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Subject: Periphyton Standing Crop and Diatom Assemblages in the Wissahickon Watershed
Wissahickon Watershed
Montgomery and Philadelphia Counties
Stream Code: Wissahickon Creek (00844)
Sandy Run (00859)
Prophecy Creek (00875)
Trewellyn Creek (00886)

To: Stream File

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Abstract

RELATIONSHIP BETWEEN PHYSICOCHEMICAL CONDITIONS AND PERIPHYTON (STANDING CROP AND DIATOM ASSEMBLAGES) IN A NORTHERN PIEDMONT CREEK IMPACTED BY MUNICIPAL SEWAGE TREATMENT PLANT DISCHARGES AND STORM WATER. A.C. EVERETT1 AND N. WEST2. 1Pennsylvania Department of Environmental Protection, Southeast Regional Office, Lee Park, Suite 6010, 555 North Lane, Conshohocken, PA 19428, 2Patrick Center for Environmental Research, Academy of Natural Sciences, Philadelphia, PA 19103

Periphyton standing crop and diatom assemblages were used to assess the effect of nutrients from municipal discharges and storm water on Wissahickon Creek. Wissahickon Creek is tributary to the Schuylkill River and drains 167 km2 of Montgomery and Philadelphia Counties in Southeastern Pennsylvania. Physicochemical and benthic algal sampling was performed at 7 main stem stations and 3 tributary stations during base flow conditions in August and September 1998. Total reactive phosphorus and inorganic nitrogen concentrations at stations influenced by municipal dischargers were respectively 13 to 51 times and 3 to 12 times greater than suggested mesotrophic-eutrophic boundary concentrations. Large diel dissolved oxygen swings and low minimum DO concentrations associated with excessive algal growth were documented at two stations. Periphyton chlorophyll-a concentrations ranged from 48 mg/m2 to 276 mg/m2 and were negatively related to percent canopy cover. Standing crop at open canopy stations was higher than at closed canopy stations and positively related to inorganic N concentration. Diatom assemblages were indicative of eutrophic conditions, with Kelly's Trophic Diatom Index ranging from 76% to 92%. Our study demonstrates the importance of riparian vegetation in limiting algal biomass in nutrient enriched streams and documents the need for nutrient reductions in the Wissahickon Watershed.

Introduction

Benthic algal communities are significant primary producers in wadable streams and can be utilized as indicators of environmental conditions (Barbour et al. 1999). Periphyton standing crop and community composition are influenced by nutrient levels, light, hydrologic condition, temperature, substrate type and herbivore grazing (Stevenson 1996). Accrual of benthic algal standing crop depends primarily on the level of two resources: nutrients and light (Biggs, 1996). Eutrophication may cause different algal taxa to become more competitive and taxa composition can shift (Dodds and Welch 2000). Generally, filamentous chlorophytes become abundant, sometimes creating nuisance conditions, when high nitrogen and phosphorous levels and adequate sunlight are provided. Studies have shown that phosphorus concentrations of only 25 to 50 ug/l orthophosphate are needed to maintain maximum benthic algal biomass in streams (Borchardt 1996). In small streams, riparian leaf canopies can intercept 95% of incident solar radiation. Benthic algal standing crops, as chlorophyll-a, can be 4 to 5 times higher at open canopy sites than at closed canopy sites (Hill 1996). Nuisance levels of algae and periphyton community shifts associated with high nutrients may cause water quality impairment (e.g. low dissolved oxygen), negative impacts to macroinvertebrates and fish, or aesthetic impairments for water users (Dodds and Welch 2000). Pennsylvania does not have nutrient or biological response (e.g. algal biomass) criteria incorporated into water quality standards (Chapter 93). Large diel variation and associated low dissolved oxygen concentrations are currently used as indicators of nuisance algae conditions. Recent research, examining nutrient levels and biological responses, could provide the basis for future criteria.

Dodds (1998) examined a worldwide temperate stream database and developed a suggested classification of stream trophic state based upon frequency distributions of total nitrogen (TN), total phosphorus (TP) and Chlorophyll a. The oligotrophic-mesotrophic boundary was 700 ug/l for TN, 25 ug/l for TP, 20 mg/m^2 for benthic Chl-a, and 60 mg/m^2 for maximum benthic Chl-a. The mesotrophic-eutrophic boundary was suggested to be 1500 ug/l for TN, 75 ug/l for TP, 70 mg/m^2 for mean benthic Chl-a, and 200 mg/m^2 for maximum benthic Chl-a. EPA's (2000) nutrient guidance criteria for Nutrient Ecoregion IX, which includes Wissahickon Creek, is similar to Dodds' oligotrophic-mesotrophic boundary: TN = 692 ug/l, TP = 37 ug/l, and Chl-a = 20mg/m^2. Other work has estimated that levels of nuisance algae are reached when Chl-a concentrations reach a threshold of 100 to 150 mg/m^2 (Welch et al. 1989) or macroalgae coverage exceeds 40 % (Biggs, 1996). Diatom assemblages have also been used to determine the trophic status of streams (Kelly 1996). These studies lack a region-specific perspective, but provide suitable references for comparison with nutrients and biological responses in the Wissahickon Watershed.

The purpose of this survey was to examine algal standing crop and community composition within the Wissahickon Watershed, determine relationships between physicochemical conditions and benthic algae, and compare results with literature reported chemical and biological values that indicate eutrophication. Semi-quantitative rapid periphyton (macroalgae) survey methods were compared with quantitative standing crop measurements as part of the survey.

The Wissahickon Creek is tributary to the Schuylkill River and drains 64 square miles of Montgomery and Philadelphia Counties in Southeastern Pennsylvania. Residential and commercial/industrial land uses dominate the watershed. Boyer (1997) provides a good geologic description of the basin. The Wissahickon Creek Basin is located in the Northern Piedmont Ecoregion (64). Three subecoregions are represented in the watershed: Triassic Lowlands (64a), Piedmont Lowlands (64d), and Piedmont Uplands (64c). The upper watershed from the headwaters to Fort Washington State Park is contained in the Triassic Lowlands Subecoregion and has shale, siltstone and sandstone parent materials. A two mile wide valley (Chester Valley) running southwest to northeast encompasses part of the Wissahickon Creek near Fort Washington State Park, most of the Sandy Run Basin, and some small UNTs to Wissahickon Creek. Chester Valley is located in the Piedmont Lowlands and has limestone parent materials. The lower Wissahickon Basin is located in the Piedmont Uplands Subecoregion and contains gneiss and schist parent material.

Summaries of the Department's Wissahickon Creek surveys prior to 1996 have been provided elsewhere and will not be reviewed here (Boyer 1997). Schubert (1996) investigated the nutrient status of Wissahickon Creek utilizing chemical sampling and the *Selenastrum capricornutum* Printz Algal Assay Bottle Test. Schubert concluded the following: 1) the Wissahickon Watershed was nutrient enriched, 2) water collected at all stations (4 main stem) exhibited high algal growth potentials, and 3) *Selenastrum capricornutum* biomass increased with increasing trace element concentrations but did not increase with increasing nitrogen and phosphorus concentrations, indicating trace element limitation and nonlimiting concentrations of nitrogen and phosphorus in the Wissahickon Creek water samples.

Boyer (1997) listed 26 NPDES permitted facilities which discharge treated effluent into the Wissahickon Creek Basin. Treated effluent represented 33.7% of average stream flow and 249% of the 7 day average low flow which occurs every 10 years (Q7,10) of the Wissahickon Creek at Bells Mill Road Bridge (Boyer 1997). Boyer's (1997) 13 station survey of the watershed examined base flow water chemistry, habitat, macroinvertebrates, and fish and concluded that the Wissahickon Creek is nutrient enriched and all stations were biologically impaired based upon EPA's Rapid Bioassessment Protocol for macroinvertebrates.

Everett (internal DEP data, UW Program) conducted a survey in 1997 examining macroinvertebrates and habitat utilizing Pa. DEP's Unassessed Waters Screening Protocol. Twelve tributary stations and 6 main stem stations were included in the survey. All stations except the Prophecy Creek station were biologically impaired. Benthic macroinvertebrate communities at impaired stations had low numbers of taxa, low numbers of pollution sensitive EPT taxa, and were dominated by the caddis fly family Hydropsychidae. Prophecy Creek's macroinvertebrate community was found to be unimpaired, having 16 total families, 4 pollution sensitive EPT families, and Philopotamidae as the dominant family. Everett (internal DEP data, UW Program) conducted a point source follow-up survey in 1998 which examined water chemistry and macroinvertebrate communities upstream and downstream from five municipal sewage treatment plants (Upper Gwynedd STP, North Wales STP, Ambler STP, Abington STP and Upper Dublin STP) and at the mouth of Wissahickon Creek. These five municipal dischargers account for approximately 92% of treated effluent discharging to the basin (Boyer 1997) All stations had impaired macroinvertebrate communities relative to the Muddy Creek ambient reference station. Base flow nutrient concentrations downstream from point sources indicated enriched conditions with the five municipal dischargers accounting for a majority of phosphorous and nitrogen loadings. The five municipal STPs accounted for 34% of the total flow at the mouth on July 7, 1998. Conclusions of the Unassessed Waters Screening and Point Source Survey were that storm water (flow variability, in stream sediment, nutrients) and municipal point sources (nutrients) were the primary sources of impairment in the basin. The Wissahickon Basin was placed on Pennsylvania's 303d list in 1998.

Wissahickon Creek and its tributaries are classified Trout Stocked Fishery (TSF) under the Department's Chapter 93 Water Quality Standards. TSF designation provides for the maintenance of stocked trout from February 15th to July 31st, and the maintenance and propagation of fish species and additional flora and fauna that are indigenous to a warm water habitat.

Wissahickon Creek periphyton was surveyed by Water Pollution Biologists Mike Boyer, Steve Schubert and Allen Whitehead, Watershed Coordinator Nancy Crickman, and the writer on September 10,11,14, and 15 1998. Gary Jones, section leader for DEP laboratory biological services, and staff performed analyses for Chl-a, phaeophytin, and AFDM. Natalie West, a NSF REU student intern in Dr. Don Charles' Phycology Lab at the Academy of Natural Sciences of Philadelphia (ANSP), performed diatom identification and enumeration on qualitative rock samples.

The National Institute for Environmental Renewal (NIER) requested that Pa DEP conduct the survey in conjunction with NIER's base flow water quality sampling within the watershed (NIER, 1999). NIER had funding to develop an action plan for the basin, model pollutant loads, and organize the Wissahickon Partnership, a consortium of private and public stakeholders in the watershed.

Methods

Periphyton measurements were made at 7 stations on Wissahickon Creek, and one station on each of three tributary streams: Prophecy Creek, Trewellyn Creek, and Sandy Run (Fig. 1). Conditions within the watershed were well represented and included main stem stations and a Sandy Run station influenced by storm water and municipal point sources, a station influenced by storm water (Trewellyn Creek) and a station representing the best biological condition in the watershed (Prophecy Creek) based upon the Unassessed Waters Screening. Stations were not located upstream of point sources on the Wissahickon and Sandy Run because lack of base flow precluded sampling in riffle areas. All stations corresponded to NIER water quality stations allowing for comparison of chemical and biological data at each station (Table 1). NIER water quality sampling was conducted within a 3-week time interval prior to the mid September periphyton sampling. Results of NIER's water quality sampling are given in Appendix 1. Total phosphorus results were not included in the data set because of suspected contamination. All periphyton stations except P-MR (Prophecy Creek) and T-GH (Trewellyn Creek) had corresponding dissolved oxygen diel surveys that were conducted by NIER between 7/30/98 and 9/29/98. Diel dissolved oxygen data was collected at 15 minute intervals using YSI multiparamater data sondes which also recorded temperature, specific conductance, pH and turbidity. For the purposes of this report, data immediately following the 8/17/98 storm event were excluded because of the potential effect of scour on benthic algae standing crop.

Methods described below are modifications of those described in Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (Barbour 1999). Riffle areas in close proximity to NIER water quality sampling stations were chosen for physical and biological sampling.

Physical Sampling

Length of riffle reach and percent substrate type were estimated visually. One transect, perpendicular to the stream, was randomly selected in the upper, middle, and lower 1/3 of the reach for a total of three transects. Wetted stream width at base flow was measured for each transect and averaged for a station stream width. Water depth ranges were estimated for the riffles. Canopy coverage was measured at mid-channel / mid-reach using a Model C Spherical Densiometer. Presence of tree or shrub canopy was calculated for 96 equi-spaced dots on the gridded concave mirror. Readings taken for North, East, South, and West were averaged and a percent cover was calculated for the station.

Biological Sampling

Periphyton Standing Crop

Periphyton sampling was performed over a six-day period (9/10 to 9/16/98) under stable base flow conditions. Boulder, cobble, or large gravel substrates were randomly sampled from the left, center, and right 1/3 of the channel along each transect and composited prior to analysis. Periphyton was collected by pressing a 2-inch diameter (20.3 cm^2) PVC pipe section, fitted with a foam gasket (collar), against the substrate. With the PVC pipe section firmly pressed against the rock's surface, the rock was removed from the stream and attached algae was removed with a modified hard bristle toothbrush. The algal slurry was transferred to a plastic container with a cooking baster or wide-bore pipette. Samples were sieved (800um X 900 um mesh) to remove moss from the sample. Moss was gently brushed and shaken to remove entangled or epiphytic algae. Filamentous algae collected on the sieve was segmented with a razor blade on a glazed tile and rinsed back into the sample. A total sample volume was recorded for each transect.

Well-mixed subsamples were taken for Chlorophyll-a and Phaeophytin-a analysis, Ash Free Dry Mass (AFDM) analysis and algal identification and enumeration. Chl-a and AFDM samples were field filtered onto glass fiber filters (Gelman A/E, 1um). Filter volumes ranged from 20 to 50 mls depending on concentration of algal material. $MgCO_3$ slurry (1gm/100ml) was added to the filtered Chl-a sample for buffering and stabilization. Samples were stored on dry ice in the field (-20°C), in a conventional freezer at the DEP field office, shipped to Harrisburg (DEP Laboratory) on dry ice and stored in deep freeze (-30°C) prior to analysis. Samples were analyzed on 11/17, 11/23, 12/1 and 12/2/98.

Analysis and calculation of Chl-a (mg/l) and phaeophytin (mg/l) at DEP's Bureau of Laboratories followed spectrophotometric methods (Method 10200) described in Standard Methods for the Examination of Water and Wastewater (19th edition, 1995). Chl-a and phaeophytin concentrations per unit substrate surface area (mg/m^2) were calculated by multiplying the laboratory determined concentration (mg/l) by the total sample volume (l) and dividing by the total surface area (0.00608 m^2).

AFDM filters were analyzed gravimetrically by drying to a constant weight at 105 °C and igniting for one hour at 500 °C. This method is a modification of Method 10300c in Standard Methods for the Examination of Water and Wastewater (1995). Five filter blanks were analyzed and the average AFDM associated with filters blanks were subtracted from the AFDM samples. AFDM per unit substrate area (mg/cm^2) was calculated by multiplying AFDM sub sample concentration (mg/l) by total sample volume (l) and dividing by surface area (cm^2). Duplicate analyses for Chl-a, phaeophytin and AFDM were collected for two stations. The autotrophic index was calculated for each station as AFDM (mg/m^2) per Chlorophyll a (mg/m^2).

A 15 to 20 ml subsample was transferred to a scintillation vial and preserved with glutaraldehyde (2% diluted concentration) for algal identification and enumeration. These samples remain archived at DEP's Southeast Regional Office.

Diatom Flora

Rock, gravel, woody debris and sand/silt microhabitats were sampled separately at three random locations within the riffle at each station. Collections for each microhabitat were composited and a well-mixed 15ml sub sample was transferred to a 20 ml scintillation vial and preserved with glutaraldehyde. Sampling was conducted with a modified hard bristle toothbrush and a wide-bore pipette.

Rock samples were identified to species and enumerated at ANSP (West 2000). Gravel, woody debris and sand/silt microhabitat samples were not examined because of resource constraints and remain at ANSP.

The diatom assemblage was described using five metrics: number of taxa, Trophic Diatom Index (TDI)(Kelly 1996), Shannon-Wiener Diversity Index, % Dominants and Siltation Index. The TDI is based upon species or genera specific pollution (nutrient) sensitivity ratings. Taxa are rated from 1, indicating taxa favored by very low nutrient concentrations, to 5, indicating taxa favored by very high nutrient concentrations. Taxa are also weighted from 0 to 3 according to their value as indicators. For example, predominately planktonic diatoms, which have settled in the benthos, would be given a value of 0. A weighted mean sensitivity of taxa present at a station is calculated and expressed as a percentage on a scale from 0 to 100. A eutrophic-mesotrophic boundary TDI of 67% was assigned by the writer based upon Kelly's sensitivity scale of 1 to 5. Percent dominants is the percentage of total diatom valves that accounted for greater than 10% of overall abundance in the sample and is a measure of community evenness. Siltation index represents the percentage of motile taxa. Motile taxa are better able to maintain substrate surface position in high siltation environments than nonmotile taxa.

Rapid Periphyton Survey

Semi-quantitative visual assessments were performed which estimated the maximum length (mm) and percent coverage of macroalgae (typically filamentous green algae). Three random locations along each transect, in the left, center, and right 1/3 of the channel, were examined using a viewing bucket with 49 equi-spaced dots organized in a 7" X 7" grid. Percent macroalgae coverage was estimated for each location by counting the dots where macroalgae was present. Maximum macroalgae length found within the grid was measured and recorded. Average percent coverage and average maximum length for each transect was considered one sample. Transect results for each station were then averaged for the mean station score. These quick objective visual methods were performed to see if they were correlated to standing crop and if they had potential as a screening protocol for other Department work. The rapid periphyton survey described in EPA's RBP Manual also discusses characterization of the microalgae. Microalgae assessments were not included in this survey because of difficulty in characterizing community type and thickness.

Aquatic Macrophyte Survey

The riffle reach and abutting upstream and downstream pools were surveyed for aquatic macrophytes. If present the relative abundance of the macrophyte was recorded based on a scale of one (rare) to 4 (abundant). Moss was found to be a significant component of biomass at some sites and samples collected in the standing crop transect sampling were collected in foil pouches and analyzed for AFDM according to methods described above for algal samples.

Statistical Analysis

All statistical analyses were performed using Microsoft Excel (Microsoft Office 2000) data analysis tools, except Principal Component Analysis (PCA). Descriptive statistics (mean, standard deviation, coefficient of variation, and variance) were calculated for Chl-a, phaeophytin, AFDM, % macroalgae coverage and maximum algae length. One way analysis of variance, with significance set at $p < 0.05$, was calculated for all biological variables at all stations except % macroalgae coverage at S-TR. Macroalgae coverage at S-TR included moss and therefore was not included in the ANOVA matrix. All data met the assumption of homogeneity of variance using the Fmax-test except AFDM and the autotrophic index. AFDM and autotrophic index data were log(base10) transformed to meet the assumptions of ANOVA. Pearson Product Moment Correlation analyses were performed on selected biological, chemical and physical variables for all stations. Correlation analyses were also used to examine interdependence of standing crop and field macroalgae results. PCA was used to graphically show physicochemical and biological relationships between stations. PCA analysis was performed using Statistica at the Philadelphia Water Department.

Results

Physical Assessment

Stream width ranged from 2.5 meters for Prophecy Creek station P-MR to a maximum width of 16.8 meters for Wissahickon Creek station W-RA (Appendix 1). Four 2nd order, three 3rd order, and three 4th order reaches were included in the survey. Percentage of boulder/cobble substrate in the sampled riffles ranged from 35% to 80% and provided adequate benthic algae sampling substrate. Percent canopy coverage ranged from a low of 1% (S-TR) at the Lu Lu Country Club along Sandy Run to a high of 58% (P-MR) on a forested reach of Prophecy Creek downstream from Morris Road.

Nutrients

Nutrient concentrations indicate enriched conditions at all Wissahickon Creek stations and at the Sandy Run station (S-TR). Total reactive phosphorus (TRP) ranged from 50 ug/l at T-GH to 3,800 ug/l at station S-TR (Fig.2). TRP concentrations at Wissahickon Creek stations and Sandy Run station S-TR were 13 to 51 times greater than Dodd's suggested mesotrophic-eutrophic boundary concentration for total phosphorous (TP = 75 ug/l). TRP does not include condensed phosphates and organically based phosphates that are included in TP analysis. Therefore, TP concentrations could be expected to be somewhat higher depending on concentrations of water column solids. The highest concentrations were found at stations located directly below municipal sewage treatment plants (S-TR, W-NW, W-PR, and W-GA). Phosphorus uptake, increased flow from tributary streams having lower P concentrations (e.g. Lorraine Run quarry discharge), and adsorption/sedimentation are probably responsible for lower levels found in Fairmount Park (W-BM, W-RA).

TRP concentrations in Prophecy Creek (P-MR) and Trewellyn Creek (T-GH), the only stations without point source contributions, were below Dodd's suggested mesotrophic-eutrophic TP boundary concentration, but above EPA suggested nutrient criteria for Nutrient Ecoregion IX (TP = 37 ug/l) (EPA 822-B-00-019). Tinicum Creek, an ambient reference stream located in the Triassic Lowlands Subecoregion, and Cooks Creek, an ambient reference stream located in the Piedmont Lowlands Ecoregion, were sampled as part of Pa DEP's Water Quality Network (WQN) within the same 3 week period as NIER's water quality sampling (8/31/98). TP concentrations for Tinicum Creek and Cooks Creek were 10ug/l and 15 ug/l respectively, indicating that phosphorus is naturally low in streams having similar geology to the Upper Wissahickon and Sandy Run basins.

Inorganic nitrogen ranged from 222 ug/l (T-GH) to 17,478 ug/l (S-TR) (Fig.3). Wissahickon Creek and Sandy Run stations had inorganic nitrogen concentrations 2.6 to 11.7 times greater than Dodd's suggested mesotrophic-eutrophic boundary concentrations for Total Nitrogen (TN) (1500ug/l). Inorganic nitrogen values in the present study underestimate TN because organic nitrogen was not analyzed. Nitrate accounted for ≥ 97% of inorganic nitrogen except for stations P-MR (94%) and T-GH (71%). Nitrate concentrations exceeded Chapter 93 Water Quality Standards for public water supply at stations S-TR, W-PR, W-GA, and W-73.

Similarly to phosphorus, the highest nitrogen concentrations were found at stations located below municipal sewage treatment plants (S-TR, W-PR, W-GA). Nitrogen uptake, denitrification and tributary dilution flows probably account for lower concentrations found in Fairmount Park (W-BM, W-RA). Inorganic nitrogen concentrations in Prophecy Creek (P-MR) and Trewellyn Creek (T-GH) were below Dodd's suggested mesotrophic-eutrophic boundary (1500 ug/l) and below EPA developed nutrient criteria guidelines for Nutrient Ecoregion IX (692 ug/l). Total nitrogen concentrations in Tinicum Creek and Cooks Creek were 230 ug/l and 1,720 ug/l respectively, suggesting naturally low nitrogen in the Triassic Lowland Ecoregion, but higher nitrogen in the Piedmont Lowlands (limestone geology).

Diel Dissolved Oxygen Sampling

NIER's diel dissolved oxygen (DO) data is summarized in Table 2. Average DO concentrations ranged from 4.16 mg/l at station W-NW to 8.78 mg/l at station W-RA. Minimum DO concentrations ranged from 1.34 mg/l (W-NW) to 7.11(W-RA). Wissahickon Creek at North Wales Rd. Bridge had average DO and minimum DO violations of Chapter 93 Water Quality Standards (Avg. = 5.0mg/l, Min. = 4.0 mg/l). Sandy Run at Twining Rd Bridge had minimum DO violations. Average diel swings were calculated by subtracting daily minimum DO from daily maximum DO and averaging diel swings for all days included in the sample. Physical parameters such as bed slope, flow, and temperature, or chemical parameters (BOD) can all influence dissolved oxygen in streams but diel productivity/respiration cycles associated with algal biomass are primarily responsible for dissolved oxygen swings. Diel DO swings were extremely high at stations S-TR (5.6 mg/l) and W-NW (5.9 mg/l), indicating that DO violations are the result of high algal biomass. Diel swings also appear high at stations W-PR and W-WA but water quality criteria violations were not found. Percent DO saturation ranged from 49% at station W-NW to 97% at station W-RA.

Other Chemical Parameters

Biological Oxygen Demand (BOD_5) was elevated at stations W-NW, W-PR, W-GA and W-73, indicating organic pollution associated with municipal sewage treatment plants. Fecal coliform concentrations were elevated above Chapter 93 Water Quality Standards at all stations except W-RA. Copper concentrations at stations W-NW, W-PR, and W-GA were elevated above Chapter 16 Toxics Criteria (estimate for total metals). However, a Water Effects Ratio (WER) was approved for Upper Gwynedd Twp. STP and Ambler STP resulting in site-specific criteria that are higher than concentrations found at corresponding downstream stations (W-PR, W-GA).

Periphyton Standing Crop

Periphyton standing crop as chlorophyll-a (Chl-a) ranged from a low of 48 mg/m^2 at station W-GA to 276 mg/m^2 at station W-PR (Fig. 4). Prophecy Creek (P-MR), which exhibited the best macroinvertebrate community in the watershed (1997 Unassessed Waters Survey), had Chl-a concentrations (73 mg/m^2) which were significantly lower ($P<0.05$) than six of the stations with the highest concentrations (Appendix 2). Chl-a concentrations at station W-NW was slightly underestimated because some filamentous algal strands were not disentangled from moss. Nine stations had Chl-a concentrations that exceeded the mesotrophic-eutrophic boundary for mean Chl-a (70 mg/m^2) and five stations exceeded the mesotrophic-eutrophic boundary for maximum Chl-a (200 mg/m^2) (Dodds et al. 1998). Dodds' mean Chl-a refers to seasonal means for a 2 to 3 month period in a single year. Maxima in some regions may occur in the late fall or early spring when canopy coverage is reduced. Seven of the stations exceeded or were within a threshold level for nuisance algal conditions suggested by Welch (1988) (100-150 mg Chl-a/m^2). The upper level of this threshold (150 mg/m^2) was chosen to represent nuisance conditions in the Wissahickon Creek. Dodds' mesotrophic-eutrophic maximum Chl-a boundary (200 mg/m^2) would not have included station W-NW, which had dissolved oxygen violations and high percent macroalgae coverage. Dodds' mesotrophic-eutrophic mean Chl-a boundary would have included station P-MR, which represented the best overall biology in the survey. All stations exceeded EPA's recommended guidelines for Chl-a (20 mg/m^2) for Nutrient Ecoregion IX.

Ash Free Dry Mass (AFDM) ranged from 1.04 mg/cm^2 at station W-GA to 6.25 mg/cm^2 at station S-TR (Fig. 5). Large variation between station transects made the AFDM data a less reliable measure of periphyton standing crop than Chl-a concentrations (Appendix 2).

The autotrophic index (AI) ranged from 250 at station W-GA to 103 at station W-PR. Intra-station AFDM variability limited significant differences among stations (Appendix 2). AI values typically range from 50 to 200 (WEF, 1995). Values greater than 200 are indicative of poor water quality where heterotrophic processes dominate the periphyton community. Mean AI values provide evidence of organic pollution at three stations. Station T-GH, a stormwater influenced station had an AI value of 206. Station S-TR, located 0.7 miles downstream from the Abington Township STP, and station W-GA, located 0.4 miles downstream from the Ambler Borough STP had AI values of 241 and 250 respectively. AI values at these stations were not significantly different than station P-MR, which had an AI of 180. Station W-GA had a significantly higher AI than station W-WA. Other data and observations provide further evidence of organic pollution at or near stations S-TR and W-GA : 1) Water column BOD concentrations were elevated at station S-TR (20 day) and station W-GA (5 day and 20 day), 2) Average % DO Saturation was low at station S-TR (75%) and W-GA (81%), and although results are not directly comparable because the diel survey was conducted on different dates, % DO saturation decreased from 94% at station W-WA to 81% at station W-GA, 3) Macroinvertebrate communities in Sandy Run, 0.15 miles downstream from the Abington Township STP were dominated by the black fly *Simulium* (66%) and the organic pollution tolerant red midge *Chironomus* (28%) (Everett, 1998, internal DEP data, UW Program), and 4) Light brown organic solids were noted in depositional areas at station W-GA. These solids were not noted at W-WA and were likely attributable to the Ambler Borough STP discharge. AI values and BOD concentrations were not significantly correlated ($p > 0.05$). Excluding station W-NW, which had a low AI value relative to % DO saturation, AI values and % DO saturations were significantly negatively correlated ($p < 0.05$), suggesting a causal response to heterotrophic benthic biomass. High intra-station AI variance and a high AI value at the biologically unimpaired station P-MR (Everett, 1997, internal DEP data, UW Program) limits the ability to reach strong conclusions relative to the AI. However, based upon AI values, DO saturation, macroinvertebrate data and visual observation, organic enrichment does appear to negatively impact benthic communities at stations W-GA and S-TR.

Duplicate Chl-a and AFDM data showed that field and laboratory methods had good precision. Coefficient of variations for Chl-a and AFDM duplicate data were < 3% and <8% respectively (Appendix 3).

Diatom Flora

Metric scores for diatom assemblages were compared qualitatively (Table 3). Stations P-MR and W-73 had the best diatom assemblage exhibiting : highest number of taxa, highest diversity, best evenness (low % dominant), and a lower percentage of motile species. Treweylln Creek's (T-GH) diatom community was poorest, having the lowest number of taxa, lowest diversity, lowest evenness, and highest percentage of motile species. Metric scores indicate that stations S-TR and W-NW were also among the poorest stations. TDI values were all high and ranged narrowly from a low of 76% (W-BM) to a high of 92% (W-GA). Based upon the TDI, all sites are considered eutrophic with the diatom flora indicative of high to very high nutrient concentrations.

Rapid Periphyton Survey

Percent macroalgae coverage ranged from 3% at station P-MR to 95% at station W-NW (Fig. 6). Prophecy Creek (P-MR) had percent macroalgae coverage that was significantly lower ($p<0.05$) than percent coverage at 5 stations (T-GH, W-NW, W-PR, W-WA and W-73). Three stations had excessive coverage of filamentous algae with coverage exceeding 70% of the streambed examined. Station S-TR was not included in statistical analysis because moss was included in the macroalgal coverage estimate. The summed coverage of moss and filamentous algae at station S-TR (57%) is high relative to that found at P-MR or in the Lower Wissahickon (W-BM, W-RA). A macroalgae coverage of greater than 40% has been suggested as a nuisance algae threshold that indicates nutrient or organic enrichment (Biggs 1996).

Average maximum filamentous algae lengths ranged from 2.2 mm at station W-GA to 113.9mm at station (W-NW). Prophecy Creek (P-MR) had a maximum algal length (11.7 mm) that was significantly lower ($p<0.05$) than the maximum algal length found at 5 stations (T-GH, S-TR, W-NW, W-PR, and W-73). Four sites, T-GH, S-TR, W-NW and W-PR had excessive lengths with maximum lengths exceeding 50 mm.

Aquatic Macrophyte Survey

Five aquatic macrophyte taxa were found during the survey (Table 4). Moss was found at five stations and was the most commonly encountered macrophyte. Based upon AFDM results, moss at stations S-TR, W-NW, and W-GA may contribute significantly to productivity within the reaches.

Results Summary

Quantitative standing crop results and semi-quantitive macroalgae results were compared utilizing correlation analysis (Appendix 5). Chl-a and AFDM were significantly positively correlated ($p < 0.01$), and percent macroalgae coverage and maximum macroalgae length were significantly positively correlated ($p < 0.01$). Macroalgae coverage and length were positively correlated with Chl-a, but the correlations were not significant ($p > 0.05$). The methods comparison suggests that the macroalgae survey cannot be used as a surrogate for standing crop, but does provide objective measurements that could be used as part of a screening procedure to prioritize more quantitative analysis.

Figure 7 graphically shows station differences based upon principal components analysis of selected physicochemical and biological variables (Appendix 4). Principal component axis 1 (PCA1) had high negative loading coefficients for nutrients, conductivity, and metals and accounted for 34% of the total station variance. Generally, Sandy Run (S-TR) and the main stem stations in the Upper Wissahickon exhibited high nutrients, high conductivity and high metals that are attributable to point source discharges. Lower Wissahickon Watershed stations showed improving water quality condition compared to Sandy Run and the Upper Wissahickon main stem stations. The two tributary streams that are not impacted by treated sewage discharges had the lowest concentration of nutrients and metals. Principal component axis 2 (PCA2) accounted for 21% of the total variance between stations and had high positive loading coefficients for Chl-a and high negative loading coefficients for percent canopy coverage and hardness. PCA2 illustrates the strong negative relationship between periphyton standing crop (Chl-a) and canopy coverage. Stations with low percent canopy coverage (S-TR, W-NW, W-73, and T-GH) had higher Chl-a concentrations, whereas stations with high percent canopy cover (W-GA, W-BM, P-MR) had lower Chl-a concentrations. Percent canopy coverage (independent variable) and Chl-a (dependent variable) are significantly negatively related ($p<0.005$, $r^2 = 0.71$) (Fig. 8).

The relationship between nutrients (dependent variable) and chlorophyll-a (independent variable) was examined separately for open canopy and closed canopy stations. The separation between open canopy and closed canopy stations was distinct, with the exception of one intermediate station (W-RA). Five stations had % canopy covers less than 25% and four stations had % canopy covers greater than 38%. The intermediate station (32% canopy cover) was included with open canopy sites because of similar Chl-a concentrations (> 150 mg/m^2). Chl-a concentrations at open canopy sites were positively related to TRP and inorganic N (Figs. 9 and 10). This relationship was significant for inorganic N ($r^2=0.66$, $p<0.05$) but not significant for TRP ($r^2=0.41$, $p>0.05$). Nutrients and Chl-a were not related at closed canopy stations.

Average diel DO swings were greatest at sites having less canopy coverage located in the headwaters of Sandy Run and Wissahickon Creek, and accordingly were significantly negatively correlated ($p< 0.05$) with % canopy coverage and stream width (Appendix 6). The positive correlation of TRP with Inorganic N ($p<0.01$) and BOD_{20}($p<0.05$) was expected because water quality is effluent dominated throughout much of the main stem Wissahickon and Sandy Run.

Discussion

Wissahickon Creek and Sandy Run are influenced by point source discharges from sewage treatment plants and have very high concentrations of nutrients. Nutrient concentrations at all Wissahickon Creek stations and Sandy Run station S-TR indicate that nutrients are available in nonlimiting supplies for the development of excessive algal standing crops if light is nonlimiting. Benthic Chl-a concentrations were greater than 175 mg/m^2 for all open canopy stations, indicating nuisance levels of algae (Welch et al 1989, Biggs 1996). The positive relationship between Chl-a and inorganic N at open canopy sites illustrates that increasing nutrient concentrations will cause Chl-a to increase even when nutrient concentrations are extremely high. Zones of relatively stationary water (boundary zones) that develop within periphyton communities can reduce the input of nutrients to the community (Mullholland 1996). Nutrient uptake and subsequent depletion within the periphyton boundary zone are probably responsible for the positive biomass response to increasing inorganic N concentrations at stations with high Chl-a concentrations. Schubert's (1996) *Selenastrum capricornutum* Printz Algal Assay Bottle Test found Wissahickon surface water from four point source influenced main stem stations to be nonlimiting with respect to N and P concentrations. Schubert's study is consistent with the present study, because the Printz Algal Assay is performed with a phytoplanktonic alga in well mixed vessels and, therefore, no nutrient depleted boundary zone would be expected. Biomass at station T-GH was high suggesting that relatively low nutrient concentrations are required for accrual of high algal standing crop when canopy coverage is low. Storm water nutrient concentrations were not sampled, but may help explain the large algal biomass at station T-GH.

Table 7 presents an ecoregion (64) specific summary of nutrient data for ambient reference streams and the Wissahickon Water Quality Network Station. Wissahickon Creek near its mouth, where nutrient concentrations are lower than in the upper watershed, has inorganic nitrogen levels several times higher than reference streams (except Muddy Creek), and total phosphorus concentrations 18 to 25 times higher than reference streams. Ratios of N:P suggest that algal communities in Ecoregion 64 streams that are minimally impacted by anthropogenic pollution and have similar geology to the Wissahickon Watershed are phosphorus limited (Borchardt 1996). While N:P ratios in natural stream conditions are helpful when discussing restoration efforts, the N:P ratio shown for Wissahickon Creek is irrelevant because nutrients are present in overwhelming supply.

Diatom assemblages have proven to be reliable indicators of water quality (Barbour 1999) and may be better predictors of eutrophication than standing crop when hydrologic disturbance is high (Kelly 1996). The Trophic Diatom Index classified all stations as eutrophic, indicating that nutrient levels are sufficient to sustain high algal biomass with adequate light. TDI scores for Prophecy Creek conflict with other indicators (nutrients, Chl-a, other diatom metrics, macroinvertebrates), which suggest fair to good conditions. Generally, weighted average phosphorus indices utilizing diatoms provide good separation of stream trophic states (Don Charles, ANSP, personal communication). The assemblages indicative of the poorest water quality were found at stations T-GH, S-TR, and W-NW. These stations also had correspondingly high benthic algal biomass and % coverage of macroalgae. Some stations (W-73, W-BM) had metric scores that conflicted with other measures of station health (nutrients, biomass, % canopy cover).

Three stations, T-GH, W-NW and W-PR, had macroalgae coverage greater than the 40% threshold that had been related to aesthetic nuisance levels of algae (Biggs 1996). Moss was included in coverage estimates for station S-TR. Moss and macroalgae coverage combined exceeded 40 % for this station.

Nutrients, excessive biomass accrual and floral community shifts can cause water quality problems (Dodds and Welch 2000) and changes in macroinvertebrate community structure (Mason 1996). NIER's diel dissolved oxygen data shows large DO swings and violations of Chapter 93 Criteria at stations S-TR and W-NW. Everett and Ateyeh (1999, nonreported DEP data) found substantial DO swings and minimum DO violations at S-TR, W-NW, W-GA and W-73 indicating excessive in-stream biomass. Many macroinvertebrates that are sensitive to organic pollution require high dissolved oxygen. Past macroinvertebrate surveys in the Wissahickon Creek have found few sensitive EPT genera and communities that are facultative with respect to organic pollution (Boyer 1997). Nutrients, light, and resultant biomass accrual and low dissolved oxygen are in part responsible for impaired macroinvertebrate communities.

Community shifts from low growing diatoms to filamentous green algae and stalked or filamentous diatoms are associated with increasing nutrients and biomass (Biggs 1996). Some filamentous chlorophytes are too large for macroinvertebrates to effectively graze (Steinman 1996). Therefore, abundances of macroinvertebrates may be altered by algal community shifts, with a reduction in grazer feeding groups and an increase in filter collectors that can utilize sloughed filamentous algae. Algal community shifts in Wissahickon Creek may negatively impact macroinvertebrate assemblages by altering food quality.

Chl-a showed a strong negative relationship with percent canopy coverage, suggesting that when N and P are present in nonlimiting concentrations, riparian canopy cover and resultant shading limits standing crop. A preliminary assessment of paired forested and nonforested sites within the Southeastern Pennsylvania piedmont physiographic province showed larger Chl-a standing crops (8X to 77X) for unforested reaches than for forested reaches in urbanized watersheds (> 50% urban) (Hession et al 2000). A nonforested reach in a largely forested watershed (> 70% forested) (Beaver Run, HQ-TSF) showed a Chl-a standing crop that was 2.5 times higher than the standing crop found in the forested reach. However, both Chl-a concentrations in Beaver Run represented oligotrophic conditions. Diatom floras in the unforested reaches were found to have lower diversity and evenness.

The relationship between percent canopy coverage and Chl-a for the Wissahickon Watershed would indicate that percent canopy coverage, as measured with the spherical densiometer, would need to be > 53% in order to achieve Chl-a concentrations below Dodds' mesotrophic-eutrophic mean Chl-a boundary of 70 mg/m^2. Riparian reforestation on 1^{st}, 2^{nd}, and 3^{rd} order streams where canopy can overreach the channel (ex."Trewellyn Creek) should provide benefits by decreasing nuisance algal conditions and restoring a more natural benthic flora. Reduction of filamentous chlorophytes should also benefit macroinvertebrate and fish communities by providing more easily used food resources and higher dissolved oxygen concentrations. Wider stream reaches (4^{th} order) would not benefit as greatly from shading, but riparian buffers could still provide an important light limitation function. Department biologists frequently note large aerial cover of long stranded filamentous green algae in streams that indicate potential eutrophication. The rapid periphyton survey in combination with nutrient sampling could provide a quick semi-quantitative method for describing benthic algal conditions. While not significantly correlated with Chl-a in this study, percent macroalgae coverage and maximum macroalgae length were positively correlated with standing crop. Two of the sites, which had the highest maximum macroalgae lengths, also had dissolved oxygen violations and high Chl-a standing crops indicative of eutrophic conditions.

Conclusions

1. Based upon suggested eutrophication criteria from current literature and Pa DEP Water Quality Standards for dissolved oxygen, the Wissahickon Creek and Sandy Run are eutrophic, exhibiting high nutrients and causal biological responses (Chl-a, macroalgae coverage, TDI, and DO) (Table 8).
2. Benthic algal standing crop (Chl-a) was negatively related to percent canopy cover, illustrating the importance of riparian vegetation in limiting biomass when eutrophication potential (ie. nutrients) is high. The Wissahickon Watershed's fair to good existing riparian corridors are protecting the stream from more widespread nuisance algal conditions and DO violations that could further erode ecological health.
3. Autotrophic index values, BOD concentrations, % DO saturation, and visual observations from the present study along with macroinvertebrate data from other DEP assessments provide evidence that organic enrichment negatively impacts benthic communities at stations S-TR and W-GA.
4. Trewellyn Creek station T-GH, a storm water influenced station, had high benthic algal standing crops (Chl-a), but low to moderate base flow nutrient concentrations (Ing.N = 222ug/l, TRP = 50 ug/l), suggesting these nutrient levels can maintain nuisance benthic standing crops with adequate light. This is in agreement with other studies (Borchardt 1996, Welch et al 1989) and would suggest low nutrient concentration goals for stream restoration.
5. Rapid periphyton assessments may provide a good semi-quantitative screening tool for Department biologists in determining stream segments that require additional biomass or community biological sampling.

Recommendations

1. This study supports the listing of Wissahickon Creek on the Pennsylvania 303d list for nutrients. TMDLs should be developed and implemented for nutrient reduction in the Wissahickon Watershed. Past Department studies and NIER's base flow water quality

report indicate that point sources account for the majority of nutrient loading in the Wissahickon Watershed.

2. Riparian reforestation and maintenance of existing buffers should be encouraged throughout the watershed. Generally, the lower main stem Wissahickon Creek including stream segments in Fort Washington State Park and Fairmount Park have good riparian buffers (personal observation). Ecological and water quality benefits of riparian buffers are scientifically defensible. Riparian buffers should be protected in the Departments Rules and Regulations (Chapter 105).
3. The Department will be required to develop nutrient criteria, including response criteria (e.g. Biomass, DO) by 2003. Including periphyton (standing crop and community indices) in criteria development would provide a more direct trophic link between nutrients and biological impairment. Development of protocols, a monitoring program, and an index of biotic integrity for periphyton would provide the Department with another assessment tool that could supplement macroinvertebrate and fish data.
4. The contribution of organic enrichment to stream impairment should be evaluated further for stream segments located downstream from Ambler Borough STP and Abington Township STP.

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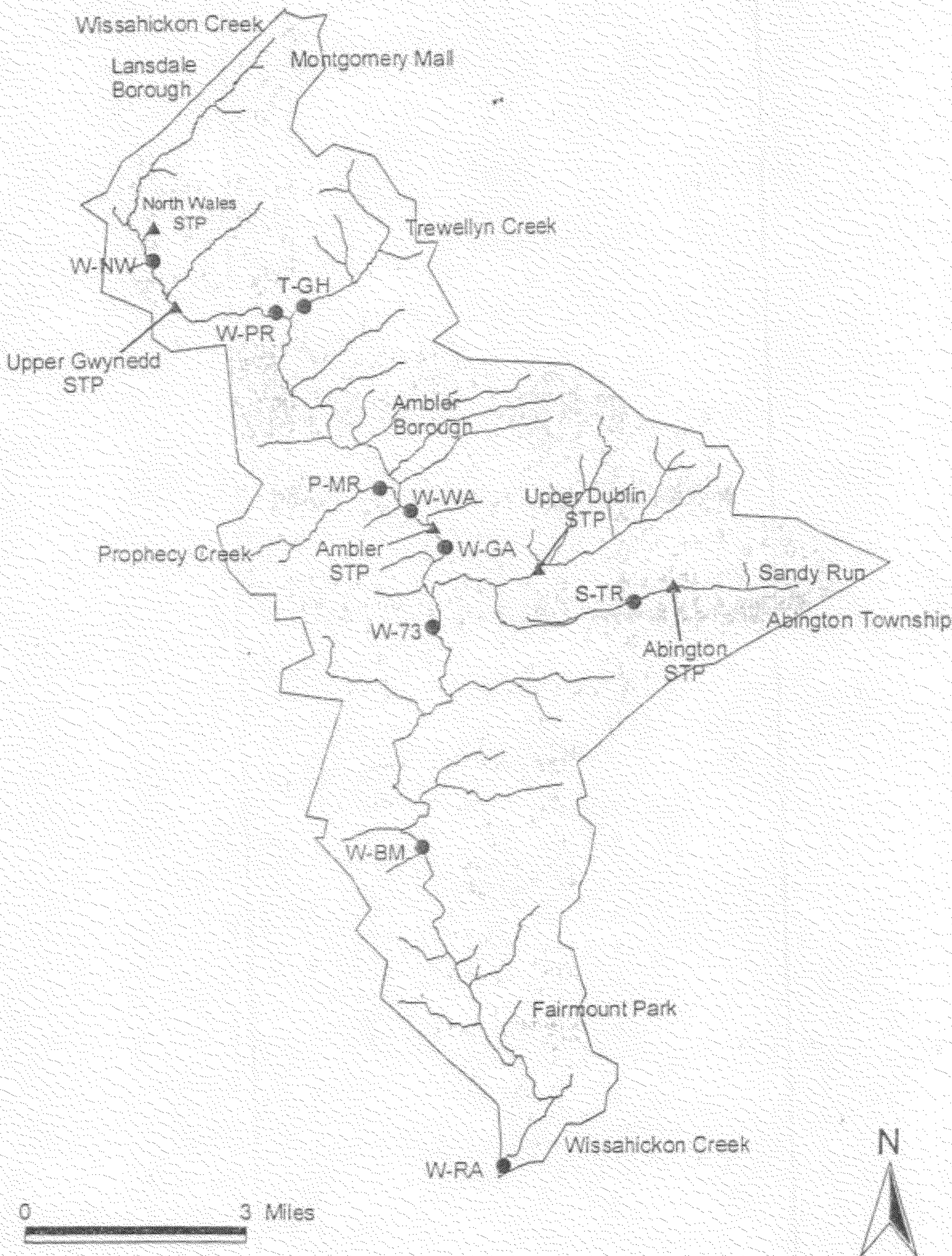


Figure 1. Wissahickon Creek Watershed. Locations of 10 sampling sites on Prophecy Creek, Trewellyn Creek, Sandy Run, and Wissahickon Creek are shown.

Table 1. Station Locations with corresponding NIER station IDs.

DEP/ANSP Station	NIER Station	River Mile	Latitude	Longitude	Location
P-MR	NIER-P	0.3	40.1520	-75.2311	Prophecy Creek near confluence with Wiss.
T-GH	NIER-T	0.2	40.1877	-75.2532	Trewellyn Creek at Gypsy Hill Rd. Bridge
S-TR	NIER-SR2	3.5	40.1269	-75.1686	Sandy Run at Twinning Rd. Bridge
W-NW	NIER-4	19.3	40.1988	-75.2895	Wissahickon at North Wales Rd. Bridge
W-PR	NIER-6A	16.9	40.1863	-75.2550	Wissahickon at Plymouth Rd. Bridge
W-WA	NIER-10	12.7	40.1469	-75.2260	Wissahickon at WVWA
W-GA	NIER-11	12.0	40.1392	-75.2170	Wissahickon at Morris Rd. Bridge
W-73	NIER-12	10.6	40.1238	-75.2209	Wissahickon at Rt. 73
W-BM	NIER-15	6.1	40.0793	-75.2260	Wissahickon at Bells Mill Rd. Bridge
W-RA	NIER-20	0.1	40.0144	-75.2073	Wissahickon at Ridge Ave Bridge

Table 2. NIER Wissahickon base flow water quality sampling : diel dissolved oxygen and temperature results for periphyton survey stations.

	Dates	n	Avg. Temp °C	Avg. DO mg/l	Avg. DO Sat. %	Avg. Diel Swing (mg/l)	Min. DO mg/l	Max. DO mg/l
P-MR	not sampled							
T-GH	not sampled							
S-TR	8/1/98 to 8/16/98	14	23.2	6.42	75	5.60	**3.09**	10.41
W-NW	8/4/98 to 8/16/98	13	22.8	**4.16**	49	5.90	**1.34**	6.92
W-PR	9/15/98 to 9/29/98	15	21.3	7.90	90	3.67	5.64	12.06
W-WA	7/30/1998 to 8/16/98	18	23.5	7.95	94	3.97	5.25	11.74
W-GA	8/26/98 to 9/8/98	14	22.7	6.98	81	2.72	5.25	9.39
W-73	7/30/98 to 8/16/98	17	23.0	6.81	80	3.15	4.98	9.35
W-BM	7/31/98 to 8/7/98	8	21.9	8.27	95	1.74	7.04	10.17
W-RA	9/16/98 to 9/29/98	14	20.0	8.78	97	3.20	7.11	12.38

Where : highlighted data are violations of Chapter 93 Water Quality Standards

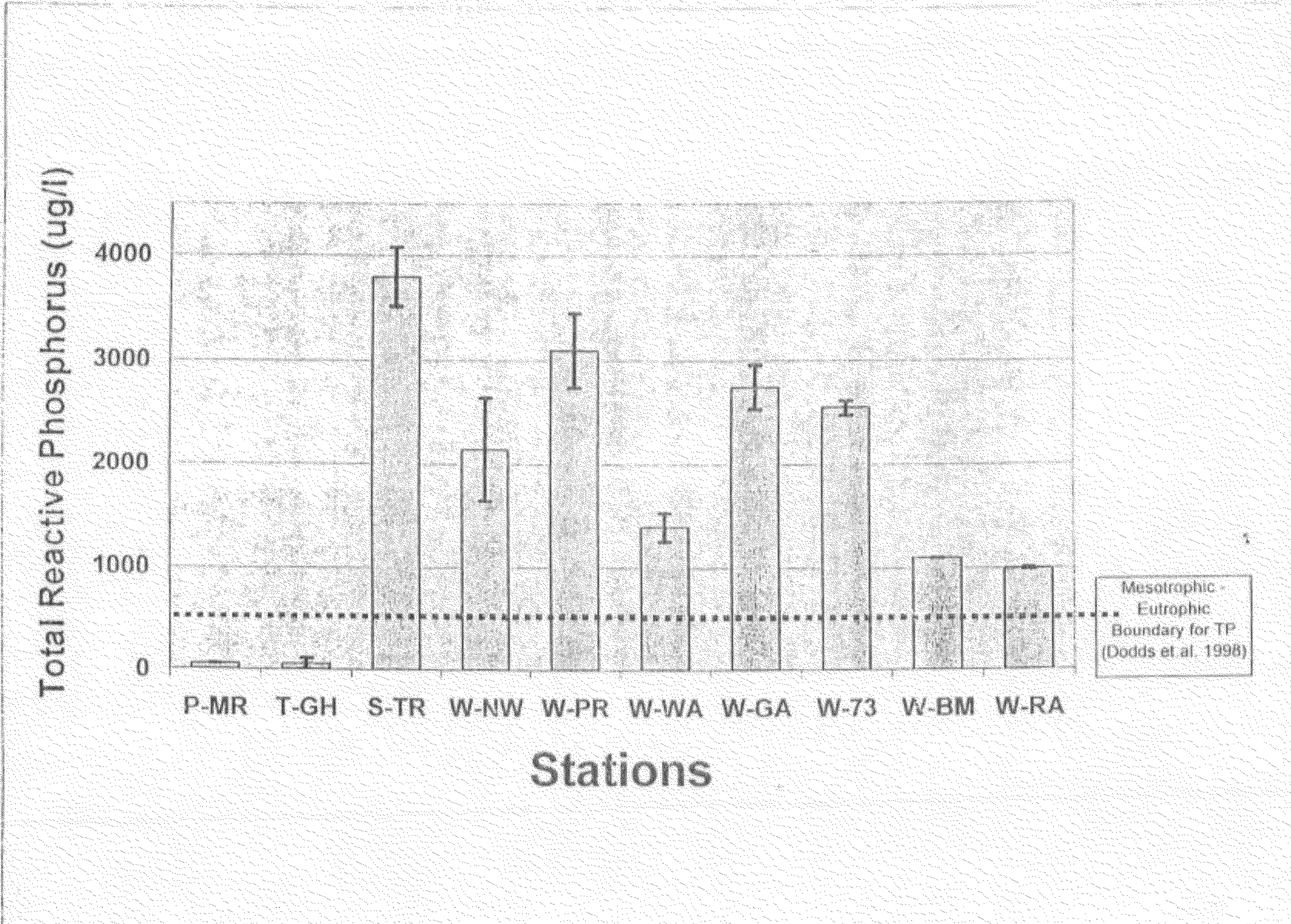


Figure 2. Total reactive phosphorus concentration (mean +/- 1SE) for stations. Suggested mesotrophic-eutrophic boundary for TP shown as dotted line (= 75 ug/l).

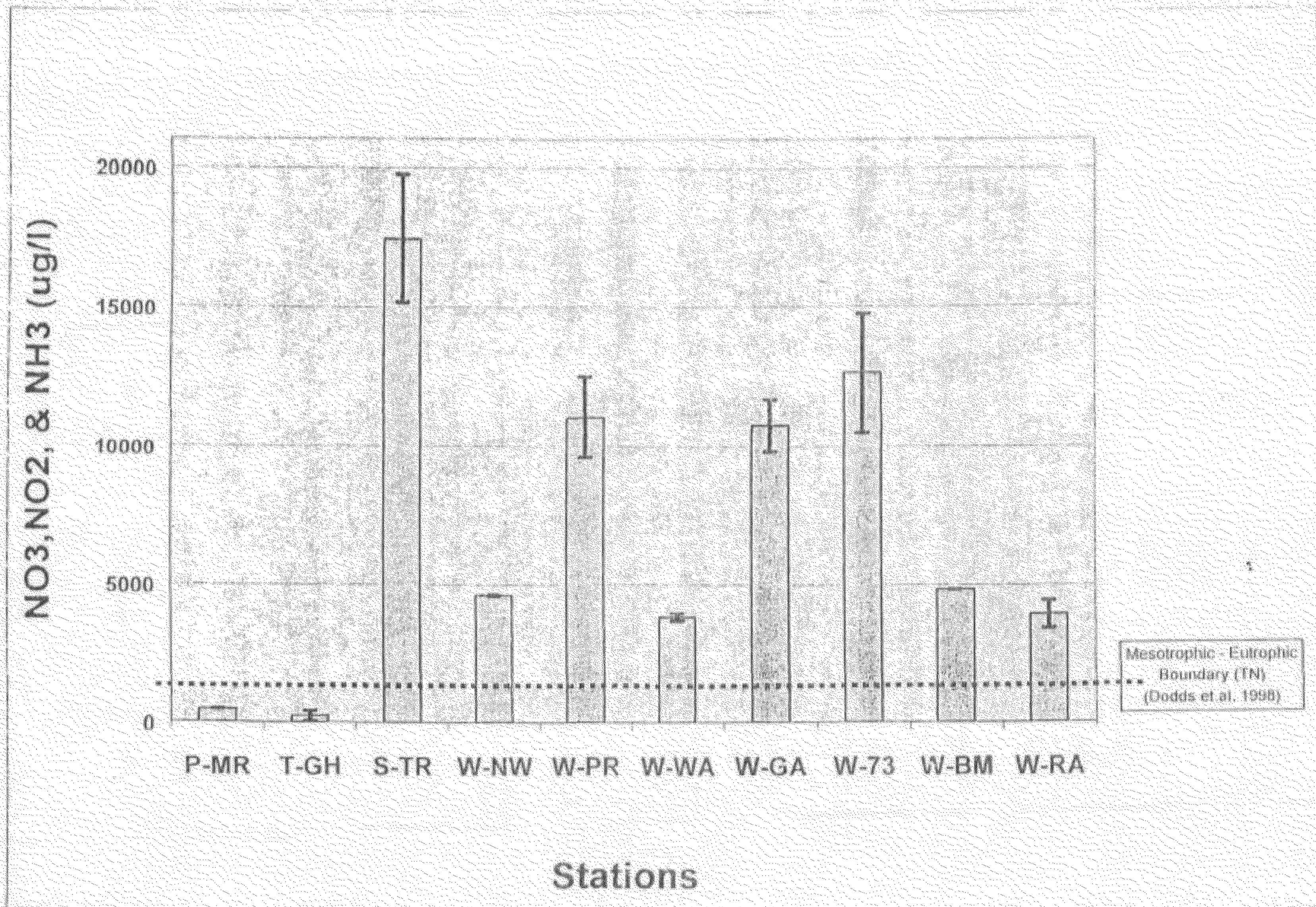
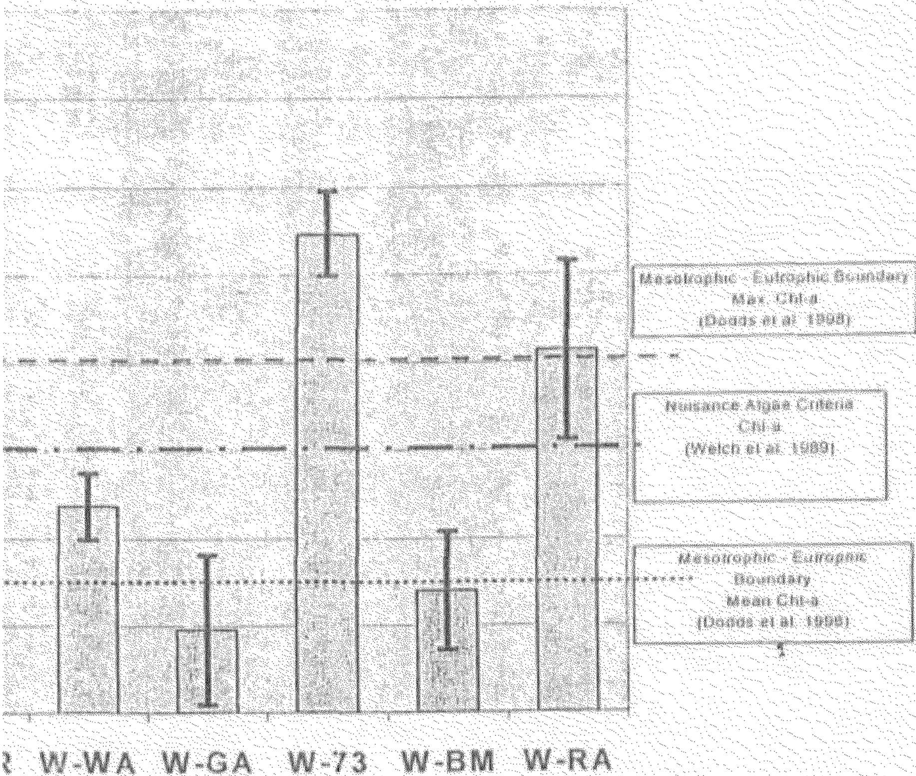


Figure 3. Inorganic nitrogen concentration (mean +/- 1SE). Inorganic nitrogen = $NH_3 + N0_3 + NO_2$ Suggested mesotrophic-eutrophic boundary concentration for TN shown as dotted line (= 1500ug/l)



ation

phyll-a (mg/m^2) (mean +/- 1SE, n=3). Suggested
chl-a shown as dashed line (= 200 mg/m^2). Suggested
dash-dot line (= 150 mg/m^2). Suggested mesotrophic-
otted line (= 70 mg/m^2).

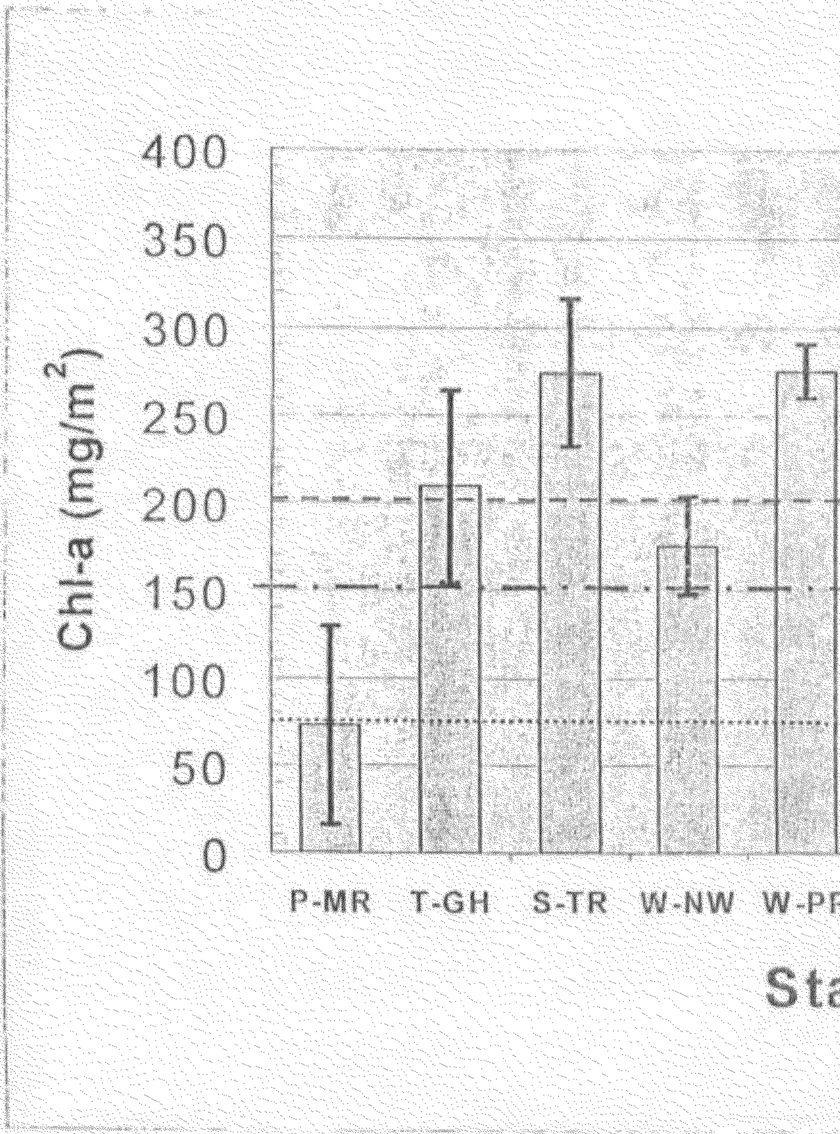


Figure 4. Periphyton standing crop as Chlorop mesotrophic-eutrophic boundary for maximum c boundary for nuisance algal conditions shown as eutrophic boundary for mean chl-a shown as a d

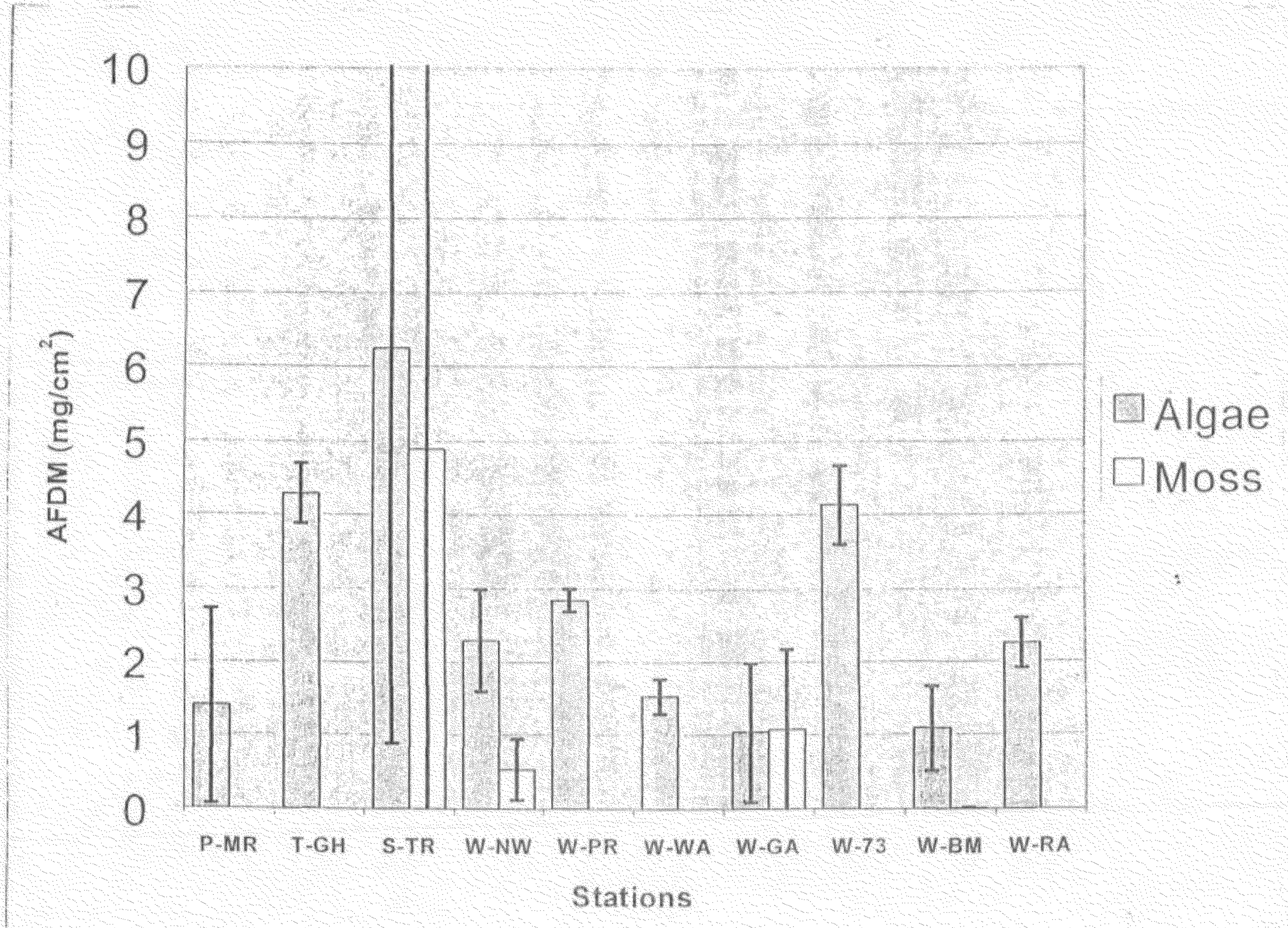


Figure 5. Periphyton and moss standing crop as AFDM (mg/cm^2), mean +/- 1SE, n=3.

Table 3. Diatom Community Metrics. Where: TDI = Trophic Diatom Index, % Dominants = % of total diatom valves which accounted for greater than 10% of overall abundance, Siltation Index = % of motile genera (*Navicula*, *Nitzschia*, *Cylindrotheca*, and *Surirella*).

Station	Total Count	# of Taxa	TDI (%)	Shannon-Wiener Diversity Index (base 2)	% Dominants	Siltation Index
P-MR	600	42	86	3.60	27.00	0.51
T-GH	617	28	79	1.52	73.42	0.86
S-TR	602	31	83	2.41	60.63	0.72
W-NW	604	33	92	2.78	68.87	0.59
W-PR	601	35	83	2.67	53.41	0.67
W-WA	602	35	84	2.99	42.86	0.64
W-GA	611	35	92	2.88	57.61	0.51
W-73	611	48	83	3.44	27.33	0.61
W-BM	611	38	76	2.45	71.19	0.60
W-RA	609	42	85	3.20	56.81	0.48

Table 4. Aquatic macrophyte survey results. Where : * = found exclusively along stream margins, x = not found, R= rare , P = present, C = common and A = abundant.

	Station									
Aquatic Macrophytes	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
Undet. Moss	x	x	A	C	x	x	C	P	P	P
Callitriche sp.*	x	x	x	P	R	R	R	R	x	x
Elodea sp.	x	P	x	P	x	x	x	x	x	x
Myriophyllum sp.	x	R	x	x	x	x	x	C	x	x
Nasturtium sp.*	x	x	C	x	C	x	x	x	x	x
Potamogeton sp.	x	x	x	R	x	x	x	R	x	x

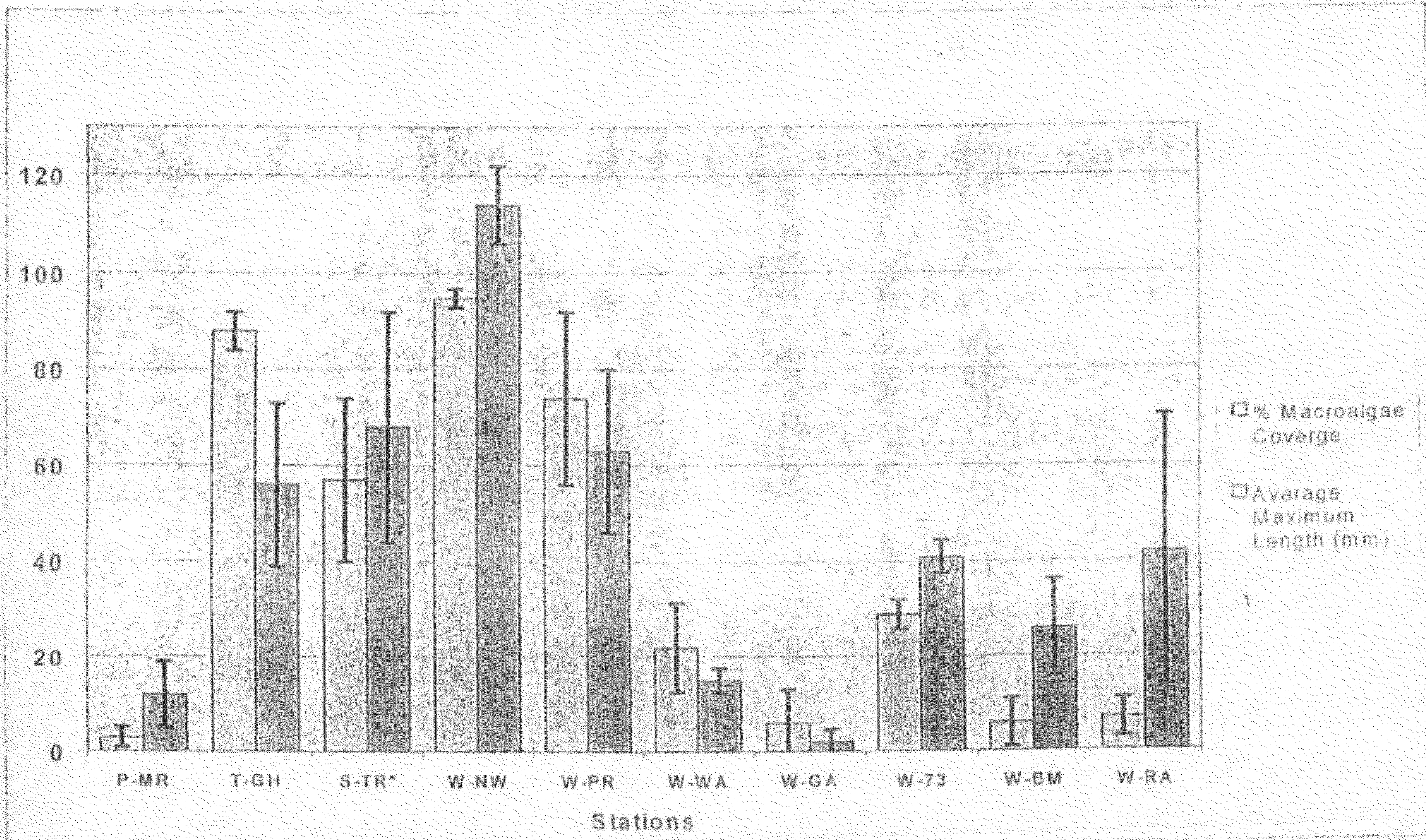


Figure 6. Results of field-based rapid periphyton survey : Percent Macroalgae Coverage (mean +/- 1SE, n=3) and Maximum Macroalgae Length (mm) (mean +/- 1SE, n=3), Where * = moss coverage included in macroalgae coverage.

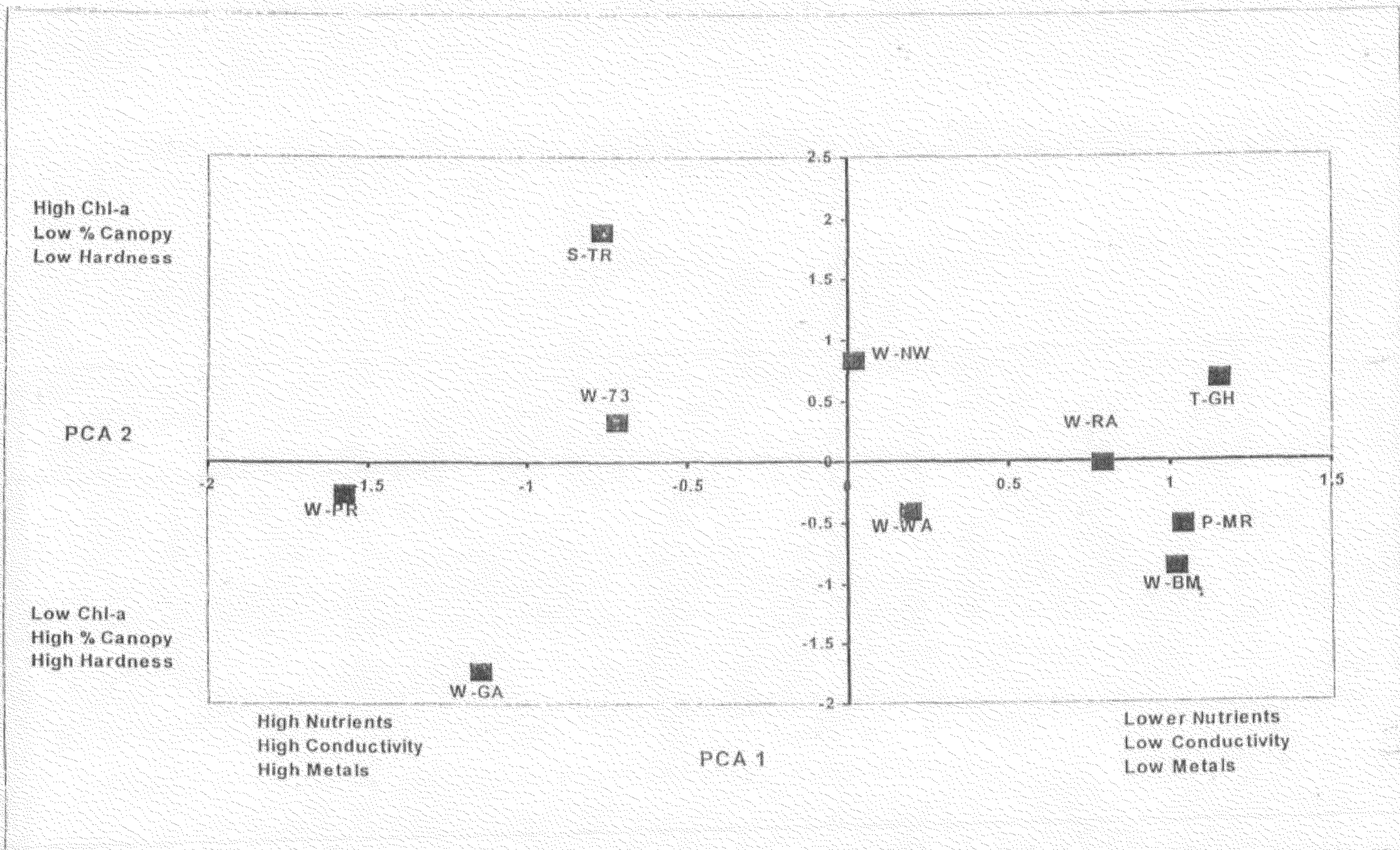


Figure 7. Principal Component Analysis of select physicochemical and biological variables. Positive and negative loading coefficients greater than 0.70 (Appendix 4) are shown on axis 1 and axis 2. PCA 1 explained 34% of total station variance and PCA 2 explained 21% of total station variance.

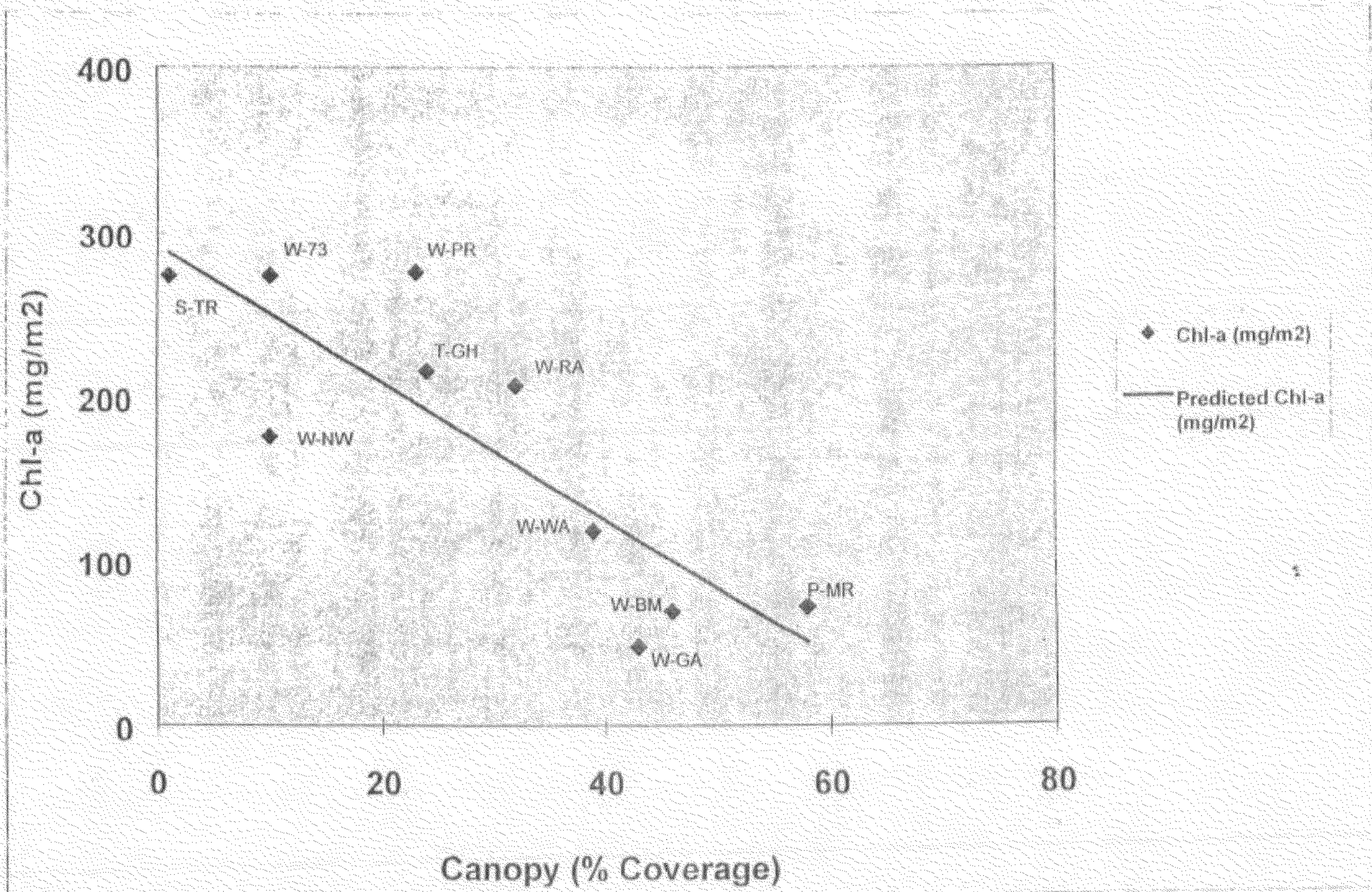


Figure 8. Linear regression showing the relationship between % canopy cover (dependent variable) and Chl-a (mg/m^2). Diamonds represent station data and line represents predicted Chl-a ($y = -4.18x + 292$, $r^2 = 0.71$, $P < 0.005$).

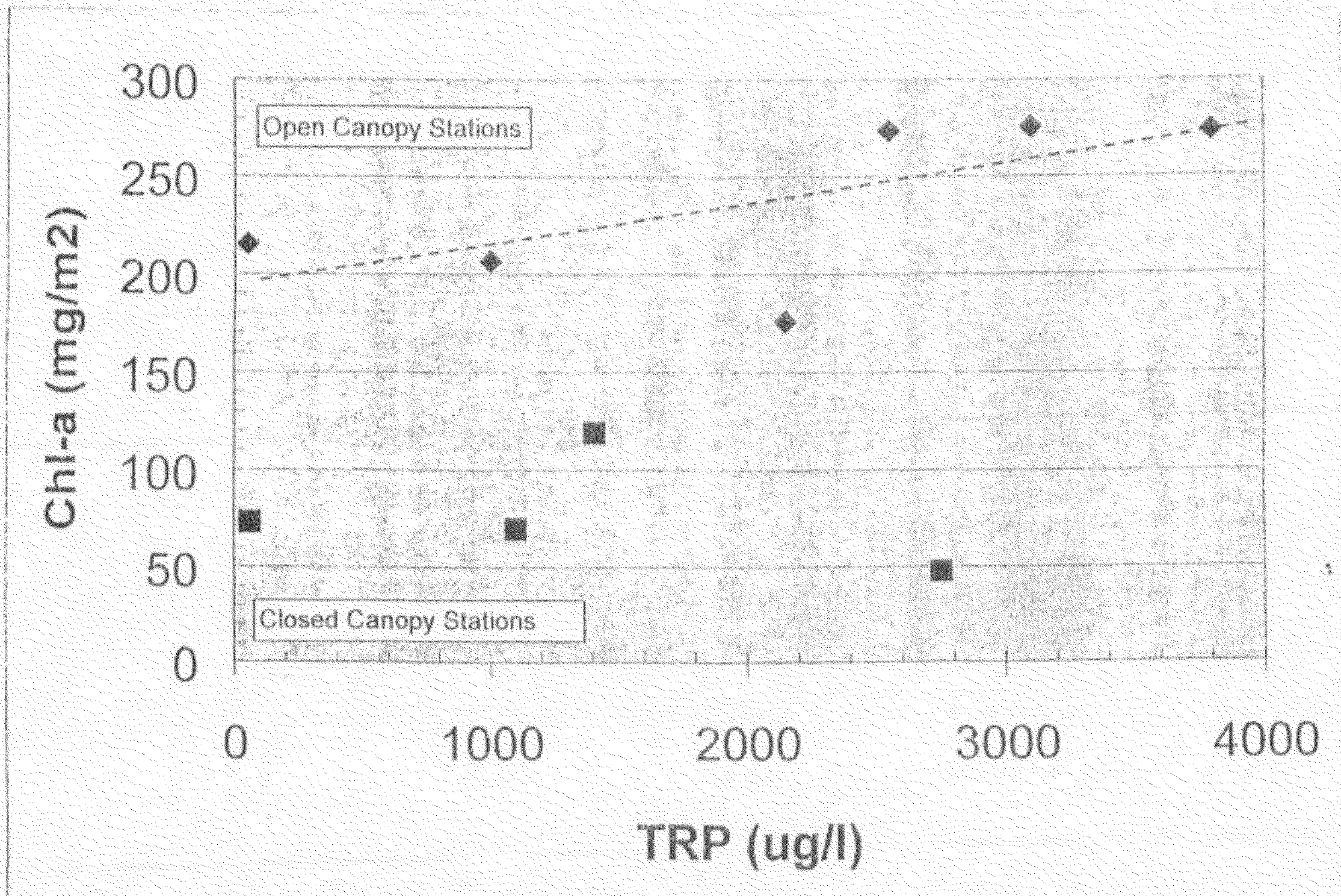


Figure 9. Relationship between total reactive phosphorus (ug/l) and chlorophyll-a (mg/m^2). Diamonds represent open canopy stations (1 to 32% canopy cover range) and squares represent closed canopy stations (39 to 58% canopy cover range). Dashed line represents predicted Chl-a ($y = 0.02x + 195$, $r^2 = 0.41$, $p>0.05$) at open canopy sites.

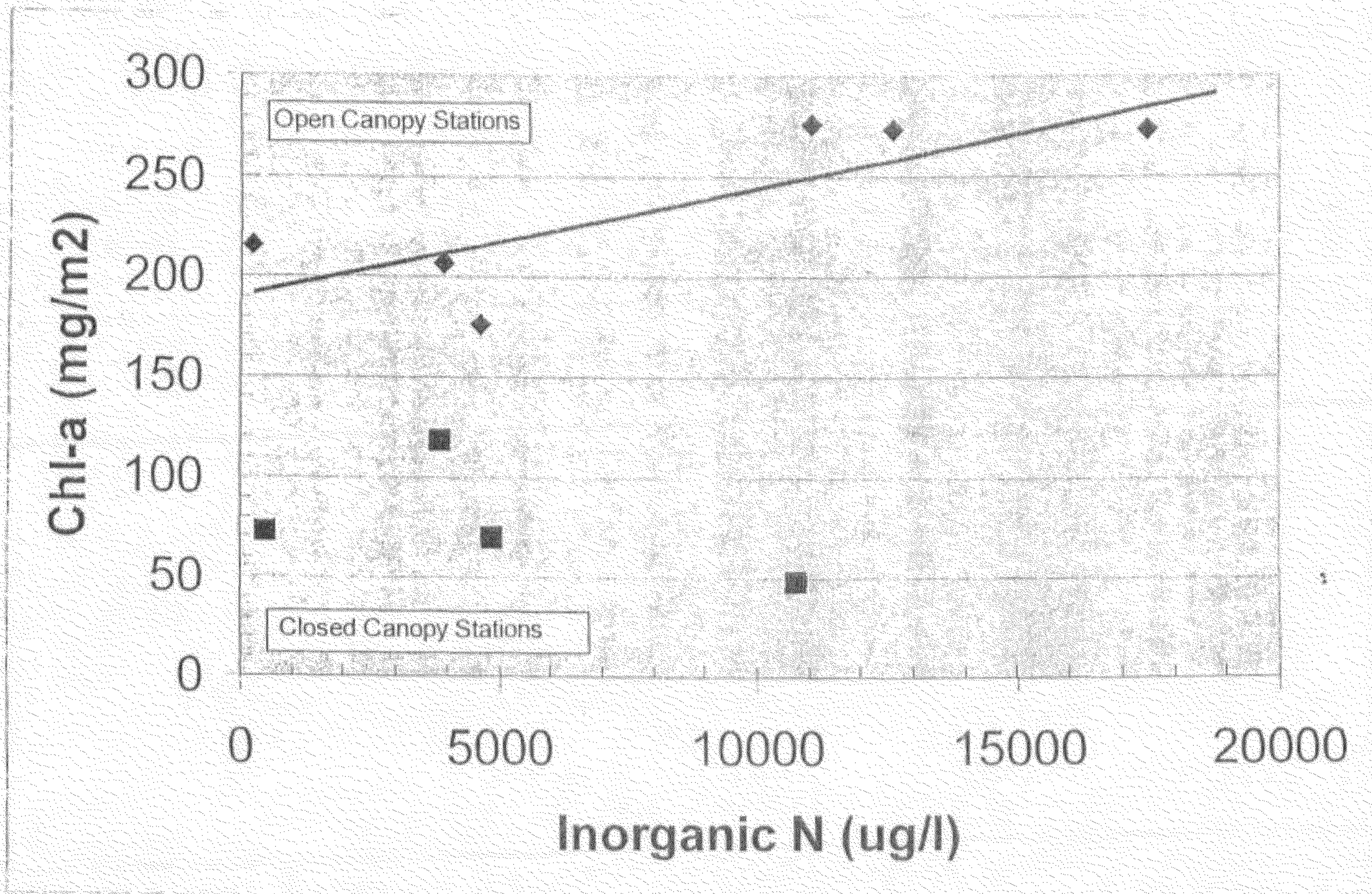


Figure 10. Relationship between inorganic nitrogen (ug/l) and chlorophyll-a (mg/m^2). Diamonds represent open canopy stations (1 to 32% canopy cover range) and squares represent closed canopy stations (39 to 58% canopy cover range). Solid line represents predicted Chl-a ($y = 0.0054x + 192$, $r^2 = 0.66$, $p < 0.05$) at open canopy sites.

Table 5. Nutrient data for ambient reference streams in Ecoregion 64 and Wissahickon Creek at W-RA (WQN 115). Concentrations represent geometric means for monthly sampling. The Wissahickon Watershed is located in three subecoregions (a,c, and d). WQN 115 is located in 64c.

Creek	Subecoregion	Yrs. of Data Acquisition	Inorganic N (ug/l)	TP (ug/l)	N:P
Cooks Creek	64d	1998-2000	1837	24	76:1
Tinicum Creek	64a	1998-2000	507	26	20:1
French Creek	64c	1999-2000	1298	28	46:1
Muddy Creek	64	1990-2000	4511	34	133:1
Wissahickon Creek*	64a,c,d	1990-2000	4200	622	7:1

Table 6. Wissahickon Creek periphyton stations compared to suggested eutrophication criteria(nutrient and biological) and Pa DEP Water Quality Standards for Dissolved Oxygen. A yes value indicates that the station exceeded the criteria. Where : ns = not sampled, * = 1998 NIER and 1999 DEP sampling, and ** = moss coverage included in macroalgae coverage.

Station	Nutrients (ug/l) TN > 1500, TP > 75 (Dodds et al. 1998)	Chl-a (mg/m^2) 150 (Welch et al. 1989)	Macroalgae Coverage > 40% (Biggs, 1996)	TDI > 67 % (Kelly, 1996)	DO (mg/l)* < 5.0 (2/15-7/31), < 4.0 (8/1-2/14) (Pa DEP Chap 93)
P-MR	No	No	No	Yes	ns
T-GH	No	Yes	Yes	Yes	ns
S-TR	Yes	Yes	Yes**	Yes	Yes
W-NW	Yes	Yes	Yes	Yes	Yes
W-PR	Yes	Yes	Yes	Yes	No
W-WA	Yes	No	No	Yes	No
W-GA	Yes	No	No	Yes	Yes
W-73	Yes	Yes	No	Yes	Yes
W-BM	Yes	No	No	Yes	No
W-RA	Yes	Yes	No	Yes	No

Appendices

… Survey : Physical, Chemical and Biological Data.

Stations	Units	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
NIER Chem. Sampling Dates		9/1	8/25, 9/1, 9/10	9/3, 9/10	8/24, 9/2	9/1, 9/10	8/25, 9/2	8/25, 9/2	9/1, 9/15	9/3	9/4, 9/11
Bio. Sampling Dates		9/11	9/15	9/14	9/10	9/15	9/11	9/11	9/15	9/14	9/14
NIER Diel Sampling Dates				8/1 to 8/16	8/4 to 8/16	9/15 to 9/29	7/30 to 8/16	8/26 to 9/8	7/30 to 8/16	7/31 to 8/7	9/16 to 9/29
Stream Order	Order	2	3	2	2	2	3	3	4	4	4
Steam Width	m	2.5	1.8	7.2	4.8	8.1	8.5	8.5	15.6	21.7	16.8
Flow (Baseflow)	cfs		0.1	5.3	1.5	2.5	4.5	11.6	16.5		30.4
Canopy (% Coverage)	%	58	24	1	10	23	39	43	10	46	32
%Boulder/Cobble	%	35	65	35	50	60	65	55	35	80	70
Total Reactive Phophorus	ug/l	60	50	3800	2150	3100	1400	2750	2550	1100	1000
Inorganic Nitrogen	ug/l	480	222	17478	4641	11050	3832	10760	12620	4840	3903
Conductivity	umhos/cm	518	379	703	575	1175	991	989	848	725	659
Hardness	mg/l	220	143	180	130	200	190	235	195	230	190
Cu	ug/l	9.0	7.5	12.8	12*	34**	12.5	23*	12.5	4.5	4.5
Fe	ug/l	24	25	33	38	125	34	49	35	17	26
Zn	ug/l	7	6	42	11	105	45	45	35	12	19
Pb	ug/l	2.0	1.7	1.0	1.0	3.0	1.5	4.0	1.5	1.0	1.0
BOD$_5$	mg/l	1.0	1.0	1.0	2.1	1.5	1.0	4.2	4.3	1.0	1.0
BOD$_{20}$	mg/l	1.0	1.0	3.2	5.9	2.5	2.4	6.6	5.1	1.0	1.0
CBOD$_5$	mg/l	1.0	1.0	1.0	1.0	1.5	1.0	2.5	1.8	1.0	1.0
Mean DO (NIER Sonde)	mg/l			6.4	4.2	7.9	8.0	7.0	8.8	8.3	8.8
Avg. DO Diel Swing	mg/l			5.6	5.9	3.7	4.0	2.7	3.2	1.7	3.2
Avg. Temp. (NIER Sonde)	°C			23.2	22.8	21.3	23.5	22.7	23.0	21.9	20.0
pH	SU	7.9	8.0	8.1	7.9	8.1	7.8	7.9	7.9	8.2	8.1
Total Solids	mg/l	1.0	2.0	1.3	0.8	1.5	3.0	6.0	12.5	4.0	3.0
Turbidity	ntu	1.1	1.3	1.5	2.2	1.2	1.6	3.6	2.5	1.9	1.5
Fecal Coliform	#/100ml	**230**	304	**2754**	**437**	**432**	**524**	269	**348**	**220**	62
Chl-a	mg/m^2	73	216	274	176	276	119	48	274	70	207
AFDM	mg/cm^2	1.40	4.29	6.25	2.29	2.85	1.53	1.04	4.14	1.09	2.26
Autotrophic Index		180	206	241	128	103	130	250	152	152	112
% Macroalgae Coverage	%	3	88	57***	95	74	22	6	29	6	7
Macroalgae Max. L.	mm	12	56	68	114	63	15	2	41	26	42
Trophic Diatom Index (ANSP)	%	86	79	83	92	83	84	92	83	76	85

Where : highlighted data are violations of Chapter 93 (Water Quality Standards) or Chapter 16 (Toxics).

* = Fish and aquatic life criteria (continuous)

** = Fish and aquatic life criteria (continuous and maximum)

*** = moss included in macroalgae coverage

Appendix 2. Descriptive statistics and analysis of variance for Chlorophyll-a, Pheophytin,AFDM, Autotrophic Index, Percent Macroalgae Coverage, and Maximum Macroalgae Length. Where: SD = standard deviation, CV = coefficient of variation, and V = variance, V-LT = $\log_{10}$ transformed variance.

Chl-a :Mean, SD, CV,V & ANOVA 1998 Wissahickon Periphyton Survey

	Chlorophyll a (ug/cm2)				chl-a
Station	Mean	SD	CV	V	mg/m2
P-MR	7.3	5.7	78	**32.4**	73
T-GH	21.6	5.5	25	30.8	216
S-TR	27.5	4.2	15	17.7	275
W-NW	17.6	2.8	16	8.0	176
W-PR	27.6	1.5	5	**2.2**	276
W-WA	11.9	1.9	16	3.6	119
W-GA	4.8	4.3	90	18.1	48
W-73	27.4	2.4	9	5.7	274
W-BM	7.0	3.4	49	11.6	70
W-RA	20.7	5.1	25	25.8	207

Chlorophyll a, P-values, <0.05 Highlighted

Station	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
P-MR	1.000									
T-GH	**0.036**	1.000								
S-TR	**0.008**	0.213	1.000							
W-NW	**0.049**	0.321	**0.027**	1.000						
W-PR	**0.004**	0.141	0.971	**0.005**	1.000					
W-WA	0.255	**0.045**	**0.004**	**0.045**	**<0.001**	1.000				
W-GA	0.575	**0.014**	**0.003**	**0.012**	**0.001**	0.058	1.000			
W-73	**0.005**	0.168	0.973	**0.010**	0.908	**0.001**	**0.001**	1.000		
W-BM	0.935	**0.017**	**0.003**	**0.014**	**0.001**	0.094	0.529	**0.001**	1.000	
W-RA	**0.039**	0.840	0.147	0.407	0.085	**0.049**	0.014	0.105	**0.018**	1.000

Pheophytin : Mean, SD, CV,V & ANOVA 1998 Wissahickon Periphyton Survey

	Pheophytin a (ug/cm2) Mean	SD	CV	V	mg/m2
P-MR	1.7	1.4	82	2.01	17
T-GH	2.7	0.4	15	0.19	27
S-TR	4.6	2.4	52	**5.86**	46
W-NW	4.2	1.1	26	1.17	42
W-PR	5.1	0.4	8	0.11	51
W-WA	2.0	0.2	10	**0.05**	20
W-GA	0.6	0.6	100	0.28	6
W-73	6.1	1.2	20	1.38	61
W-BM	2.1	0.8	38	0.77	21
W-RA	5.0	1.1	22	0.11	50

Pheophytin a, P-values, <0.05 Highlighted

Station	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
P-MR	1.000									
T-GH	0.267	1.000								
S-TR	0.135	0.245	1.000							
W-NW	0.061	0.078	0.823	1.000						
W-PR	**0.014**	**0.001**	0.742	0.257	1.000					
W-WA	0.655	0.056	0.134	**0.023**	**<0.001**	1.000				
W-GA	0.320	**0.006**	**0.048**	**0.001**	**<0.001**	**0.015**	1.000			
W-73	**0.013**	**0.009**	0.390	0.113	0.233	**0.004**	**0.002**	1.000		
W-BM	0.584	0.377	0.171	0.056	**0.005**	0.755	0.054	**0.009**	1.000	
W-RA	**0.009**	**0.025**	0.685	0.206	0.702	**<0.001**	**<0.001**	0.280	**0.004**	1.000

AFDM :Mean, SD, CV,V & ANOVA 1998 Wissahickon Periphyton Survey

Ash-Free Dry Mass (mg/cm2) algae

	Mean	SD	CV	V	V-LT
P-MR	1.40	1.33	95	1.78	
T-GH	4.29	0.41	10	0.17	
S-TR	6.25	5.37	86	**28.84**	**0.12**
W-NW	2.29	0.70	31	0.49	
W-PR	2.85	0.15	5	**0.02**	**0.0006**
W-WA	1.53	0.24	16	0.06	
W-GA	1.04	0.94	90	0.88	
W-73	4.14	0.53	13	0.28	
W-BM	1.09	0.57	52	0.32	
W-RA	2.26	0.34	15	0.12	

AFDM (algae), P-values, <0.05 Highlighted (log transformed)

Station	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
P-MR	1.000									
T-GH	0.061	1.000								
S-TR	0.094	0.766	1.000							
W-NW	0.260	**0.028**	0.180	1.000						
W-PR	0.138	**0.003**	0.297	0.253	1.000					
W-WA	0.528	**<0.001**	0.066	0.149	**0.003**	1.000				
W-GA	0.680	0.062	0.081	0.189	0.117	0.336	1.000			
W-73	0.067	0.684	0.708	**0.038**	**0.011**	**0.001**	0.068	1.000		
W-BM	0.924	**0.017**	0.051	0.119	**0.044**	0.306	0.701	**0.019**	1.000	
W-RA	0.235	**0.004**	0.167	0.948	0.065	**0.040**	0.176	**0.007**	0.093	1.000

Autotrophic Index :Mean, SD, CV,V & ANOVA

1998 Wissahickon Periphyton Survey

	Maximum Length (mm)				
Station	Mean	SD	CV	V	V-LT
P-MR	180	64	36	4100	
T-GH	206	44	21	1971	
S-TR	241	228	95	**52146**	**0.1477**
W-NW	128	20	16	399	
W-PR	103	4	4	**14**	**0.00027**
W-WA	130	32	25	996	
W-GA	250	76	30	5822	
W-73	152	29	19	837	
W-BM	152	28	18	792	
W-RA	112	17	15	301	

Autotrophic Index, P-values, <0.05 Highlighted (Log Transformed)

Station	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
P-MR	1.000									
T-GH	0.550	1.000								
S-TR	0.916	0.843	1.000							
W-NW	0.314	**0.036**	0.526	1.000						
W-PR	0.106	**0.005**	0.331	0.103	1.000					
W-WA	0.356	0.061	0.544	0.954	0.188	1.000				
W-GA	0.301	0.445	0.623	**0.029**	**0.008**	**0.042**	1.000			
W-73	0.654	0.129	0.734	0.296	**0.025**	0.400	0.076	1.000		
W-BM	0.658	0.133	0.736	0.296	**0.026**	0.398	0.077	0.095	1.000	
W-RA	0.170	**0.015**	0.397	0.370	0.479	0.428	**0.016**	0.096	0.999	1.000

Macroalgae (% Coverage) :Mean, SD, CV,V & ANOVA
1998 Wissahickon Periphyton Survey

Station	Macroalgae (% Coverage) Mean	SD	CV	V
P-MR	3.1	2.1	68	4.4
T-GH	88.0	4.4	5	19.4
S-TR*	57.3	17.7	31	311.8
W-NW	94.5	2.0	2	**4.0**
W-PR	74.0	18.0	24	**324.0**
W-WA	22.4	9.5	42	90.3
W-GA	6.2	7.1	115	50.4
W-73	29.4	3.0	10	9.0
W-BM	5.8	5.4	93	29.2
W-RA	7.1	3.8	54	14.4

* = moss was included with macro coverage estimate, sample was not included in ANOVA and correlation analyses.

Macroalgae (% Coverage), P-values, <0.05 Highlighted

Station	P-MR	T-GH	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
P-MR	1.000								
T-GH	**<0.001**	1.000							
W-NW	**<0.001**	0.082	1.000						
W-PR	**0.002**	0.261	0.122	1.000					
W-WA	**0.026**	**<0.001**	**<0.001**	**0.012**	1.000				
W-GA	0.510	**<0.001**	**<0.001**	**0.004**	0.077	1.000			
W-73	**<0.001**	**<0.001**	**<0.001**	**0.013**	0.289	**0.006**	1.000		
W-BM	0.469	**<0.001**	**<0.001**	**0.003**	0.057	0.937	**0.003**	1.000	
W-RA	0.188	**<0.001**	**<0.001**	**0.003**	0.060	0.861	**0.001**	0.749	1.000

Macroalgae Maximum Length (mm) :Mean, SD, CV,V & ANOVA
1998 Wissahickon Periphyton Survey

Station	Maximum Length (mm) Mean	SD	CV	V
P-MR	11.7	7.3	62	53.3
T-GH	56.1	17.1	30	292.4
S-TR*	68.3	24.0	35	576.0
W-NW	113.9	8.2	7	67.2
W-PR	62.8	16.8	27	282.2
W-WA	14.5	2.5	17	6.2
W-GA	2.2	2.5	114	6.2
W-73	40.6	3.4	8	11.6
W-BM	25.6	10.2	40	104.0
W-RA	41.9	28.2	67	795.2

Macroalgae Maximum Length (mm), P-values, <0.05 Highlighted

Station	P-MR	T-GH	S-TR	W-NW	W-PR	W-WA	W-GA	W-73	W-BM	W-RA
P-MR	1.000									
T-GH	**0.014**	1.000								
S-TR	**0.018**	0.513	1.000							
W-NW	**<.001**	**0.006**	**0.036**	1.000						
W-PR	**0.008**	0.656	0.759	**0.009**	1.000					
W-WA	0.564	**0.014**	**0.018**	**<0.001**	**0.008**	1.000				
W-GA	0.102	**0.006**	**0.009**	**<0.001**	**0.004**	**0.004**	1.000			
W-73	**0.003**	0.197	0.119	**<0.001**	0.088	**<0.001**	**<0.001**	1.000		
W-BM	0.127	0.056	**0.047**	**<0.001**	**0.030**	0.141	**0.018**	0.073	1.000	
W-RA	0.146	0.496	0.284	**0.013**	0.332	0.168	0.072	0.939	0.398	1.000

Appendix 3. Duplicate data for Chlorophyll-a, Pheophytin-a, and AFDM. Where sd = standard deviation and cv = coefficient of variation.

Wissahickon Periphyton Survey - 1998

Duplicate Data :

Sample ID	Chlorophyll a (ug/cm2)	Pheophytin a (ug/cm2)	AFDM (mg/cm2)
W-RA-C	22.40	5.90	2.73
W-RA-C dup	22.00	3.80	2.42
mean	22.2	4.9	2.6
sd	0.3	1.5	0.2
cv	1	31	8

Sample ID	Chlorophyll a (ug/cm2)	Pheophytin a (ug/cm2)	AFDM (mg/cm2)
W-PR-A	28.90	3.50	2.67
W-PR-A dup1	27.30	4.90	2.78
W-PR-A dup2	27.70	5.80	2.84
mean	28.0	4.7	2.8
sd	0.8	1.2	0.1
cv	3	26	4

Appendix 4. Results of Principal Components Analysis for select physicochemical and biological parameters.

Eigenvalues (algae2.sta)
Extraction: Principal components

	Eigenval	% total Variance	Cumul. Eigenval	Cumul. %
1	5.861616867	34.48009922	5.861617	34.4801
2	3.528553041	20.75619436	9.39017	55.23629

Factor Loadings (Unrotated) (algae2.sta)
Extraction: Principal components
(Marked loadings are > .700000)

	Factor 1	Factor 2
STR_WIDT	0.042263006	-0.272861375
CANOPY	0.450668449	**-0.817438126**
BLDR_COB	0.359642301	-0.406362883
TRP	**-0.909575663**	0.246628879
INORG_N	**-0.834472522**	0.275940405
CONDUCT	**-0.772291472**	-0.422303987
HARD	-0.152242322	**-0.741862616**
CU	**-0.861567483**	-0.222697486
FE	**-0.734434645**	-0.121445884
ZN	**-0.830399451**	-0.117701327
PB	-0.554925789	-0.633859978
BOD20	-0.668877193	-0.045645961
TOT_SOL	-0.278792483	-0.225833471
TURBID	-0.418989085	-0.425358061
FEC_COLI	-0.337912059	0.683616571
CHL_A	-0.383116581	**0.743352658**
TDI	-0.378505773	-0.145602851
Expl.Var	5.861616867	3.528553041
Prp.Totl	0.344800992	0.207561944

Factor Scores (algae2.sta)
Rotation: Unrotated
Extraction: Principal components

	Factor 1	Factor 2
P-MR	1.03755423	-0.508975435
T-GH	1.152357854	0.676308549
S-TR	-0.76702258	1.893061697
W-NW	0.018645404	0.841737171
W-PR	-1.573028937	-0.258352101
W-WA	0.193749979	-0.398551705
W-GA	-1.148745369	-1.712571585
W-73	-0.720028983	0.330428745
W-BM	1.015308724	-0.850597969
W-RA	0.791209678	-0.012487367

Appendix 5. Pearson Product Moment Correlation matrix for standing crop measurements and macroalgae measurements. Highlighted correlations are significant (* = p < 0.01).

	Chl-a	AFDM	% Macroalgae Coverage	Macroalgae Max. Length
Chl-a	1.00			
AFDM	**0.83***	1.00		
% Macro Coverage	0.58	0.61	1.00	
Macro Max. Length	0.62	0.49	**0.85***	1.00

Appendix 6. Pearson Product Moment Correlation matrix for selected physicochemical and biological variables. Highlighted correlations are significant (* = p< 0.05, ** = p < 0.01).

	Chl-a	TDI	TRP	Inorg. N	Avg. Diel DO Swing	BOD20	Cond.	% Canopy Coverage	Stream Width
Chl-a	1.00								
TDI	-0.21	1.00							
TRP	0.44	0.29	1.00						
Inorg. N	0.48	0.10	**0.95****	1.00					
Avg. Diel DO Sw.	0.47	0.45	0.47	0.24	1.00				
BOD20	0.01	**0.72***	**0.64***	0.52	0.31	1.00			
Conductivity	0.06	0.14	0.62	0.54	-0.32	0.33	1.00		
% Canopy Coverage	**- 0.84 ****	-0.04	-0.63	-0.60	**- 0.77 ***	-0.40	0.01	1.00	
Stream Width	-0.04	-0.39	0.10	0.19	**- 0.79 ***	-0.10	0.28	0.08	1.00