indices showing proportion of Delaware River high/low nutrient indicator species. Left: Relative abundance (%) of low nutrient indicator species. Middle: Relative abundance (%) of high nutrient indicator species. Right: Ratio of high/low nutrient indicator species abundance. Results shown in upstream to downstream direction.

Results as Related to General Water Quality

Indicators of general water quality and organic pollution tolerance include: Percent Diatoms; Percent Cyanobacteria; Percent Dominant Diatom; Total Number of Diatom Genera; Shannon Diversity; Kentucky Pollution Tolerance Index; Montana Diatom Pollution Tolerance Index; Percent *Fragilaria* and *Cymbella* Group; the Autotrophic Index; and the Kentucky Diatom Biotic Index. All are described in Appendix C.

Results generally indicate good to excellent water quality in the Delaware River, with a couple of potential problem spots. Percent Cyanobacteria was relatively high at Portland and Washington Crossing. The Autotrophic Index was greater than 200 at Portland, Upper Black Eddy and Washington Crossing, and was extremely high at Upper Black Eddy and Washington Crossing. According to Weber (1973) and Weitzel (1979), an AI value over 200 indicates community dominance by heterotrophic organisms, and extremely high values may indicate poor water quality. Heterotrophic organisms can remain viable without light through uptake of dissolved organic compounds (Wetzel, 2001), so a community dominated by heterotrophic organisms may indicate relatively high levels of organic pollution. This metric is known to be highly variable, and can be artificially inflated by including non-living organic detritus in the sample (Kentucky DEP, 2002).

The two northern-most sites, Port Jervis and Kittatinny Access, contained notably less rich, less diverse, and more pollution-sensitive diatom assemblages than those downstream. The reason for this is unknown, but may be that organic pollution, nutrient concentrations, and specific conductance concentrations are much lower at the northern sites. Additional sampling may reveal such relationships.

Results as Related to Biological Integrity

Biological assemblages possess biological integrity when they are rich, diverse, balanced, and pollution intolerant. Using the metrics presented here, the periphyton assemblage of the Delaware River seems relatively rich, diverse, and balanced. Pollution intolerant diatoms are strongly represented in the algal community at the northern sites. The northern sites seem less rich and diverse, which may be characteristic of naturally nutrient-poor waters.

Results as Related to Specific Stressors

Some metrics, such as Percent Acidophilic Diatoms and Percent Motile Diatoms, relate directly to specific environmental conditions. Percent Acidophilic Diatoms results show that the Delaware River is at no time an acid environment. Motile Diatoms were strongly represented at Portland and Washington Crossing, indicating that these sites may experience siltation or substrate instability.

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Appendix A

List of Diatoms and Abundance

			Frustule Count / 600					Biovolume %				
Family	**XTaxon**		**Washington Crossing 1418B**	**Upper Black Eddy 1666B**	**Portland 2073B**	**Kittatinny Access 2499B**	**Port Jervis 2550B**	**Washington Crossing 1418B**	**Upper Black Eddy 1666B**	**Portland 2073B**	**Kittatinny Access 2499B**	**Port Jervis 2550B**
Achnanthidiaceae	Achnanthidium minutissimum (Kützing) Czarnecki	Diatom	13	39	49	62	135					
Achnanthidiaceae	Achnanthidium sp. 10 NAWQA MP	Diatom	8	3	16	6	24					
Achnanthidiaceae	Achnanthidium exiguum (Grunow) Czarnecki	Diatom	2	1								
Achnanthaceae	Achnanthes conspicua Mayer	Diatom		1								
Achnanthaceae	Achnanthes subhudsonis var. kraeuselii (Cholnoky) Cholnoky	Diatom	27	43	11	12	8					
Catenulaceae	Amphora veneta Kützing	Diatom	2									
Catenulaceae	Amphora pediculus (Kützing) Grunow	Diatom	2	10								
Catenulaceae	Amphora copulata (Kützing) Schoeman et Archibald	Diatom	1									
Aulacoseiraceae	Aulacoseira granulata (Ehrenberg) Simonsen	Diatom	1									
Pinnulariaceae	Caloneis bacillum (Grunow) Cleve	Diatom	2	15								
Achnanthaceae	Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	Diatom	117	172	92	119	67					
Stephanodiscaceae	Cyclotella meneghiniana Kützing	Diatom	8	15								
Stephanodiscaceae	Cyclotella stelligera (Cleve et Grunow) Van Heurck	Diatom	1									
Stephanodiscaceae	Cyclotella bodanica var. lemanica Müller	Diatom					1					
Stauroneidaceae	Craticula molestiformis (Hustedt) Lange-Bertalot	Diatom	2									
Cymbellaceae	Cymbella tumida (Brébisson ex Kützing) Van Heurck	Diatom			1	5	2					
Fragilariaceae	Diatoma vulgaris Bory	Diatom	1				2					
Diploneidaceae	Diploneis parma Cleve	Diatom		1								
Fragilariaceae	Fragilaria capucina Desmazières	Diatom					2					
Fragilariaceae	Fragilaria vaucheriae (Kützing) Petersen	Diatom	4		3	7						
Fragilariaceae	Fragilaria pinnata var. acuminata Mayer	Diatom	2									
Fragilariaceae	Fragilaria capucina var. rumpens (Kützing) Lange-Bertalot	Diatom			15	5	9					
Amphipleuraceae	Frustulia vulgaris (Thwaites) deToni	Diatom		2			2					
Gomphonemataceae	Gomphonema angustatum (Kützing) Rabenhorst	Diatom		1								
Gomphonemataceae	Gomphonema parvulum (Kützing) Kützing	Diatom		2	5							
Gomphonemataceae	Gomphonema micropus Kützing	Diatom	1				2					
Gomphonemataceae	Gomphonema minutum (Agardh) Agardh	Diatom	1									
Gomphonemataceae	Gomphonema patrickii Kociolek et Stoermer	Diatom		2	7	7	31					
Gomphonemataceae	Gomphonema kobayasii Kociolek et Kingston	Diatom		2	2	3	5					
Pleurosigmataceae	Gyrosigma spencerii (Smith) Griffith et Henfrey	Diatom	8									
Pleurosigmataceae	Gyrosigma reimeri Sterrenburg	Diatom		1								
Melosiraceae	Melosira varians Agardh	Diatom	4	8	22	1	9					
Fragilariaceae	Meridion circulare var. constrictum (Ralfs) Van Heurck	Diatom				2						
Naviculaceae	Navicula cryptocephala Kützing	Diatom			11							
Naviculaceae	Navicula gregaria Donkin	Diatom	4	4	2							

			Frustule Count / 600					Biovolume %				
Family	**XTaxon**	_	**Washington Crossing 1418B**	**Upper Black Eddy 1666B**	**Portland 2073B**	**Kittatinny Access 2499B**	**Port Jervis 2550B**	**Washington Crossing 1418B**	**Upper Black Eddy 1666B**	**Portland 2073B**	**Kittatinny Access 2499B**	**Port Jervis 2550B**
Naviculaceae	Navicula minima Grunow	Diatom	19	32	2	2						
Naviculaceae	Navicula notha Wallace	Diatom			6	119	158					
Naviculaceae	Navicula tripunctata (Müller) Bory	Diatom	1									
Naviculaceae	Navicula menisculus Schumann	Diatom		6	6		16					
Naviculaceae	Navicula schroeteri var. escambia Patrick	Diatom	2		1	1						
Naviculaceae	Navicula veneta Kützing	Diatom	2									
Naviculaceae	Navicula cryptotenella Lange-Bertalot ex Krammer et Lange-Bertalot	Diatom	2	6								
Naviculaceae	Navicula perminuta Grunow	Diatom		2								
Naviculaceae	Navicula subminuscula Manguin	Diatom	10	5								
Naviculaceae	Navicula germainii Wallace	Diatom	14	2								
Naviculaceae	Navicula recens Lange-Bertalot	Diatom	134									
Naviculaceae	Navicula capitatoradiata Germain	Diatom	4	10	4							
Naviculaceae	Navicula lanceolata (Agardh) Ehrenberg	Diatom	5	9								
Naviculaceae	Navicula antonii Lange-Bertalot	Diatom	16	25	56	83	3					
Naviculaceae	Navicula rostellata Kützing	Diatom	11	10								
Bacillariaceae	Nitzschia acicularis (Kützing) Smith	Diatom					1					
Bacillariaceae	Nitzschia amphibia Grunow	Diatom	13	26	8							
Bacillariaceae	Nitzschia dissipata (Kützing) Grunow	Diatom		2								
Bacillariaceae	Nitzschia fonticola Grunow	Diatom	5	7	32		10					
Bacillariaceae	Nitzschia frustulum (Kützing) Grunow	Diatom	8	20	6	2	8					
Bacillariaceae	Nitzschia palea (Kützing) Smith	Diatom	3	3								
Bacillariaceae	Nitzschia recta Hantzsch ex Rabenhorst	Diatom		2								
Bacillariaceae	Nitzschia inconspicua Grunow	Diatom	28	6	2							
Bacillariaceae	Nitzschia intermedia Hantzsch ex Cleve et Grunow	Diatom	11	8								
Bacillariaceae	Nitzschia liebethruthii Rabenhorst	Diatom			2	2						
Bacillariaceae	Nitzschia sigmoidea (Nitzsch) Ehrenberg	Diatom	2									
Bacillariaceae	Nitzschia palea var. debilis (Kützing) Grunow	Diatom	18	15	53	4	15					
Bacillariaceae	Nitzschia solita Hustedt	Diatom		2								
Bacillariaceae	Nitzschia archibaldii Lange-Bertalot	Diatom			73	2						
Pleurosigmataceae	Pleurosigma salinarum Grunow	Diatom				2						
Gomphonemataceae	Reimeria sinuata (Gregory) Kociolek et Stoermer	Diatom	25	16	3	4	12					
Rhoicospheniaceae	Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	Diatom	2	6	3	4						
Fragilariaceae	Synedra ulna (Nitzsch) Ehrenberg	Diatom	1	3								
Fragilariaceae	Synedra acus Kützing	Diatom			1							
Bacillariaceae	Bacillaria paradoxa Gmelin	Diatom		2								
Naviculaceae	Navicula radiosafallax Lange-Bertalot	Diatom	6	3	58	10	2					
Cymbellaceae	Encyonema minutum (Hilse) Mann	Diatom	7	6	6	4	6					
Cymbellaceae	Encyonema silesiacum (Bleisch) Mann	Diatom	5	4	29	128	70					
Achnanthaceae	Karayevia clevei (Grunow) Bukhtiyarova	Diatom	2	1								

			Frustule Count / 600					Biovolume %				
Family	**XTaxon**		Washington Crossing 1418B	Upper Black Eddy 1666B	Portland 2073B	Kittatinny Access 2499B	Port Jervis 2550B	Washington Crossing 1418B	Upper Black Eddy 1666B	Portland 2073B	Kittatinny Access 2499B	Port Jervis 2550B
Diadesmidaceae	Luticola goeppertiana (Bleisch) Mann	Diatom		1								
Diadesmidaceae	Luticola mutica (Kützing) Mann	Diatom		1								
Achnanthaceae	Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	Diatom	1									
Achnanthaceae	Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	Diatom	3	4								
Achnanthaceae	Planothidium rostratum (Østrup) Lange-Bertalot	Diatom		4								
Sellaphoraceae	Sellaphora pupula (Kützing) Meresckowsky	Diatom			2							
Sellaphoraceae	Sellaphora seminulum (Grunow) Mann	Diatom	21	24	2							
Naviculaceae	Geissleria acceptata (Hustedt) Lange-Bertalot et Metzeltin	Diatom	2	2								
Naviculaceae	Geissleria decussis (Hustedt) Lange-Bertalot et Metzeltin	Diatom	6	3	9	4						
	ALL DIATOMS COMBINED	Diatom						62	86	15	68	71
Oocystaceae	Ankistrodesmus falcatus (Corda) Ralfs	Soft Algae								1	7	
Desmidiaceae	Closterium moniliferum Ehrenberg	Soft Algae								0.5		
Desmidiaceae	Cosmarium granatum Brébisson ex Ralfs	Soft Algae								3		0.5
Desmidiaceae	Cosmarium formosulum Hoffman	Soft Algae								0.5		
Palmellaceae	Gloeocystis sp.	Soft Algae						6	6	1		18.5
Zygnemataceae	Mougeotia sp.	Soft Algae								1		
Oedogoniaceae	Oedogonium sp.	Soft Algae										4
Hydrodictyaceae	Pediastrum boryanum (Turpin) Meneghini	Soft Algae								0.5		
Hydrodictyaceae	Pediastrum tetras (Ehrenberg) Ralfs	Soft Algae								3		
Scenedesmaceae	Scenedesmus ecornis (Ralfs) Chodat	Soft Algae								0.5		
Scenedesmaceae	Scenedesmus spinosus Chodat	Soft Algae							0.2			
Scenedesmaceae	Scenedesmus acuminatus (Lagerheim) Chodat	Soft Algae								1		
Scenedesmaceae	Scenedesmus denticulatus Kirchner	Soft Algae								0.5	0.5	
Scenedesmaceae	Scenedesmus serratus (Corda) Bohlin	Soft Algae							0.5			0.5
Chaetophoraceae	Stigeoclonium lubricum (Dillwyn) Kützing	Soft Algae								25		
Chamaesiphonaceae	Chamaesiphon incrustans Grunow	Soft Algae										2
Pseudanabaenaceae	Geitlerinema splendidum (Greville) Anagnostidis	Soft Algae									0.5	
Mastigocladaceae	Hapalosiphon sp.	Soft Algae									1	
Pseudanabaenaceae	Homoeothrix janthina (Bornet et Flahault) Starmach	Soft Algae						1		25	22	0.5
Pseudanabaenaceae	Leptolyngbya sp.	Soft Algae						30	2.5			2.5
Phormidiaceae	Phormidium sp.	Soft Algae							0.5		1	0.5
Phormidiaceae	Phormidium hiemale (Jaag) Anagnostidis	Soft Algae								22.5		
Pseudanabaenaceae	Pseudanabaena sp.	Soft Algae							0.3			
(undetermined)	Unknown Cyanophyte (colonial coccoid)	Soft Algae						1	4			

Appendix B

Autoecological Information

XTaxon		KY PT I	MT PT C	MT PTC genu s	UST P	UST N	Acido philic	Eutrap hentic	Motile	Cyanob acteria	TDI s	TDIv
Achnanthes conspicua Mayer	Diatom	3		3		H	0	0	0	0	5	2
Achnanthes subhudsonis var. kraeuselii (Cholnoky) Cholnoky	Diatom	***3***		3			0	0	0	0	3	1
Achnanthidium exiguum (Grunow) Czarnecki	Diatom	***3***		***3***	H	H			0	0	2	2
Achnanthidium minutissimum (Kützing) Czarnecki	Diatom	3	3	***3***	L	L			0	0	2	2
Achnanthidium sp. 10 NAWQA MP	Diatom	***3***		***3***					0	0	2	2
Amphora copulata (Kützing) Schoeman et Archibald	Diatom			2			0	1	0	0	5	1
Amphora pediculus (Kützing) Grunow	Diatom	3	3	2		H	0	1	0	0	5	2
Amphora veneta Kützing	Diatom	1	1	2		H	0	1	0	0	5	1
Aulacoseira granulata (Ehrenberg) Simonsen	Diatom	3	3	3	H	H	0	0	0	0	0	0
Bacillaria paradoxa Gmelin	Diatom	2	2	2	H		0	0	0	0	4	1
Caloneis bacillum (Grunow) Cleve	Diatom	3	2	3			0	0	1	0	3	1
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	Diatom	3	3	3			0	1	0	0	3	2
Craticula molestiformis (Hustedt) Lange-Bertalot	Diatom				H	H				0	5	1
Cyclotella bodanica var. lemanica Müller	Diatom	3		3			0	0	0	0	0	0
Cyclotella meneghiniana Kützing	Diatom	1	2	3	H	H	0	0	0	0	0	0
Cyclotella stelligera (Cleve et Grunow) Van Heurck	Diatom	3	3	3			0	0	0	0	0	0
Cymbella tumida (Brébisson ex Kützing) Van Heurck	Diatom	4	3	3						0	2	1
Diatoma vulgaris Bory	Diatom	3	3	3			0	1	0	0	5	3
Diploneis parma Cleve	Diatom			3			0	0	1	0	1	1
Encyonema minutum (Hilse) Mann	Diatom	3		***3***	L	L				0	3	2
Encyonema silesiacum (Bleisch) Mann	Diatom	4		***3***		L				0	3	2
Fragilaria capucina Desmazières	Diatom	2	2	3	L	L	0	1	0	0	2	2
Fragilaria capucina var. rumpens (Kützing) Lange-Bertalot	Diatom	2		3			0	1	0	0	2	2
Fragilaria pinnata var. acuminata Mayer	Diatom	3	3	3			0	1	0	0	4	1
Fragilaria vaucheriae (Kützing) Petersen	Diatom	2	2	3			0	1	0	0	3	2
Frustulia vulgaris (Thwaites) deToni	Diatom	3	2	3			1	0	1	0	1	2
Geissleria acceptata (Hustedt) Lange-Bertalot et Metzeltin	Diatom									0	4	1
Geissleria decussis (Hustedt) Lange-Bertalot et Metzeltin	Diatom									0	4	1
Gomphonema angustatum (Kützing) Rabenhorst	Diatom	2	2	3			0	1	0	0	1	2
Gomphonema kobayasii Kociolek et Kingston	Diatom			3			0	1	0	0	3	1
Gomphonema micropus Kützing	Diatom			3			0	1	0	0	3	1
Gomphonema minutum (Agardh) Agardh	Diatom	2	3	3		H	0	1	0	0	4	2
Gomphonema parvulum (Kützing) Kützing	Diatom	1	1	3	H	H	0	1	0	0	5	3
Gomphonema patrickii Kociolek et Stoermer	Diatom			3			0	1	0	0	3	1
Gyrosigma reimeri Sterrenburg	Diatom			2			0	1	1	0	5	2
Gyrosigma spencerii (Smith) Griffith et Henfrey	Diatom	3	2	2			0	1	1	0	5	2
Karayevia clevei (Grunow) Bukhtiyarova	Diatom	4								0	4	2
Luticola goeppertiana (Bleisch) Mann	Diatom					H				0	5	2
Luticola mutica (Kützing) Mann	Diatom	2								0	5	2

XTaxon		KY PTI	MT PTC	MT PTC genus	UST P	UST N	Acidophilic	Eutraphentic	Motile	Cyanobacteria	TDI s	TDIv
Melosira varians Agardh	Diatom	2	2	3			0	1	0	0	4	2
Meridion circulare var. constrictum (Ralfs) Van Heurck	Diatom	3	3	3			0	1	0	0	2	3
Navicula antonii Lange-Bertalot	Diatom			2			0	0	1	0	4	1
Navicula capitatoradiata Germain	Diatom	2	2	2			0	0	1	0	3	2
Navicula cryptocephala Kützing	Diatom	4	3	2			0	0	1	0	4	1
Navicula cryptotenella Lange-Bertalot ex Krammer et Lange-Bertalot	Diatom	2	2	2		H	0	0	1	0	5	2
Navicula germainii Wallace	Diatom	***2***		***2***	H		0	0	1	0	4	1
Navicula gregaria Donkin	Diatom	2	2	2	H	H	0	0	1	0	5	1
Navicula lanceolata (Agardh) Ehrenberg	Diatom	2	2	2			0	0	1	0	5	2
Navicula menisculus Schumann	Diatom	2	2	2		H	0	0	1	0	5	2
Navicula minima Grunow	Diatom	1	1	2	H	H	0	0	1	0	4	1
Navicula notha Wallace	Diatom	3	2	2			0	0	1	0	4	1
Navicula perminuta Grunow	Diatom			2			0	0	1	0	4	1
Navicula radiosafallax Lange-Bertalot	Diatom			2			0	0	1	0	4	1
Navicula recens Lange-Bertalot	Diatom	2	2	2	H	H	0	0	1	0	4	1
Navicula rostellata Kützing	Diatom	***2***		***2***	H	H	0	0	1	0	4	1
Navicula schroeteri var. escambia Patrick	Diatom	3	2	2			0	0	1	0	4	1
Navicula subminuscula Manguin	Diatom	1	1	2	H	H	0	0	1	0	4	1
Navicula tripunctata (Müller) Bory	Diatom	3	3	2		H	0	0	1	0	4	2
Navicula veneta Kützing	Diatom	1	1	2	H	H	0	0	1	0	4	1
Nitzschia acicularis (Kützing) Smith	Diatom	2	2	2	H	H	0	1	1	0	4	1
Nitzschia amphibia Grunow	Diatom	1	2	2	H	H	0	1	1	0	5	3
Nitzschia archibaldii Lange-Bertalot	Diatom		2	2			0	1	1	0	4	1
Nitzschia dissipata (Kützing) Grunow	Diatom	3	3	2		H	0	1	1	0	5	2
Nitzschia fonticola Grunow	Diatom	2	3	2			0	1	1	0	3	2
Nitzschia frustulum (Kützing) Grunow	Diatom	1	2	2	H	H	0	1	1	0	4	1
Nitzschia inconspicua Grunow	Diatom	2	2	2	H	H	0	1	1	0	5	1
Nitzschia intermedia Hantzsch ex Cleve et Grunow	Diatom	2	3	2	H	H	0	1	1	0	4	1
Nitzschia liebethruthii Rabenhorst	Diatom		3	2			0	1	1	0	4	1
Nitzschia palea (Kützing) Smith	Diatom	1	1	2	H	H	0	1	1	0	5	1
Nitzschia palea var. debilis (Kützing) Grunow	Diatom	1		2	H	H	0	1	1	0	5	1
Nitzschia recta Hantzsch ex Rabenhorst	Diatom	3	3	2			0	1	1	0	4	2
Nitzschia sigmoidea (Nitzsch) Ehrenberg	Diatom	3	3	2			0	1	1	0	4	2
Nitzschia solita Hustedt	Diatom			2	H	H	0	1	1	0	4	1
Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	Diatom					H				0	5	2
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	Diatom	3				H				0	5	2
Planothidium rostratum (Østrup) Lange-Bertalot	Diatom									0	5	2
Pleurosigma salinarum Grunow	Diatom			2	H	H				0	4	1
Reimeria sinuata (Gregory) Kociolek et Stoermer	Diatom	4			L	L				0	4	3
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	Diatom	3	3	3	H	H	0	1	0	0	5	1

XTaxon		KY PT I	MT PT C	MT PTC genu s	UST P	UST N	Acido philic	Eutrap hentic	Motile	Cyanob acteria	TDI s	TDIv
Sellaphora pupula (Kützing) Meresckowsky	Diatom	3				H				0	5	1
Sellaphora seminulum (Grunow) Mann	Diatom	1			H	H				0	5	1
Synedra acus Kützing	Diatom	3	2	3			0	1	0	0	4	1
Synedra ulna (Nitzsch) Ehrenberg	Diatom	3	2	3	L	L	0	1	0	0	3	1
ALL DIATOMS COMBINED	Diatom											
Ankistrodesmus falcatus (Corda) Ralfs	Soft Algae						0	0	0	0		
Chamaesiphon incrustans Grunow	Soft Algae						0	0	0	1		
Closterium moniliferum Ehrenberg	Soft Algae						0	0	0	0		
Cosmarium formosulum Hoffman	Soft Algae						0	0	0	0		
Cosmarium granatum Brébisson ex Ralfs	Soft Algae						0	0	0	0		
Geitlerinema splendidum (Greville) Anagnostidis	Soft Algae						0	0	0	1		
Gloeocystis sp.	Soft Algae						0	0	0	1		
Hapalosiphon sp.	Soft Algae						0	0	0	1		
Homoeothrix janthina (Bornet et Flahault) Starmach	Soft Algae						0	0	0	1		
Leptolyngbya sp.	Soft Algae						0	0	0	1		
Mougeotia sp.	Soft Algae						0	0	0	0		
Oedogonium sp.	Soft Algae						0	0	0	0		
Pediastrum boryanum (Turpin) Meneghini	Soft Algae						0	0	0	0		
Pediastrum tetras (Ehrenberg) Ralfs	Soft Algae						0	0	0	0		
Phormidium hiemale (Jaag) Anagnostidis	Soft Algae						0	0	0	1		
Phormidium sp.	Soft Algae						0	0	0	1		
Pseudanabaena sp.	Soft Algae						0	0	0	1		
Scenedesmus acuminatus (Lagerheim) Chodat	Soft Algae						0	0	0	0		
Scenedesmus denticulatus Kirchner	Soft Algae						0	0	0	0		
Scenedesmus ecornis (Ralfs) Chodat	Soft Algae						0	0	0	0		
Scenedesmus serratus (Corda) Bohlin	Soft Algae						0	0	0	0		

XTaxon		KY PTI	MT PTC	MT PTC genus	UST P	UST N	Acidophilic	Eutraphentic	Motile	Cyanobacteria	TDI s	TDIv
Scenedesmus spinosus Chodat	Soft Algae						0	0	0	0		
Stigeoclonium lubricum (Dillwyn) Kützing	Soft Algae						0	0	0	0		
Unknown Cyanophyte (colonial coccoid)	Soft Algae						0	0	0	1		

APPENDIX C

Description of Algae Community Metrics

Description of Algae Community Metrics

% Diatoms (Hill et. al 2000) – WATER QUALITY INDICATOR

Organic enrichment or highly toxic conditions cause shifts in algal communities from domination by diatoms to domination by non-diatom taxa, especially green algae and the Cyanobacteria. As environmental stressors increase, percent diatoms is expected to decrease.

% Cyanobacteria (Hill et. al 2000) – WATER QUALITY INDICATOR

This is the opposite to percent diatoms. As water quality declines, the percent Cyanobacteria is expected to increase.

% Dominant Diatom (Hill et. al 2000) – WATER QUALITY INDICATOR

The relative abundance of a diatom genus can influence the evenness and diversity of the community. Species adapted to poor water quality gain advantage over all other species, causing an uneven distribution of individuals among taxa. Percent dominance by a single diatom taxon is expected to increase with increased environmental stress.

% Acidophilic Diatoms (Hill et. al 2000) – ACID CONDITIONS INDICATOR

As pH decreases, the diatom community is expected to shift toward those taxa that can tolerate acidic conditions ($pH<5.5$).

% Eutraphentic Diatoms (Hill et. al 2000) – NUTRIENT INDICATOR

As nutrients and organic matter increase, the diatom community is expected to shift toward taxa that can tolerate high nutrients and organic enrichment.

% Motile Diatoms (Siltation Index, %NNS) (Hill et. al 2000) – SILT INDICATOR

Silt is a common product of development and agricultural activity in a watershed, and it causes severe stress to biological communities. This is a common indicator in state assessment programs. As siltation increases the non-motile diatoms become physically covered in silt, and the percentage of motile diatoms is expected to increase as these are the only taxa able to thrive under such conditions.

Chlorophyll *a* concentration (mg/m^2) (KYDEP 2002) – NUTRIENT INDICATOR

This has been widely used to assess nutrient conditions in streams, and as estimates of algal biomass. Because algae are very patchy in their distribution on a stream bottom, this can be an extremely variable indicator. As with any chemical measurement, a large number of samples are required for confident assessment. High chlorophyll a values may indicate nutrient enrichment, while low values may indicate low nutrient availability, toxicity, low light availability by shading or turbidity, or sedimentation. Kentucky DEP recommends that chlorophyll a values be used only in support of other analyses.

Ash Free Dry Weight (AFDW, mg/m^2) (KYDEP 2002) – NUTRIENT INDICATOR

Ash Free Dry Weight (AFDW) or Ash Free Dry Mass (AFDM) values are used to estimate total organic material accumulated on the substrate. This includes all living organisms (algae, bacteria, fungi, protozoa and macroinvertebrates) as well as non-living detritus. AFDW values have been used along with Chlorophyll a to determine the trophic state (autotrophic vs. heterotrophic) of streams. See Autotrophic Index (AI). AFDW is also a highly variable parameter.

Autotrophic Index (AI) (KYDEP 2002) – NUTRIENT INDICATOR

The Autotrophic Index is calculated: AI = AFDW / Chlorophyll a. As a rule of thumb, high values (>200) indicate that the community is dominated by heterotrophic organisms, and extremely high values indicate poor water quality (Weitzel 1979). Non-living organic detritus can artificially inflate the AI, and this indicator is calculated upon two highly variable measures, so this indicator should only be used to support other data.

Total Number of Diatom Genera (TNDT) (KYDEP 2002) – WATER QUALITY INDICATOR

TNDT is an estimate of diatom species richness. High richness is expected at un-impacted sites, and richness is expected to decrease with increasing pollution. Slight levels of nutrient enrichment might increase richness in naturally unproductive, nutrient poor streams (Bahls 1992). The Upper Delaware River, where nutrient concentrations are very frequently undetectable, may fall into this category at times. In the Delaware River data set, this value is expressed in terms of number of genera per 600 frustule count.

H'=Shannon Diversity of Diatoms (Base 10) (KYDEP 2002) – WATER QUALITY INDICATOR

Shannon diversity is commonly used by aquatic biologists as a standard biological integrity interpretive indicator and for comparison with other literature values. The value of H' = 0 when only one species is present in the collection, and H' is at its maximum when all individuals are evenly distributed among the S species. Diversity is expected to decline with increasing pollution. It is calculated as follows:

$$H' = - \sum (n_i / N) \log_{10} (n_i / N)$$

where:

ni = number of individuals of species i
N = total number of individuals

H'=Shannon Diversity of Diatoms (Base e) – WATER QUALITY INDICATOR

This metric is calculated the same way as shown above, but using natural log (ln) rather than log 10. DRBC diversity measures have been most commonly expressed using natural log, while base 10 may be the most commonly used form elsewhere. For purposes of comparison, both forms are shown in these data. This measure may be best used to assess changes in water quality over time, as change in diversity - rather than the diversity value alone - is a reliable water quality indicator. Shannon diversity should only be used in combination with other measures, as it is difficult to clearly interpret.

KY Diatom PTI (1=tolerant, 4=sensitive) – WATER QUALITY INDICATOR

The pollution tolerance index (PTI) used by the Kentucky Division of Water resembles the Hilsenhoff Biotic Index for macroinvertebrates (Hilsenhoff, 1987). According to their tolerance to increased pollution, with species assigned a value of 1 for most tolerant taxa to 3 for relatively sensitive species, the PTI tolerance values range from one (most tolerant) to four (most sensitive). Because the index is based on relative abundances, rare species will have little effect on the final index value. If no autecological data is known, the species is given a PTI value of 0 and is not used in PTI index calculation.

The formula used to calculate PTI is:

$$PTI = (\sum n_i \times t_i) / N$$

where ni = number of individuals in species i
ti = tolerance value of species i
N =total number of individuals

US Diatom TP and TN metrics (1 low, 3 med., 5 high) – NUTRIENT INDICATOR

These metrics were developed based on USGS National Water Quality Assessment diatom nitrogen and phosphorus indicator species analysis (Potapova and Charles, 2005, Appendix A). Indicator values were assigned according to the following indicator species analysis groupings:

<u>Total Phosphorus</u>
L = Low TP = <0.01 mg/l TP and significant at $p<0.05$
H = High TP = >0.1 mg/l TP and significant at $p<0.05$

<u>Total Nitrogen</u>
L = Low TN = <0.2 mg/l TN and significant at $p<0.05$
H = High TN = >3.0 mg/l TN and significant at $p<0.05$

TP and TN indices are calculated as percent abundance of species identified as low or high nutrient indicator species. Results are further expressed as a ratio of high/low nutrient indicator species (see Figure 2 in the text).

MT Diatom PTI (1=tolerant, 3=sensitive) – WATER QUALITY INDICATOR

The Montana Diatom PTI is similar to the Kentucky Diatom PTI. Indicator values range from 1 (pollution tolerant) to 3 (most sensitive) and are listed in Appendix 1 of Bahls (1993).

UK WMS (1=very low nutrients, 5=very high) – NUTRIENT INDICATOR
UK Trophic Diatom Index (1-100)

The TDI is the WMS expressed on a scale of 1-100. The WMS is a nutrient sensitivity index using values assigned to each taxon ranging from:
1 = favored by very low nutrients; to
5 = favored by very high nutrients

The WMS is calculated using abundance data, sensitivity values, and an indicator value (1-3) as assigned on pages 32-36 of Kelly et. al (2001). WMS and TDI are calculated as:

1. Calculate, for each taxon, (abundance (a) $\times$ v) and (a $\times$ s $\times$ v)
2. Add together all values for av to give Σav
3. Repeat for asv to give Σasv
4. Calculate Σasv $\div$ Σav to give WMS.
5. Calculate TDI as (WMS $\times$ 25) - 25

Fragilaria + Cymbella Group Richness (%max) – WATER QUALITY INDICATOR

This metric is a combined version of two metrics used by KYDEP (2002). Presence of Fragilaria Group and Cymbella Group taxa is indicative of high water quality. Using the formulae below, this metric is calculated as FGR + CGR (number of genera).

<u>Fragilaria Group Richness (FGR)</u>
The total number taxa represented in the sample from the genera *Ctenophora*, *Fragilaria*, *Fragilariforma*, *Pseudostaurosira*, *Punctastriata*, *Stauroforma*, *Staurosira*, *Staurosirella*, *Tabularia* and *Synedra* reflects high water quality. As water pollution increases, the FGR is expected to decrease.

FGR=*Ctenophora*+*Fragilaria*+*Fragilariforma*+*Pseudostaursira*+*Punctastriata*+*Stauroforma*+*Staurosira*+*Staurosirella*+*Synedra*+*Tabularia*

<u>Cymbella Group Richness (CGR)</u>
The total number of taxa represented in the sample from the genera *Cymbella*, *Cymbopleura*, *Encyonema*, *Encyonemopsis*, *Navicella*, *Pseudoencyonema* and *Reimeria* reflects high water quality. As water pollution increases, the CGR is expected to decrease.

CGR=*Cymbella*+*Cymbopleura*+*Encyonema*+*Encyonemopsis*+*Navicella*+*Pseudoencyonema*+*Reimeria*

Kentucky DBI (modified) – WATER QUALITY INDICATOR

This is a multimetric index used by Kentucky DEP for water quality assessment (KY DEP 2002). Each metric is given a calculated score (range 0-100) based on the percent of the standard metric value (i.e., the 95th percentile or 5th percentile) of the entire database (impaired and reference). These percentile thresholds are used to eliminate outliers. The formulae for calculating DBI scores are shown below.

Metric Scoring Formulae for the Diatom Bioassessment Index

Metric	**Formula**
TNDT	(TNDT/95th%ile) X 100
H′	(H′/95th%ile) X 100
PTI	(PTI/95th%ile) X 100
FGR + CGR	(FGR/95th%ile + CGR/95^{th}%ile) X 100
%NNS	(100 - %NNS)/(100 - 5th%ile) X 100

The mean of the five DBI metrics is the final DBI score on a 0-100 scale.

Since there were only 5 samples, DRBC modified this index in two ways. First, instead of using 95^{th} or 5^{th} percentiles, we used maxima or minima. Second, we combined the FGR and CGR richness measures into a single metric, leaving 5 metrics instead of 6 used by KYDEP.

Appendix D.

Site List for Annual Periphyton Survey of Richest Targeted Habitat

Hancock, New York to Trenton, New Jersey

Survey to Commence in 2006

Periphyton Annual Survey
Sampling Sites and Locations

Site Name	Site Number	River Mile	Latitude	Longitude
West Branch Delaware River	DRBC3310W	331.0	41.95250	-75.29121
East Branch Delaware River	DRBC3310E	331.0	41.95199	-75.28016
Buckingham Access	DRBC3250	325.0	41.86627	-75.26293
Long Eddy (Down's Residence)	DRBC3150	315.0	41.84669	-75.13317
Callicoon Bridge	DRBC3040	304.0	41.76508	-75.06120
Castillo del Rio	DRBC2935	293.5	41.64772	-75.04939
Ascalona Campground	DRBC2790	279.0	41.49817	-74.98205
Pond Eddy (Landers Base)	DRBC2690	269.0	41.44466	-74.86242
Port Jervis	DRBC 2550	255.0	41.37229	-74.69813
Kittatinny Access	DRBC 2499	249.9	41.34134	-74.75964
Cadoo Rd. (NPS Property)	DRBC 2475	247.5	41.32364	-74.78502
Spackman's Island	DRBC 2336	233.6	41.17032	-74.89400
Bushkill Access	DRBC 2285	228.5	41.10439	-74.98422
Worthington	DRBC 2150	215.0	41.00448	-75.10609
Arrow Island	DRBC 2108	210.8	40.96275	-75.11989
Portland	DRBC 2073	207.3	40.89449	-75.07563
Capush Island	DRBC 1949	194.9	40.79190	-75.10891
Getter's Island	DRBC 1843	184.3	40.69973	-75.20121
Wy-Hit-Tuk Access	DRBC 1810	181.0	40.66895	-75.18187
Raubs Island	DRBC 1776	177.6	40.62486	-75.18887
Upper Black Eddy	DRBC 1666	166.6	40.55148	-75.08178
Treasure Island	DRBC 1608	160.8	40.47566	-75.06330
Paunacussing Bar	DRBC 1556	155.6	40.40936	-75.04072
Washingtons Crossing	DRBC 1418	141.8	40.29657	-74.86853
Rotary Island	DRBC 1369	136.9	40.23963	-74.81852