A NEW WATER QUALITY MONITORING AND ASSESSMENT TOOL FOR VIRGINIA'S FRESHWATER STREAMS

Mary R. Dail, Jason R. Hill, George J. Devlin, and Michael J. Scanlan, Virginia Department of Environmental Quality, 3019 Peters Creek Road, Roanoke, Virginia 24019, mrdail@deq.virginia.gov

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ABSTRACT

The Virginia Department of Environmental Quality's (VDEQ) biological and ambient water quality monitoring programs have historically used a targeted approach for monitoring the Commonwealth's aquatic resources. This is necessary for verifying regulatory compliance of pollution sources and tracking local pollution events. However, it is difficult to translate the data into estimates of water quality conditions across an entire state or river basin. Consequently, in 2001, VDEQ began a five-year probabilistic monitoring program (ProbMon) for non-tidal streams. ProbMon incorporates a random survey design that allows VDEQ to produce an accurate assessment of chemical, physical, and biological conditions in 1st through 5th order streams. This is the first survey that will provide estimates of the status of Virginia's aquatic resources with statistical confidence. Three years of data are presented for statewide benthic macroinvertebrates (n=159), physical habitat assessments (n=157), and chemical data (n=173).

INTRODUCTION

In response to the need to evaluate water quality of entire river basins or over the whole state, VDEQ added probabilistic monitoring (ProbMon) to its biological and chemical monitoring program in 2001. The goal is to provide an accurate assessment of regional chemical, physical, and biological conditions. Specifically, the ProbMon survey provides 1) estimates of the geographic coverage and extent of aquatic resource conditions with known confidence; 2) estimates of the current status, and a basis to determine trends and changes in indicators of aquatic resources with confidence; 3) statistical summaries and assessments of aquatic resources; and 4) a description of associations between indicators of natural and anthropogenic stressors and the condition of aquatic resources.

The focus of ProbMon is on non-tidal perennial streams. The station locations have been selected randomly to allow the expression of water quality conditions in statistical terms. That is, a point value can be generated with an estimate of its precision. Data will be collected from approximately 300 stream locations over a five-year period. The survey is evenly spread over the period 2001-2005, with approximately 60 locations sampled each year, to incorporate wet, dry, and normal precipitation years in the database.

METHODS

Data Collection

In 2001, field teams measured the habitat and benthic communities in the spring and fall, and stream chemistry in the fall. During subsequent years, chemical data was collected in the spring along with habitat and benthic macroinvertebrates in the spring and fall. Water and sediment samples and field parameters are collected according to VDEQ Standard Operating Procedures (VDEQ 2003). The Environmental Protection Agency's (EPA) Rapid Bioassessment Protocols (RBP) were used to evaluate physical habitat and guide benthic macroinvertebrate sampling (Barbour et. al. 1999). EPA's Relative Bed Stability methods were added in year 3 (Kaufmann et. al. 1999). In all, 79 chemical and physical parameters were measured at each site along with dissolved oxygen, temperature, pH, and specific conductance.

Station Siting

ProbMon employs a random survey design to select stream sample sites based on EPA's Environmental Monitoring and Assessment Program (EMAP) (Stevens 1997). A grid of hexagons was placed over the Commonwealth of Virginia (Figure 1). This grid ensures randomization and spatial distribution of sampling locations. The base density is one grid point per 640 km^2. This was intensified to allow regional analyses. The 640 km^2 hexagons are subdivided into 7 hexagons of 90 km^2 each. Next, the 90 km^2 hexagons are subdivided into 7 hexagons that cover 13 km^2 each. Finally, within the 13 km^2 hexals there are 7 hexagons that cover 1.8 km^2 of land surface. The sample areas were the 13 km^2 hexals whose edges are defined by the 1.8 km^2 hexagons (Figure 1). Thus, a 7 x 7 x 7 fold enhancement is used to randomly select stream reaches (Olsen 1999).

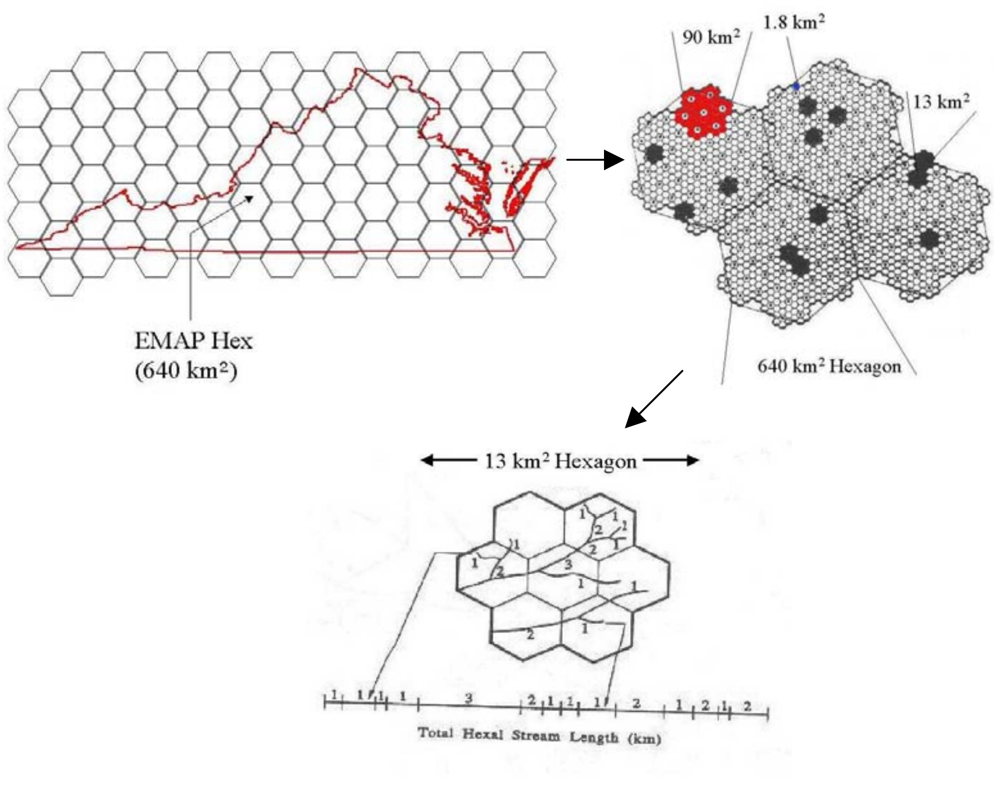

Figure 1. ProbMon Station Siting using Random Survey Design.

In ProbMon, Strahler stream order is used to assign the probability of selection to each stream segment to avoid over selecting the more common stream sizes. For example, 1st order streams make up 65% of Virginia stream kilometers and are four times as common as 2nd order streams. Thus, 1st order streams are four times as likely to be selected by a simple random design. High order streams occur less frequently and could potentially be underrepresented to the point that their statistics would be meaningless. Thus, the frequency of occurrence of each stream order was used to weight that order and ensure that all stream orders have an equal chance of being selected.

Data Analysis

Boxplots were created with STATISTICA 5.1 to permit the comparison of ProbMon variables by Strahler order. Many environmental parameters are not normally distributed, thus the median was consistently used to compare results across stream orders. Another method of analysis involved the manipulation of the data to generate the cumulative distribution function (CDF) for key variables (A. Olsen, personal communication 2000). This function is most useful when displayed as a CDF curve. CDF curves estimate the probability that a variable is less than or equal to some value. Furthermore, the likelihood that a variable would be less than a particular threshold may be interpreted from the CDF curve. It can also provide the probability that a variable would be above a threshold or within a certain range.

More information regarding survey design and data analysis is available in the 2001 ProbMon Report available at http://www.deq.virginia.gov/water/probmon.pdf, and EPA's EMAP website, http://www.epa.gov/nheerl/arm.

The Draft Stream Condition Index (SCI; Tetra Tech, Inc. 2003) is a multi-metric index based on historical benthic macroinvertebrate community data. It is applied to the ProbMon dataset as a potential assessment tool and to provide further evaluation of its Ecoregional validity.

RESULTS

First-year results from the ProbMon survey are presented in the 2001 ProbMon report (VDEQ 2003). The results presented in this paper are based on data collected in the spring of 2001 through fall 2003. The map shows ProbMon sampling sites layered with Virginia Ecoregions (Figure 2).

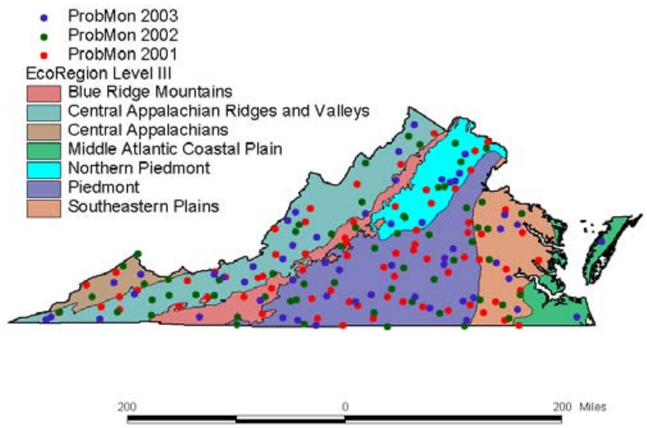

Figure 2. Map of ProbMon station locations by Ecoregion.

Ecoregions are grouped as follows: Piedmont Ecoregion = Piedmont and Northern Piedmont Ecoregions; Mountain = Central Appalachians, Central Appalachian Ridges and Valleys, and Blue Ridge Mountains; Coast = Mid-Atlantic Coastal Plains and Southeastern Plains.

Water Chemistry

Fecal coliform bacteria results are compared to VDEQ's bacteria standards in Figure 3. 12% of stream kilometers (+/- 8% margin of error) exceeded the instantaneous standard or 400 cfu/100ml. Conversely, over 80% of stream kilometers met fecal coliform standards.

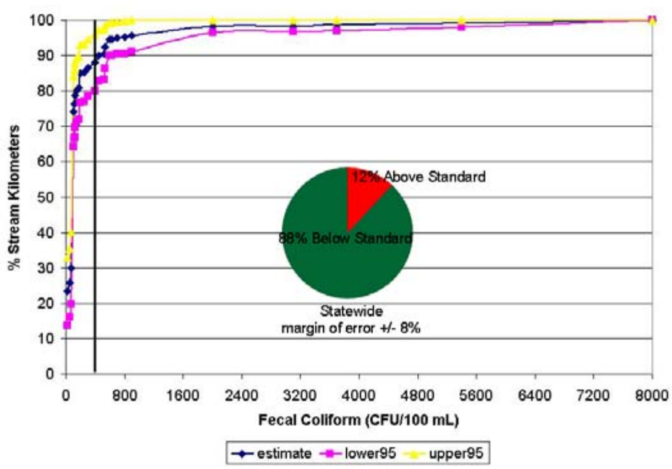

Figure 3. CDF curve and pie chart of fecal coliform bacteria by Ecoregion. The 95% confidence intervals are shown above and below the CDF curve. The vertical bar represents the instantaneous standard for fecal coliform bacteria (400 colony forming units per 100 ml water). The pie chart represents percentages of stream kilometers that are above or below the instantaneous standard.

Currently, nutrient criteria are not included in the Commonwealth's Water Quality Standards. To gauge ProbMon data, limits were applied at 0.05 and 0.1 mg/l for total phosphorus in the Mountain and Piedmont Ecoregions to produce the pie charts in Figure 4. The aforementioned thresholds were chosen based on the Mid-Atlantic Highlands Streams Assessment (EPA 2000). The majority of streams have low total phosphorus according to the CDF curves. Based on the 0.05 mg/l limit, 97% of Mountain Ecoregion streams and 79% of Piedmont Ecoregion streams were considered *good*.

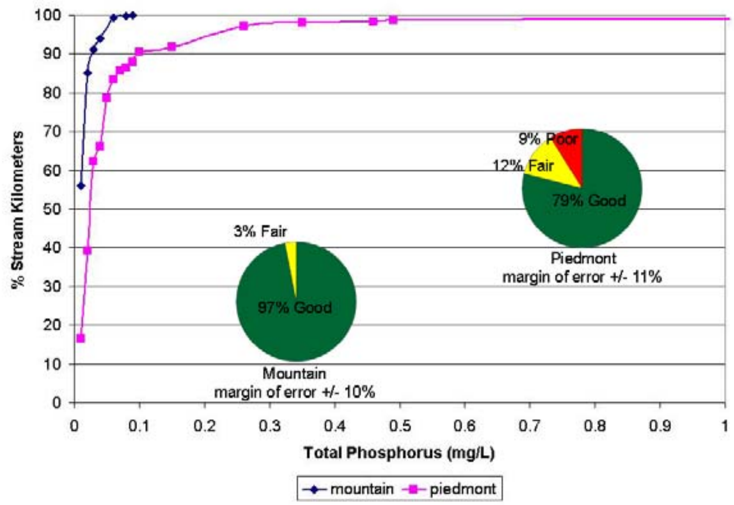

Figure 4. Total Phosphorus CDF curves and pie charts for the Mountain and Piedmont Ecoregions. *Good, fair*, and *poor* categories are designated as less than 0.05 mg/l, 0.05 to 0.1 mg/l, and greater than 0.1 mg/l, respectively (EPA 2000). Due to the presence of extreme outliers, the x-axis was cut off at 1 mg/l to show detail on the lower end.

Nitrogen in streams may indicate the presence of fertilizer, acid rain, and/or sewage discharges. Total nitrogen is comprised of nitrate (NO_3), nitrite (NO_2), ammonia (NH_4), and Total Kjeldahl Nitrogen (TKN). ProbMon results show that the dominant form of nitrogen in Mountain Ecoregions differs from other Ecoregions. The Coastal Ecoregion, which is similar to the Piedmont, was used for comparison. Nitrate (67%) is the dominant form in the Mountain Ecoregions (Figure 5). Total Kjeldahl Nitrogen (TKN) is the dominant form in the Piedmont and Coastal Ecoregions. Median total nitrogen is around 0.5 mg/l for both Piedmont and Mountain Ecoregions (Figure 5). Percentages of nitrite and ammonia were low in all three Ecoregions.

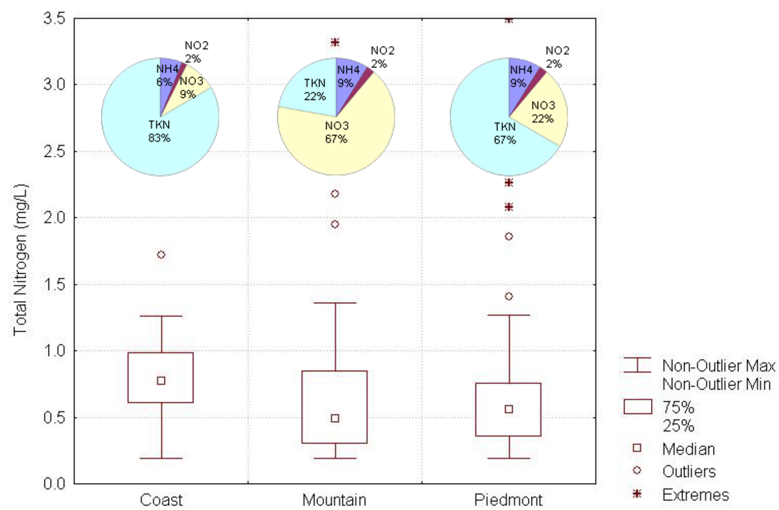

Figure 5. Total Nitrogen boxplots and pie charts for the Coast, Mountain and Piedmont Ecoregions. The pie charts display the forms of nitrogen (as a percentage of total nitrogen) in each Ecoregion.

Benthic Macroinvertebrate Communities

In addition to the RBP assessment method, VDEQ uses the SCI to evaluate benthic macroinvertebrate communities. To check its validity and application to ProbMon data, the SCI was used to generate CDF curves by Ecoregion.

Preliminary screening SCI values of >60 indicate a *good* benthic macroinvertebrate community, between 40 and 60 is considered *fair* and <40 is *poor*. Based on 3 years of data, 75% of stream kilometers fell into the *good* and *fair* categories. However, Mountain and Piedmont Ecoregions showed differences. Half of the Mountain Ecoregion stream kilometers received *good* SCI scores compared to 28% of Piedmont Ecoregion stream kilometers (Figure 6).

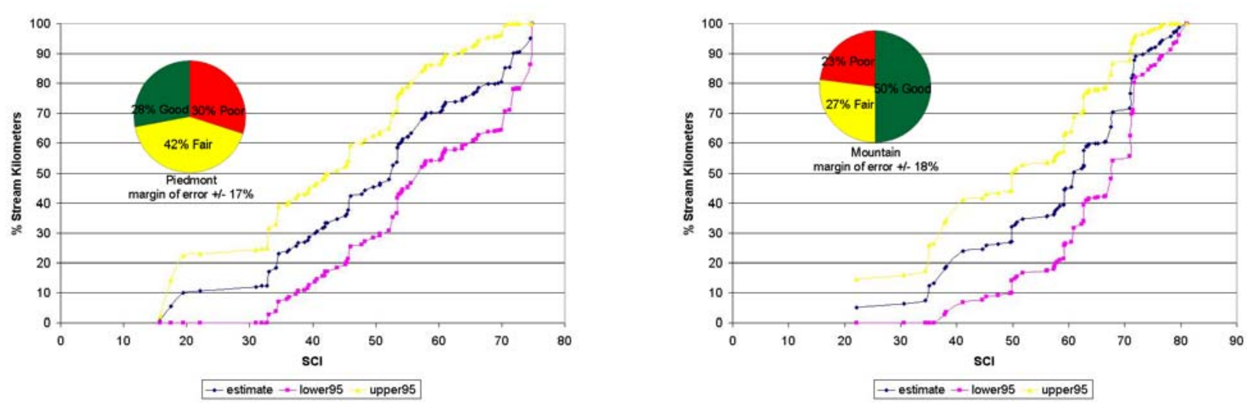

Figure 6. CDF curves and pie charts of Stream Condition Index (SCI) scores for Piedmont and Mountain Ecoregions. The 95% confidence intervals are displayed above and below

CDF curves. The pie charts show the percentage of stream kilometers that have SCI scores >60 *(good)*, between 40 and 60 *(fair)*, and <40 *(poor)*.

DISCUSSION

ProbMon has introduced a practical approach to evaluating water quality in the Commonwealth. It uses a concentrated monitoring effort to address broader questions than traditional targeted monitoring. VDEQ is beginning to see trends develop with these data. As more data is collected, Ecoregional separation may become more evident. The incorporation of the SCI raises questions about its statewide application as an assessment tool. Differences among Ecoregions were noticeable in the nutrient data as well.

Fecal coliform bacteria results demonstrate that the majority of stream kilometers are meeting Water Quality Standards. *Escherichia coli* will replace fecal coliform bacteria as an indicator of surface water pathogens by 2008 and it will be interesting to see if it exhibits the same patterns.

Nutrient enrichment is generally a result of runoff from non-point sources like agriculture and lawns or from point sources such as municipalities and industry. Total nitrogen trends are similar for both Mountain and Piedmont Ecoregions. When the data are presented as percentages of total nitrogen, the ecoregions are clearly different. TKN is the dominant form in the Piedmont whereas nitrate makes up more than half of the total nitrogen in the Mountains. Total phosphorus concentrations are higher in Piedmont Ecoregion streams than in Mountain Ecoregion streams.

As the dataset increases, the SCI will be refined and may show that individual metric scores (e.g., Taxa Richness, EPT, etc.) need to be tuned to the Ecoregion. Reference streams in the Mountain Ecoregion dominated the dataset used to develop the SCI because few Piedmont Ecoregion reference sites were available. As a result, the SCI may be more accurate for the Mountain Ecoregions. Due to random station siting techniques, many ProbMon sampling locations end up in places that have little anthropogenic impact. As a result, ProbMon has helped identify new reference sites for all Ecoregions.

Future Trends

In this brief glimpse into Virginia's ProbMon program, only a fraction of the data could be presented. ProbMon includes a habitat assessment component to determine the percent of streams that are exceptional as well as degraded. One of the more elusive parameters to quantify is sediment deposition. In 2003, VDEQ began collecting quantitative physical habitat data to determine whether sediment sources are anthropogenic or natural (Rosgen 2001). A modified version of the Relative Bed Stability method is used to answer this question (Kaufmann et. al. 1999).

Another part of the freshwater ProbMon program involves Geographic Information System analysis of land cover upstream of ProbMon sites. The land surrounding a water body can impact water quality, thereby altering the physical habitat and biological community. VDEQ intends to create a filtering matrix of habitat, benthic macroinvertebrate, and chemical data to identify potential reference sites using land cover data. As ProbMon progresses, the quantity and variety of data collected will enable VDEQ to detect relationships among physical habitat, biological communities, land cover and water quality.

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