The use of aquatic insects and benthic macroinvertebrate communities to assess water quality upstream and downstream of the Village of Stamford wastewater treatment facility

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INTRODUCTION

The use of aquatic insects and other benthic macroinvertebrates to assess the quality of rivers and streams has a long and well documented history (Bailey et al. 1995; Davis et al. 1995; Thomas et al. 2002; Zimmerman 1993). The benthic macroinvertebrate populations, in addition to various chemical and biological assessment parameters, are used to characterize a river's or lake's current water quality and can chart trends within a particular water course (Bode 2002). The benthic macroinvertebrate communities, of which the aquatic insects and especially the aquatic nymphs, comprise a critical niche, are favored as a reliable and relatively low-cost indicator of the biotic health of water bodies (Bode 2002). The benthic macroinvertebrates are favored indicators for a variety of reasons, chiefly that they have limited mobility and remain in the same general area for many months; they have documented responses to a variety of environmental conditions; they provide a valuable part of the aquatic food chain; and they are relatively easy to collect and are abundant so that statistical analysis and trending is possible (Stroud Water Research Center 2004). Their responses (e.g. absence or presence, population numbers, deformities, etc.) reflect short- and long-term environmental conditions within their native watershed (Stroud Water Research Center 2004), and reflect intermittent discharges and the synergistic effects of in-stream chemical contaminants often too dilute to detect (Bode et al. 1991). In New York State, macroinvertebrate populations, and the biotic indices generated by these populations, constitute the primary means of monitoring water quality (Bode, personal communication). Begun in earnest in the early 1970s, simple biotic indices (also known as metrics) have evolved into ever more complex regional or ecosystem-specific formulae, which today number over 50 different indices (Bode 2002; Barbour, et.al. 1999; Yandora 1998).

BACKGROUND

The scientific and regulatory communities in not only New York State but nationwide and worldwide have used populations of benthic macroinvertebrates, of which aquatic insects are included, to monitor the changing character of the nation's watersheds (Bailey et al. 1995; Thomas et al. 2002). In the New York City watershed, which encompasses 5000 square kilometers with 19 separate reservoirs and hundreds of contributing streams, the New York City Department of Environmental Protection

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(NYCDEP), in conjunction with the New York State Department of Environmental Conservation (NYSDEC), is charged with monitoring the watershed's health status with a variety of techniques. These water quality assessment techniques include routine chemical surveys within the reservoirs and contributory streams, chemical surveys of point discharges, bioassays at wastewater treatment plant discharges, bacterial and viral studies, as well as the benthic macroinvertebrate studies (Rosenfeld 2005). Most other states have adopted sampling and analysis patterns pursuant to the methods developed by Bode and refined by the United States Environmental Protection Agency (Bode 2002; Barbour et al. 1999).

In May of 1972, the New York State Department of Environmental Conservation (NYSDEC) initiated the use of biological monitoring for evaluation of the relative biological health of streams and rivers using benthic macroinvertebrate populations (Bode 2002). The method is reliable and cost effective, and over the years has been refined to permit wider application. In 1984-1986, the Rapid Assessment protocol was developed within the NYSDEC to allow for on-site screening of rivers and streams. This protocol allowed field researchers to rapidly determine problem areas within watersheds and to then focus resources on more detailed investigations into causes and sources of environmental degradation. The United States Environmental Protection Agency (USEPA) initiated similar studies into evaluating the success of their nationwide environmental protection efforts and developed their Rapid Bioassessment Protocols (RBPs) in 1989. The earlier RBPs have been revised and have found application across the vast complexities of ecosystems nationwide (Barbour et.al. 1999).

Of the 50 or more biotic indices in use, there are four primary macroinvertebrate biotic indices that have found wide application (Bode 2002; Hilsenhoff 1988; Thomas, et.al. 2002; USGS 2002) in riffle environments. The following biotic indices comprise the bases for the NYSDEC's Biological Assessment Profile:

Taxa (Species) Richness – This measures the number of different kinds of organisms; lower numbers indicate a reduced water quality. For the NYSDEC Water Quality Assessments, organisms collected in the 100-organism kick sample are identified to the species level. (A kick sample community, as defined by Bode (Bode 2002), is from a riffle with rocks, rubble, gravel or sand substrate. The depth of water is less than one meter; water velocity is greater than 0.4 m/sec. The sample period is from July to September with a 5 minute, later reduced to 2 minute, disturbance for 5 meters within the sample reach. A 23 cm x 46 cm (9" x 18") aquatic net with 0.8 mm x 0.9 mm mesh size is set in the stream 0.5 m downstream and the stream bottom is kicked and large rocks and/or sticks are scrubbed of organisms.). The expected species richness ranges are as follows: greater than 26 is non-impacted; 19-26 is slightly impacted; 11-18 is moderately impacted; and less than 11 is severely impacted (Bode et al. 1991). The Hudson Basin River Watch Guidance Document (Hudson Basin River Watch Guidance Document 1999) defines the following ranges based on family richness: greater than 13 is non-impacted; 10-13 is slightly impacted; 7-9 is moderately impacted; and less than 7 is severely impacted.

EPT Richness (Ephemeroptera, Plecoptera, and Trichoptera) – The EPT richness refers to the number of species of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) in the standard 100-organism kick sample. Since the majority of these three orders are pollution sensitive, higher species numbers indicate enhanced water quality. These three orders include members with gill breathing larvae, so they can only exist in aquatic environments with high dissolved oxygen levels, and low organic enrichment. The EPT richness number ranges for the 100-organism kick sample are as follows: greater than 10 is non-impacted; 6-10 is slightly impacted; 2-5 is moderately impacted; and 0-1 is severely impacted (Bode et al. 1991). The Hudson Basin River Watch Guidance Document (Hudson Basin River Watch Guidance Document 1999) defines the following ranges based on EPT family richness: greater than 7 is non-impacted; 3-7 is slightly impacted; 1-2 is moderately impacted; and 0 is severely impacted.

HBI (Hilsenhoff Biotic Index) or Biotic Index (BI) – This index is reflective of organism identification to species level, with each species assigned an environmental tolerance value of from 0-10. Intolerant species rate a value of 0, while most pollution tolerant species rate a value of 10. This rating system is for sensitivities to organic pollution (i.e. wastewater or agricultural runoff, as compared to heavy metals or pesticide impact). The HBI index was modified shortly after its inception to the Family Biotic Index (FBI), to be useful in the Rapid Assessment programs. As a simplification, all species in a family were weighted according to their relative abundance in aquatic systems in the State of Wisconsin (Hilsenhoff 1988). The FBI is used only in rapid assessments and is not routinely substituted for the BI. The BI is calculated by multiplying the number of organisms with their tolerance value, summing those products, and dividing that sum by the total number of individuals. The BI or HBI range for the 100-organism kick sample is as follows: 0-4.5 is non-impacted; 4.51-6.50 is slightly impacted; 6.51-8.50 is moderately impacted; and 8.51-10.00 is severely impacted (Bode et al. 1991).

Percent Model Affinity (PMA) – This index is a measure of similarity to a non-impacted aquatic community of seven major orders and their "ideal" percentages: 40% Ephemeroptera, 5% Plecoptera, 10% Trichoptera, 10% Coleoptera, 20% Chironomidae, 5% Oligochaera, and 10% Others. These percentages are for the standard 100-organism kick sample. The PMA is generated by summing the difference between the number of individuals in the collected sample and the "ideal" community for the seven major orders, multiplying that sum by 0.5 and subtracting that number from 100. Ranges for the PMA are as follows: greater than 64% is non-impacted; 50-64% is slightly impacted; 35-49% is moderately impacted; and less than 35% is severely impacted (Bode et al. 1991).
The four major indices cited above are the bases for the development of the Water Quality Score for a particular riffle habitat in New York State. Bode details the O'Brien Plot of Index Values (Bode et al. 1991), which is a graphical means of converting the four major indices to a common 0-10 water quality scale, and eventually to a single water quality number. Without this normalization to a 0 to 10 scale, the major indices are inversely related to each other, with some increasing in value with increasing water quality and others decreasing in value with increasing water quality.

In addition to the biotic indices mentioned herein, characterizations of riffle habitats should include chemical and physical monitoring including stream turbidity, conductivity, pH, temperature, dissolved oxygen, percentage canopy cover, stream bank stability, and stream order determination.

METHODOLOGY

This investigation focused on the wastewater treatment plant (WWTP) discharge from the bucolic Village of Stamford, Delaware County, New York (Appendix A). The Village, which in the 1890s was a destination resort for scores of New York City residents, now has a population of just over 1200 year-round residents, supplemented seasonally with metropolitan area transplants. The gravity wastewater collection system within the Village consists of approximately 15 kilometers miles of pipe, serving 400+/- residential units in addition to various businesses, restaurants, a hospital, nursing home, central school and bus garage, and an electronics manufacturing plant. The area is mountainous, part of the Catskill Mountain range, with shallow rocky soils and numerous groundwater rivulets contributing to form the headwaters of the West Branch of the Delaware River. The West Branch is one of the major tributaries to the Cannonsville Reservoir, and has been the subject of several biological assessment studies by the NYSDEC, the NYCDEP, and the Stroud Water Research Center (Bode et al. 2001; Cutietta-Olsen et al. 2000; Stroud Water Research Center 2004). The Cannonsville Reservoir is a vital part of New York City's 5000-square kilometer upstate water supply system, consisting of 19 lakes and reservoirs, and providing unfiltered potable water to nine million downstate residents. In an effort to monitor and protect this drinking water supply, the regulatory agencies are routinely conducting water quality assessments of all streams and impoundments within the New York City watershed, including the West Branch of the Delaware River. Those investigations characterize the West Branch and include sampling sites further distant from any wastewater discharge. This investigation explores the micro-environment immediately upstream and downstream of the Village of Stamford WWTP discharge. The findings of this investigation are compared to the findings of the previously referenced assessment reports.

The upstream study site is approximately 40 meters above the wastewater discharge point, in a 5-meter reach with an average water velocity of 0.38 m/sec. The downstream site was approximately 35 meters below the WWTP effluent pipe, with an average water velocity of 0.41 m/sec. A fisherman's bobber was floated down the 5-meter reaches three times and the travel times were averaged. In both sites, the stream was approximately 2 meters wide; water depths ranged from 0.16 meters to 0.35 meters. The West Branch in this area is a second order headwater stream, classified as C(T), a trout stream. Appendix A identifies the sampling sites on the Stamford USGS Quadrangle map. Sampling was conducted the morning of 22 September 2005, a sunny and windy day with temperatures approaching 16 degrees C. The sampling date was selected to correspond to an earlier NYSDEC Biological Assessment, conducted on 20 September 2000 (Bode et.al. 2001). The 2005 sampling event followed a relatively dry summer after a historically high spring snow runoff event in early April (Payne, personal communication).

This investigation modified the standard kick sampling protocol of Bode, in that a Hess sampler was used rather than a net, and the 2-minute sampling period was extended ten-fold. The Hess sampler was rotated into the stream bottom in four (4) separate locations moving upstream within the 5-meter reach. This proved difficult since the stream bottom was predominantly lined with large rocks, which were gently rubbed by hand to dislodge organisms and wash them into the 0.8 mm net. At both locations, there was a large quantity of detritus from decaying leaves and fine sediments. The canopy cover upstream was 30%; downstream canopy cover was 80%. Streamside vegetation consisted of dense groupings of shrubs and grasses, with occasional overhanging trees. In addition to the biotic sampling, physical field data was collected; this included dissolved oxygen, pH, conductivity, temperature, and turbidity; all of these measurements were completed with the WWTP analytical equipment. The field data are summarized in Appendix B.

After collection, the net contents were poured into a white enamel lab pan, where the larger stones and detritus were removed by hand. The remaining material was transferred to collection bottles filled with 70% ethanol. The collection bottles were taken to the laboratory where all material was transferred to a large watch glass for more detailed examination under the microscope. The collected macroinvertebrates were then transferred to new collection jars with fresh 70% ethanol. Subsequently, all collected organisms were examined under the microscope and identified to Order and Family (Merritt et al. 1996; Bouchard 2004; Triplehorn et al. 2005). For the downstream sample, a total of 82 organisms were identified; this represents the entirety of the sample set. The upstream sample set exceeded the 100-organism threshold with 117, and all collected organisms were identified.

RESULTS

Intuitively, a difference in water quality and benthic macroinvertebrate populations upstream and downstream of the WWTP surface discharge would be expected. And, as the field data indicates, differences were noted. The number and diversity of benthic organisms downstream were much less than in the upstream sample. In the downstream sample, only three Ephemeroptera were identified, and one of these was greatly deteriorated. Coleoptera and Diptera predominated at the downstream site; the Coleopteran families Psephenidae and Elmidae were observed, while Dipteran families Tipulidae and Chironomidae predominated (48 of the 82 organisms identified). Upstream of the discharge pipe, while the ubitiquous Chironomidae larvae still dominated, the Coleopteran families are less numerous and four Ephemeropteran families have representation. Of the 117 organisms identified upstream, 32 of these were representatives of the Ephemeropteran order. In determining the biotic indices pursuant to the NYSDEC's Biological Assessment Profile criteria, the identification and enumeration data contained in Appendix C were used to obtain the following water quality determinations (Bode et al. 1991; Rosenberg 2004):

Taxa (Family) Richness:

Upstream: 16 families identified for 117 organisms, normalized to 13 families

Water quality determination: non-impacted

Downstream: 14 families identified for 82 organisms, normalized to 17 families

Water quality determination: non-impacted

EPT Richness (Family EPT Richness):

Upstream: 8 families for 117 organisms, normalized to 7 families

Water quality determination: non-impacted

Downstream: 5 families for 82 organisms, normalized to 6 families

Water quality determination: slightly impacted

Hilsenhoff Family Biotic Index:

Upstream: 525 total score/117 organisms = 4.5

Water quality determination: non-impacted

Downstream: 386 total score/82 organisms = 4.71

Water quality determination: slightly impacted

Percent Model Affinity:

Upstream: 73.7%

Water quality determination: non-impacted

Downstream: 53.55%

Water quality determination: slightly impacted

DISCUSSION

This investigation assessed the water quality of the West Branch of the Delaware River immediately upstream and downstream of the Village of Stamford tertiary wastewater treatment plant. The standard NYSDEC Biological Assessment indices were used, with the modification that collected organisms were identified to the higher family level rather than the species level. Based upon this family level of identification, and the Hudson Basin River Watch Guidance Document water quality impact ranges, it was shown that the "upstream" sample was non-impacted pursuant to all four biotic indices; the "downstream" sample was non-impacted pursuant to the Taxa (family) Richness Index and slightly impacted pursuant to the EPT Richness Index, the Hilsenhoff Family Biotic Index and the Percent Model Affinity Index.

The West Branch of the Delaware River, as the major contributor to the Cannonsville Reservoir and ultimately the New York City drinking water supply, is a routinely studied waterbody (Bode et al. 2001; Cutietta-Olsen et al. 2000; Stroud Water Research Center 2004). The most recently published NYSDEC Biological Assessment of the West Branch, which includes seven sampling sites along 83 miles from Stamford to Beerstown, was issued for the September 2000 study year (Bode et al. 2001). This 2005 investigation focuses on the West Branch immediately upstream and downstream of the

Stamford WWTP, in a location between two of the NYSDEC sampling locations. The 2000 NYSDEC Biological Assessment indicated that their "Stamford" site, which would correspond to our "upstream site", was non-impacted, while their "Hobart" site, roughly corresponding to our "downstream" site, was slightly impacted (Bode et al. 2001), based on both macroinvertebrate and diatom communities. It is noted that the NYSDEC "Hobart" site reflects the non-point runoff from an active bovine grazing pasture. The 2000 NYSDEC survey of the West Branch included for the first time the use of diatoms as additional indicators of water quality (Bode et al. 2001), specifically for nonpoint runoff impacts. Diatoms are primary producers and as such respond directly to the input of nutrients, whereas the benthic macroinvertebrates respond secondarily. The use of diatom community assessments can be used to supplement and validate the more widely practiced benthic macroinvertebrate indices (Bode et al. 2001).

The results of this 2005 stream assessment immediately upstream and downstream of the Village of Stamford WWTP confirm the previously reported 2000 NYSDEC Biological Assessment of the West Branch of the Delaware River, based upon the four standard metrics. The wastewater discharge contributes a constant source, albeit it reduced from earlier concentrations, of nutrients to the West Branch, as well as providing recolonization insect larvae to the "downstream" sampling site. The Chironomidae, commonly referred to as midges, have routinely been observed within the wastewater treatment train as the hemoglobin-containing bloodworms (Payne, personal communication). This steady source of Chironomidae larvae and the more pollution tolerant Trichopteran and Coleopteran larvae may well be the primary food source for the trout population of the shady pools downstream of the discharge pipe. No trout were noted upstream of the discharge pipe, even though the stream there was cooler, higher in dissolved oxygen, and supported a viable larval insect population. A future study might investigate the grazing effect of the fingerling trout on the macroinvertebrate population downstream of the WWTP discharge, the nymph biomass that would be necessary to support the observed trout biomass, and the preferred nymph food for the trout.

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