Chapter 2.4 FRESHWATER PROBABILISTIC MONITORING

2.4.1 Executive Summary

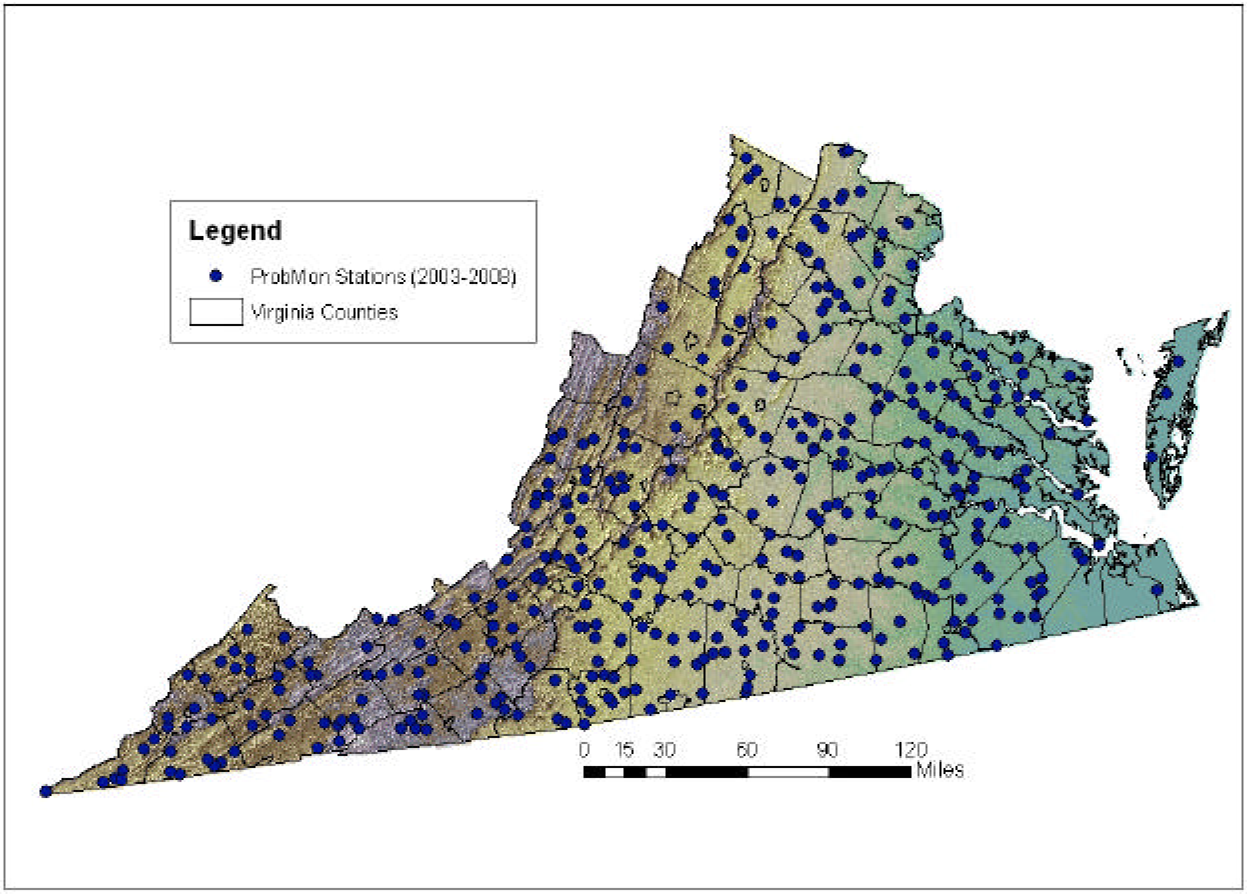
Probabilistic monitoring is designed to answer questions about statewide and regional water quality conditions. The VDEQ Probabilistic monitoring program, or ProbMon, has evaluated over 300 sites statewide since 2003. The vast majority of water quality parameters that have laws regulating their instream levels meet those requirements with the exception of the biological monitoring results. Biological monitoring uses aquatic organisms as indicators of stream health. Sedimentation, habitat disturbance and nutrients are the most common stressors to aquatic organisms and do not have laws regulating instream levels. These stressors have a negative impact on communities of aquatic organisms. ProbMon is a cost effective way to evaluate Virginia streams and rivers, test new sampling methods and support other VDEQ water quality management activities like water quality standards development and Total Maximum Daily Load Studies.

2.4.2 Introduction

Probabilistic monitoring is designed to answer basic questions like: "What are the primary water quality problems in Virginia? How widespread are these problems, and what pollutants cause the greatest environmental stress to Virginia's water resources?" The Virginia General Assembly, citizens, environmental stakeholders, and the United States Environmental Protection Agency (USEPA) have encouraged the Virginia Department of Environmental Quality (VDEQ) to answer these questions and to establish baseline water quality conditions for Virginia's streams and rivers. Freshwater probabilistic monitoring (ProbMon) is one component of VDEQ's water quality monitoring strategy. Typically water quality monitoring stations are located at bridges, boat ramps or other public access points. These monitoring stations are known as targeted monitoring sites. Targeted sampling has great utility for monitoring regulatory compliance of pollution sources, identifying impaired waters, and for tracking local pollution events. However, it is not appropriate to extrapolate results from targeted stations to un-sampled watersheds over large geographic areas. Data to address basic water quality questions are best obtained from randomly chosen sample locations (i.e., probabilistic) to ensure that all streams have an equal chance of being sampled.

In Virginia, ProbMon sites were randomly selected using USEPA's probability survey design program (Stevens 1997; USEPA 2006). VDEQ samples 50 to 60 random stations per year throughout Virginia for a variety of chemical, biological, and habitat parameters. From January 1st, 2003 until December 31st, 2008, VDEQ evaluated 425 sites and sampled 324 stations (Figure 2.4-1). Stations were evaluated, but not sampled for a variety of reasons including: the stream was not perennial, it was saltwater influenced, or the landowner denied access.

Figure 2.4-1. Virginia probabilistic monitoring locations from 2003-2008.

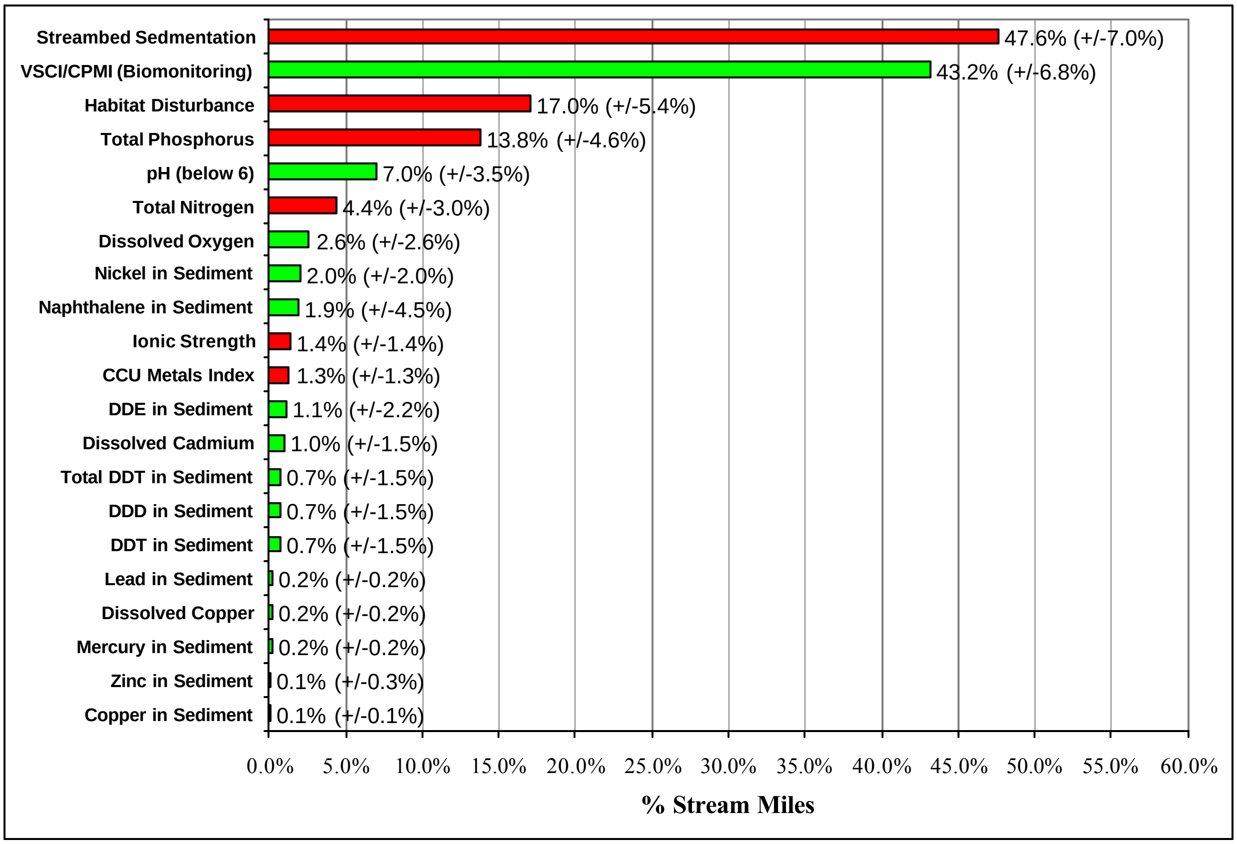


Estimates of percent miles not meeting standards or screening values are reported with 95% confidence intervals. The sampling frame provided by USEPA for Virginia streams and rivers includes 49,100 miles. It is important to note that the total amount of assessed river miles may vary to some extent by parameter. This number varies based on whether a monitoring tool was appropriate for the sampling location. For example, VDEQ biological monitoring tools are not validated for streams without a defined channel, thus streams dominated by wetlands cannot be assessed (approximately 5,000 miles). The actual number of target stream miles (perennial, flowing freshwater) is much less because several thousands of stream miles are not perennial (e.g. the stream was dry when VDEQ went to sample the stream) or were saltwater influenced. There are an estimated 1,200 miles of non-wadeable streams, which must be sampled using large river habitat and biology sampling methods. Data collection is underway for this important resource and will be the subject of future reports. The ProbMon chapter provides estimates for all perennial, non-tidal, wadeable stream and river miles which equates to approximately 41,500 miles.

VDEQ analyzed 43 water quality parameters with established water quality criteria and/or screening values. Very few parameters were observed in unacceptable levels in the environment; of the 36 parameters that have water quality standards/screening values, approximately 2% of all stream and river miles showed exceedences of applicable criteria. It appears water quality management strategies and permits are successful in these cases. The parameters that are meeting established criterion that are discussed in section 2.4.3 include: dissolved oxygen, pH, temperature, metals (dissolved and sediment), organic chemicals, and bacteria. Results are summarized in Figure 2.4-2.

Only results of biological monitoring were found to be below screening thresholds in a relatively high percentage of streams. Benthic macroinvertebrate communities were degraded in 43.2% of the wadeable streams and rivers in Virginia; a percentage that could be considered widespread. Benthic macroinvertebrate communities are indicators of water quality problems because they respond to a variety of water quality stressors that have water quality standards (e.g. dissolved oxygen levels) and parameters that do not have criteria (e.g. such as nutrients and sedimentation). The following six stressors increase the risk to aquatic organisms and do not currently have water quality standards: streambed sedimentation, habitat disturbance, total phosphorus, total nitrogen, total dissolved solids, and cumulative metals in water column. These parameters are discussed in Section 2.4.5. Overall results are presented in Figure 2.4-2.

Figure 2.4-2. Percentage of stream miles with water quality parameters exceeding criteria/screening values. Red bars indicate a parameter with no water quality standard and green bars indicate a parameter with water quality standard.



2.4.3 Parameters Evaluated that have Water Quality Standards

Dissolved oxygen, pH, temperature, metals (dissolved and sediment), organic chemicals, and bacteria have established water quality standards or criterion. Water quality standards are regulatory thresholds developed to protect water quality conditions for the support of swimming, fishing, and healthy aquatic communities. Overall results are summarized in Figure 2.4-2 and individual parameter results are discussed below.

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important parameters that measures water quality for aquatic organisms. Adequate DO is a fundamental physiological requirement for aquatic life. In streams, the concentration may be altered by photosynthesis, respiration, nutrient input, re-aeration, and temperature, all of which have seasonal or even daily cycles. These factors also change gradually with the rise in elevation westward across Virginia. This natural variability is reflected in the stream classification component of Virginia's Water Quality Standards (9 VAC 25-260, Commonwealth of Virginia 2010). For example, a mountain stream that supports native trout is expected to have higher DO than a low-gradient, warm water stream. Although expectations for DO concentration vary, all waters (excluding swamps) in Virginia are required to have a DO concentration of 4 mg/L or above. DO standards can be determined on a case-by-case basis if DO deviates due to natural conditions as in swamps and other wetlands (Commonwealth of Virginia 2010). Pollution plays an important role in dissolved oxygen concentration. Human and animal wastes released into streams provide nutrients which cause excessive growth of algae and aquatic plants. As microbes break down organic matter, their respiration can deplete the available DO and the aquatic biota may become stressed and die due to low DO concentration.

ProbMon results indicate that DO conditions for Virginia's streams and rivers are above the minimum value of 4 mg/L (Table 2.4-1). All stations with values below 4 mg/L were located in coastal ecoregions where the DO is naturally lower due to swamp conditions. These sites with low DO need to be reviewed for site specific DO standards. All mountainous zone waters, stockable trout waters, and natural trout waters met DO standards.

Table 2.4-1. Dissolved oxygen results (n=324) compared to Virginia's Water Quality Standard.

Parameter	Below Standard (4 mg/L)
Dissolved Oxygen	2.6% (+/- 2.6%)

pH

One of the primary parameters used to evaluate water quality is pH. pH measures the concentration of hydrogen ions in water or the amount of acidity present. Since the pH scale is logarithmic to base 10, a decline in pH by one unit indicates a tenfold increase in Hydrogen ions. At pH 7, a solution is neutral while pH values below 7 indicate acidic conditions and values above 7 indicate basic conditions.

Stream pH depends on local geology, ecology, and anthropogenic influences. For example, if a stream has poor buffering capacity as is the case for a stream flowing over granite or shale, it may be naturally acidic. Then, if inorganic acids such as sulfuric or nitric acid are introduced via rain, the low buffering capacity can be rapidly exhausted and the pH declines. The resulting low pH may be detrimental to aquatic biota unaccustomed to low pH. pH values harmful to aquatic life are below 6 or above 9. This range is reflected in Virginia's Water Quality Standards, where most waters must fall within a pH range of between 6 and 9. Natural pH values of 5 or below in swamp waters may not be harmful to the native fauna common to those ecosystems. pH standards can be determined on a case-by-case basis if pH deviates due to natural conditions as in swamps and other wetlands (Commonwealth of Virginia 2010).

ProbMon results show that 7% of streams and rivers in Virginia have a pH below 6 (Table 2.4-2). Ten of the fourteen stations with pH excursions occurred at sites located in the coastal ecoregion where swamp waters are common, which may indicate the need for updated site specific water quality standards. The other four stations with low pH values occurred in the mountain ecoregions, which may indicate influence from acid rain or acid mine drainage. VDEQ collects additional parameters, including Acid Neutralizing Capacity (ANC) and sulfate data, at ProbMon stations to estimate the percent of streams impacted by acid rain and acid mine drainage. High sulfate values in low pH streams are indicative of acid mine drainage whereas streams with low ANC values are susceptible to episodic acidification from acid rain runoff (USEPA 2000). VDEQ found low sulfate and low ANC values at the sites with low pH in the mountains indicating acid rain runoff is probably causing episodic acidification. ProbMon data estimates that 3.4% of streams in the Commonwealth of Virginia have low pH from acid precipitation.

Table 2.4-2. pH results (n=324) compared to Virginia's Water Quality Standard.

Parameter	Below Standard (pH 6)	Above Standard (pH 9)
pH	7.0% (+/- 3.5%)	0.0% (+/- 0.0%)

Temperature

Temperature affects water quality by potentially imposing a heat burden on aquatic life and by limiting the level of dissolved gases in water. Temperature in streams varies in relation to seasonal and daily changes. Sunlight is the primary source of temperature change. Stream temperature is also influenced by the temperature of the stream bed, groundwater inputs, and air in contact with the water surface. Temperature is inversely related to bank vegetation cover as less cover results in more exposure to the sun and higher temperature. Also, runoff from impervious surfaces in urban areas may increase water temperature. Finally, effluent that is discharged to a waterbody tends to have higher temperature than the receiving stream and may elevate instream water temperature.

Stream temperature has a significant effect on aquatic organisms. It can directly influence the types of organisms found in an aquatic system as well as their growth, behavior, metabolism, reproduction and feeding habits. Virginia's standards for temperature reflect the upper limit for the support of different forms of aquatic life (Commonwealth of Virginia 2010). Standards for temperature vary, notably in cold water fisheries, but as a general rule, all waters in Virginia are required to have a temperature below 31 or 32 degrees Celsius.

The highest temperature recorded in six years of monitoring was 28.3° C. Overall ProbMon results indicate that temperature violations are rare in Virginia (Table 2.4-3). It is important to note that ProbMon temperature data is seldom collected during the most stressful hydrologic and weather conditions. In order to gage temperature problems, additional data collected continuously and during stressful conditions is necessary.

Table 2.4-3. Temperature results (n=324) compared to Virginia's Water Quality Standard.

Parameter	Above Standard (31/32 degrees Celsius)
Temperature	0.0% (+/- 0.0%)

Dissolved Metals

Heavy metals have been identified as important influence on the benthic community structure in streams (Clements et al. 2000). Some taxa appear to be relatively tolerant to metals while other taxa are intolerant of heavy metals. Metals are most biologically available and toxic when dissolved in water. Toxicity of many metals is dependant on water hardness making it necessary to calculate site specific water quality criteria from hardness values. Table 2.4-7 lists the Virginia Water Quality Criteria for metals assuming a hardness (expressed as $CaCO_3$) of 100 mg/L. The table also summarizes the number of sites that had detectable analytical results and the number of criterion exceedences based on site specific hardness values.

Copper, nickel, zinc and arsenic were commonly detected while silver, cadmium and selenium were rarely observed. Results are shown in Table 2.4-4. Two water quality criteria exceedences were observed. One sample was above the chronic copper criterion and ProbMon results estimate only 0.2% of stream miles exceed the copper criterion. Another sample was above the chronic cadmium criteria and VDEQ estimates only 1% of streams exceed the cadmium criterion. Overall dissolved metals criteria are rarely violated in Virginia streams and rivers.

Table 2.4-4. Dissolved metals results (n=329) compared to Virginia's Water Quality Standards.

Metal	Detection Limit (ppb[1])	% Over Detection	VDEQ Acute Criteria (ppb[1])	VDEQ Chronic Criteria (ppb[1])	# Above Criteria (total n=329)	% of Miles Above Criteria
Arsenic	0.1	67%	340	150	0	0.0% (+/- 0.0%)
Cadmium	0.1	3%	3.9 $CaCO_3$=100	1.1 $CaCO_3$=100	1	1.0% (+/- 1.0%)
Chromium	0.1	64%	570 $CaCO_3$=100	74 $CaCO_3$=100	0	0.0% (+/- 0.0%)
Copper	0.1	93%	13 $CaCO_3$=100	9 $CaCO_3$=100	1	0.2% (+/- 0.2%)
Lead	0.1	19%	120 CaCO3=100	14 $CaCO_3$=100	0	0.0% (+/- 0.0%)
Mercury	0.0015	25%	1.4	0.77	0	0.0% (+/- 0.0%)
Nickel	0.1	85%	180 $CaCO_3$=100	20 $CaCO_3$=100	0	0.0% (+/- 0.0%)
Selenium	0.5	4%	20	5	0	0.0% (+/- 0.0%)
Silver	0.1	2%	3.4 $CaCO_3$=100	NA	0	0.0% (+/- 0.0%)
Zinc	1	51%	120 $CaCO_3$=100	120 $CaCO_3$=100	0	0.0% (+/- 0.0%)

ppb[1]= parts per billion

Sediment Metals

Although dissolved metals are the most toxic form, it is also important to know the concentration of metals in the sediment. Metals in sediments are also toxic and can be a contributing source of dissolved metals in the water column. Metals switch between the particulate and dissolved forms based on pH, alkalinity, and other factors. Virginia does not have sediment metal water quality standards. However, in the absence of criteria, Sediment Quality Guidelines have been used to aid in data interpretation. VDEQ uses screening values known as Probable Effects Concentrations (PEC) (VDEQ 2009) for freshwater comparison. PECs are peer reviewed, consensus based sediment quality values above which adverse effects will probably be observed in aquatic organisms (MacDonald et al 2000). Table 2.4-5 lists the sediment metals for which PEC values are available and were detected at ProbMon sites that have PEC values and lists the relative occurrences and the number of PEC exceedences observed.

Several of the metals, such as lead, chromium, copper, and zinc were commonly found in sediment samples. Other metals like cadmium and silver occurred rarely (<1% of samples) and mercury was found in 5% of the samples. Arsenic, cadmium and chromium never exceeded the screening values, while copper and zinc exceeded the screening values at only one monitoring station. Lead, mercury and nickel each exceeded the respective screening values twice. Interestingly, the two sites that exceeded the sediment mercury criteria were the South River and the North Fork of the Holston River. Both of these streams have been historically well documented for mercury contamination.

Table 2.4-5. Sediment metal (n=322) results compared to PEC Values.

Metal	Detection Limit (ppm[1])	% Over Detection	PEC (ppm[1])	# Above PEC (total n=322)	% of Miles Above Screening Value
Arsenic	5	12%	33	0	0.0% (+/- 0.0%)
Cadmium	1	1.8%	4.98	0	0.0% (+/- 0.0%)
Chromium	5	89%	111	0	0.0% (+/- 0.0%)
Copper	5	67%	149	1	0.1% (+/- 0.1%)
Lead	5	84%	128	2	0.2% (+/- 0.3%)
Mercury	0.1	5%	1.06	2	0.2% (+/- 0.2%)
Nickel	5	56%	48.6	2	2.0% (+/- 2.0%)
Silver	1	0.09%	3.7	0	0.0% (+/- 0.0%)
Zinc	5	97%	459	1	0.1% (+/- 0.1%)

ppm[1]= parts per million

Organic Chemicals in Sediment

Toxic organic chemicals occur in many forms and are expensive to analyze. Due to the expense and difficulty of the analysis, VDEQ has sampled a relatively small list of chemicals that are commonly observed in the environment and of the highest environmental concern. Table 2.4-6 is organized into three groups: Polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and pesticides. Many of these chemicals are not only toxic, but persist in the environment for decades. They tend to accumulate in sediments and occur at higher concentrations in the sediments than in the water column. For these reasons, VDEQ performed its analyses on sediment samples as opposed to water column samples. In the absence of sediment criteria, PECs are again used to aid in data interpretation. The PECs are presented in Table 2.4-6 along with the relative detection of the compounds and the number of PEC exceedences observed in the ProbMon database.

Total PCBs and Total PAHs were found in detectable quantities at almost every site and the PAH naphthalene exceeded the PEC guidelines at two sites. Pesticides were detected at less than 10% of the sites sampled. The Pesticide DDT and the associated compounds DDD and DDE were the only pesticides found to exceed the PEC guidelines. One site exceeded the PEC guidelines for all three chemicals and another site exceeded for DDE alone. DDT and associated chemicals were banned in 1972; thus their occurrence in Virginia streams is a legacy of their use prior to 1972. VDEQ has suspended sampling for organic chemicals across all monitoring programs due to high sampling costs.

Table 2.4-6. Sediment organics results (n=208) compared to PECs.

Organic Chemical	% Over Detection	PEC (ppb[1])	# Above PEC (total n=209)	% of Miles Above Screening Value
Total PCB	M	676	0	0.0% (+/- 0.0%)
Total PAH	M	22,800	0	0.0% (+/- 0.0%)
Heptachlor	4%	16	0	0.0% (+/- 0.0%)
Chlordane	5%	17.6	0	0.0% (+/- 0.0%)
Dieldrin	4%	61.8	0	0.0% (+/- 0.0%)
Lindane	0%	4.99	0	0.0% (+/- 0.0%)
Endrin	4%	207	0	0.0% (+/- 0.0%)
DDT	6%	62.9	1	0.7% (+/- 1.5%)
DDD	6%	28	1	0.7% (+/- 1.5%)
DDE	6%	31.3	2	1.1% (+/- 2.2%)
Total DDT	M	572	1	0.7% (+/- 1.5%)
Anthracene	13%	845	0	0.0% (+/- 0.0%)
Chysene	26%	1290	0	0.0% (+/- 0.0%)
Fluoranthene	38%	2230	0	0.0% (+/- 0.0%)
Naphthalene	17%	561	2	1.9% (+/- 4.5%)
Phenanthrene	27%	1170	0	0.0% (+/- 0.0%)
Pyrene	41%	1520	0	0.0% (+/- 0.0%)
BenzoAnthracene	25%	1050	0	0.0% (+/- 0.0%)
Benzo-a-pyrene	38%	1450	0	0.0% (+/- 0.0%)
M=calculated value based on multiple congeners or metabolites				

ppb[1]= parts per billion

Bacteria

Escherichia coli (E. coli) bacteria are found in the intestines and fecal matter of warm-blooded animals. High counts of *E. coli* bacteria in a stream indicate that there is an elevated risk of illness from pathogenic organisms. According to Virginia's Water Quality Standard for *E. coli*, a stream should not exceed a geometric mean (for two or more samples taken within a calendar month) of 126 colony forming units (cfu) per 100mL of water or an instantaneous maximum of 235 cfu/100mL (Commonwealth of Virginia 2010).

VDEQ bacterial impairment listing is determined based on a temporal data set where bimonthly bacteria samples are collected from a single site over two years. However, bacteria are only sampled once at each ProbMon site. Site specific bacteria problems are best characterized by repeated samples over several months as is the approach in VDEQ's ambient monitoring program. For this reason, bacteria results from the freshwater ProbMon program and ambient monitoring program are not comparable and as such the results are not presented.

2.4.4 Biological Monitoring

Biological monitoring, or Biomonitoring, of streams and rivers is an integral component of VDEQ's water quality monitoring program. Biomonitoring allows VDEQ to assess the overall ecological condition of streams and rivers by evaluating stream condition with respect to suitability for support of aquatic communities. In Virginia, benthic macroinvertebrate communities are used as indicators of ecological condition and to address the question of whether a waterbody supports the aquatic life designated use.

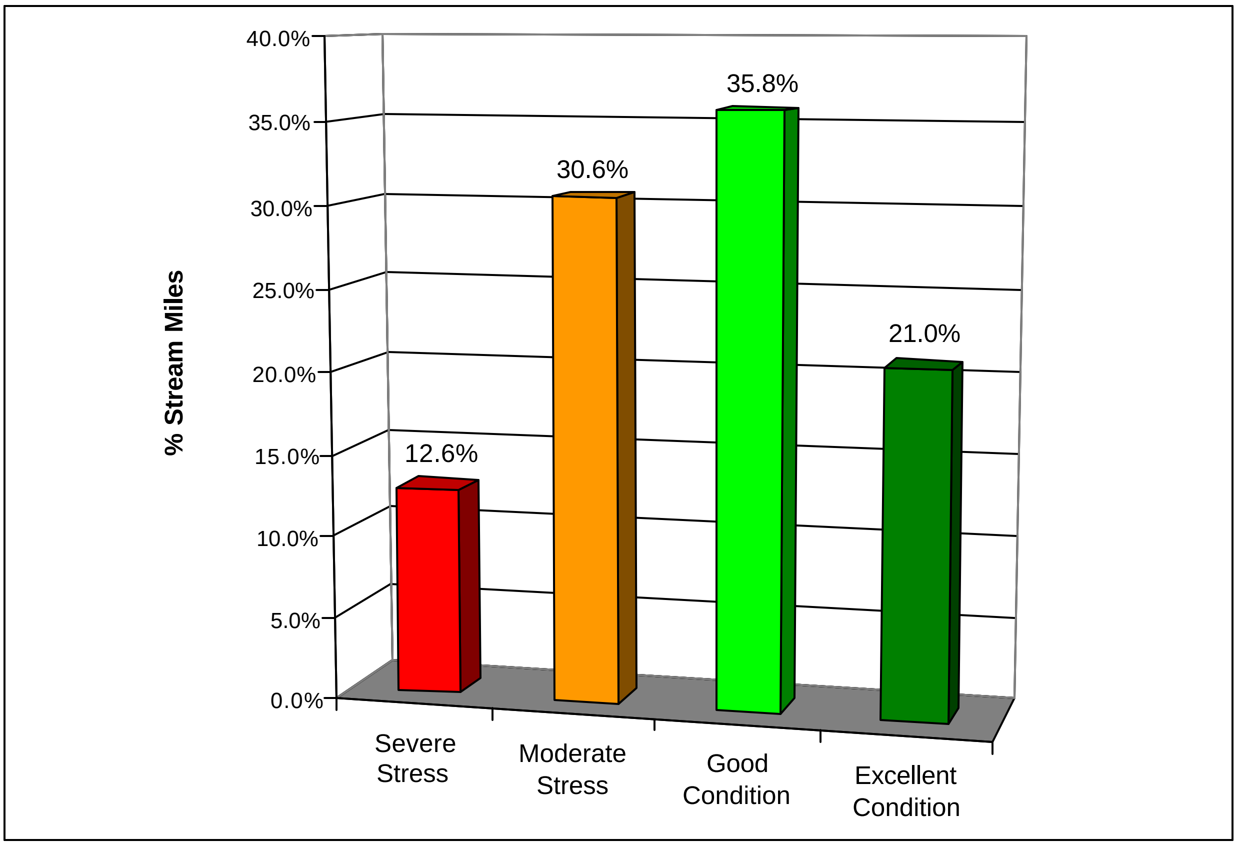
VDEQ uses multimetric macroinvertebrate indices, specifically the Virginia Stream Condition Index (VSCI) and the Coastal Plain Macroinvertebrate Index (CPMI), to assess the aquatic life use status of wadeable streams and rivers. The VSCI and the CPMI are applied to biomonitoring data collected in freshwater non-coastal areas and freshwater coastal areas, respectively. These indices utilize several biological metrics that are regionally calibrated to the appropriate reference condition (VDEQa, 2006; Maxted, 2000). Results are calculated into a single value, or score.

Table 2.4-7. VSCI/CPMI (n=287) Scores compared to Virginia's Assessment Thresholds.

Parameter	Below Standard
VSCI/CPMI	43.2% (+/- 6.8%)

Using these two multimetric indices, the VSCI and CPMI, ProbMon results indicate that 43.2% of Virginia streams and rivers do not meet the aquatic life use standard (Table 2.4-7). An estimate of statewide biological health by condition category is shown in Figure 2.4-3. It is important to remember that biological indicators represent the long term water quality conditions and respond to all sources of stress including the previously reported water quality parameters, plus an additional number of stressors that do not have water quality standards.

Figure 2.4-3. Biological stream condition based on VSCI/CPMI Scores.



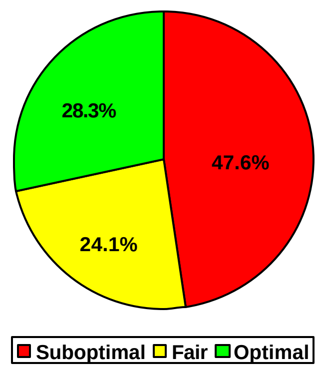
2.4.5 Parameters Evaluated that Do Not have Water Quality Standards

Stressors that increase the risk to benthic macroinvertebrate communities and do not have specific water quality standards include streambed sedimentation, habitat degradation, nutrients, ionic strength and Cumulative Criterion Unit Metals Index. Overall results for the aforementioned stressors are presented in Figure 2.4-2 and individual parameter results are discussed in this section.

Streambed Sedimentation

Excessive sedimentation is one of the most prevalent impacts to benthic communities. Excess sediment fills interstitial spaces in the stream substrates used by aquatic organisms for habitat and can potentially smother the organisms themselves. Until recently, tools for rapidly quantifying sedimentation impacts in streams have been inadequate. Methods existed for describing dominant particle size, but it was difficult to differentiate between natural conditions and man-made problems. Virginia has a variety of stream types; many are naturally sand/silt bed streams, so simply measuring the size of the sediment particles cannot differentiate natural and human-influenced sediment load.

Figure 2.4-4. Estimate of Streambed Sedimentation Conditions in Virginia Streams and Rivers (+/- 7%).

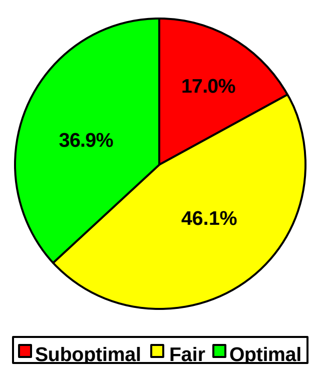


VDEQ uses the relative bed stability (RBS) tool for predicting the expected substrate size distribution for streams (Kaufmann 1999). This method incorporates stream channel shape, slope, flow and sediment supply. The method calculates a 'stream power' based on channel measurements to predict the expected sediment size distribution. The ratio of the observed sediment to the expected sediment is a measure of the RBS. A stream with an RBS of less than -1 is carrying excess sediment while streams above -0.5 have a normal sediment load (Kaufmann 1999 and USEPA 2000). Nearly half of Virginia's stream and river miles have suboptimal sedimentation values (Figure 2.4-4).

Habitat Disturbance

Habitat is defined as the area or environment where an organism or ecological community resides. It encompasses its surroundings, both living and non-living. Fish, aquatic insects and plants require certain types of habitat to thrive, so in-stream and riparian (stream bank) habitat is observed when a biomonitoring sample is collected. Since different organisms have diverse habitat components, a variety of available habitat types in a stream or river will support a diverse aquatic community. Habitat is scored by evaluating ten habitat parameters and adding them together (total scores range from 0 to 200). Habitat scores lower than 120 represent degraded habitat and scores above 150 indicate sites with habitat conditions favorable for supporting a healthy aquatic community (EPA 1999). Figure 2.4-5 shows that nearly 37% of stream and river miles have available habitat that is considered optimal.

Figure 2.4-5. Estimate of Habitat Condition in Virginia Streams and Rivers (+/- 5.4%).



Nutrients

Nutrients are substances assimilated by living things that promote growth. Total Nitrogen and Total Phosphorus are the two most important nutrients in Virginia streams and rivers. Excess nutrients can stimulate in-stream plant and algal growth. Characteristics of nutrient enriched streams can include low dissolved oxygen, fish kills, shifts in flora and fauna, and blooms of nuisance algae. Nutrients may come from fertilized lawns and cropland, failing septic systems, municipal and industrial discharges and livestock manure that is picked up by rain and carried to a stream.

Total Nitrogen above 2 mg/L and Total Phosphorus above 0.05 mg/L is considered suboptimal and can result in undesirable algae growth and shifts in biological communities (VDEQ 2006a). Over 80% and nearly 50% of stream and river miles have optimal results for total nitrogen and total phosphorus, respectively (Figures 2.4-6 and 2.4-7).

Figure 2.4-6. Estimate of Total Nitrogen Conditions in Virginia Streams and Rivers (+/- 3.0%).

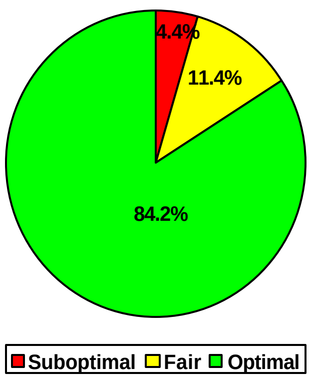
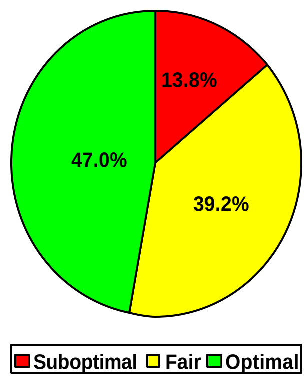


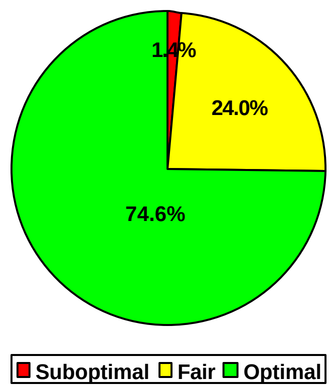
Figure 2.4-7. Estimate of Total Phosphorus Conditions in Virginia Streams and Rivers (+/- 4.6%).



Ionic Strength (Total Dissolved Solids)

Ionic strength varies with natural geology, but increases significantly due to anthropogenic activities such as surface mining or other industrial discharges. VDEQ uses total dissolved solids (TDS) to measure ionic strength which is a measure of dissolved ions, dissolved metals, minerals, and organic matter in the water column. Water quality studies have consistently demonstrated that high levels of TDS in the water column impact aquatic life (VDEQ 2006b). TDS levels above 350 mg/L increase the likelihood of having a degraded aquatic community. Results are shown in Figure 2.4-8.

Figure 2.4-8. Estimate of Ionic Strength Conditions in Virginia Streams and Rivers (+/- 1.4%).

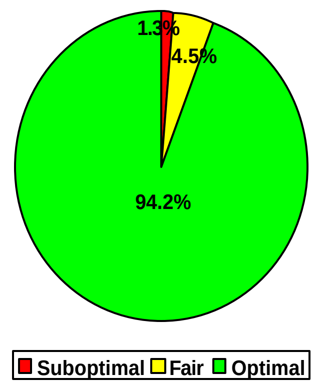


Cumulative Metals in water column (Cumulative Criterion Unit Metals Index)

Heavy metals such as mercury, chromium, cadmium, arsenic and lead in streams and rivers can damage aquatic insects at low concentrations. The metals tend to accumulate in their gills and muscles. As such, heavy metals dissolved in water, known as dissolved metals, have been identified as important predictors of stream health.

Toxicity of many metals is dependant on water hardness (calcium and magnesium) making it necessary to calculate site specific water quality criteria from hardness values. If the Cumulative Criterion Unit (CCU) Metals Index is above 2, it is considered likely to harm aquatic life in the stream (Clements 2000). Just over 1% of stream and river miles in Virginia have suboptimal CCU Metals Index scores (Figure 2.4-9).

Figure 2.4-9. Estimate of Cumulative Criterion Unit Metals Index in Virginia Streams and Rivers (+/- 1.3%).



Stressor Extent, Relative Risks, and Attributable Risks of Aquatic Stressors to Benthic Macroinvertebrate Communities in Virginia

One of the advantages of ProbMon datasets is the ability to calculate the stressor extent, relative risks, and attributable risks that different environmental stressors have on the ecological health of rivers and streams across large regions. Since the stations were selected at random, VDEQ can estimate the values of a water quality parameter over the entire state with known confidence. USEPA and other states have employed stressor extent, relative risks and attributable risks concepts extensively in their reports (ODEQ 2007; USEPA 2006; Van Sickle 2006; Van Sickle 2008). Stressor extent shows how prevalent a stressor is in Virginia streams. Relative risk and attributable risk terms are borrowed from the medical field and applied here to communicate the severity of impact a stressor has on the aquatic environment.

Here is an example of relative risk and attributable risk using medical terminology. It has been shown that an individual with total cholesterol above 240 mg/dl is at greater risk for heart disease than an individual whose cholesterol is below 200 mg/dl. When an individual has a cholesterol level above 240, their *relative* risk of having heart disease is higher than an individual with cholesterol level below 200. However, high cholesterol is just one risk factor of having heart disease. Other risk factors include obesity, high blood pressure, smoking, and physical inactivity. All of these risk factors can have an individual relative risk calculated. Medical studies use attributable risk statistics to describe the amount risk accounted for by having a particular risk factor. Attributable risk studies have shown that smoking is the single greatest risk factor for having heart disease.

The relative risks and attributable risks for aquatic stressors can be interpreted in a similar manner to the heart disease example. The second panel in Figure 2.4-10 illustrates that the relative risk to the biological community due to habitat disturbance is 4.0; thus, the biological community is 4 times more likely to be considered suboptimal when habitat disturbance (RBPII Habitat, USEPA 1999) scores are below 120. Relative risk values larger than 1 indicate an elevated risk to the biological community; consequently, only water quality stressors with a relative risk greater than 1 are reported in this chapter. Attributable risk of a stressor estimates the percent improvement in biological conditions (as measured by VSCI/CPMI biological indices) if the stress could be eliminated from the aquatic environment. The third panel in Figure 2.4-10 shows the attributable risk that habitat disturbance has on the biological community. Degraded biological conditions could be improved by 19% if all habitat disturbance stresses were removed from all watersheds.

Calculation of relative risk requires classification of water quality responses (e.g. the benthic macroinvertebrate indices – Table 2.4-8) and the water quality stressors (Table 2.4-9) into optimal and suboptimal categories. VDEQ classified biological response parameters based on the aquatic life use standard. The stressor indicators in Table 2.4-9 were classified using screening values from peer reviewed literature studies.

Table 2.4-8. Thresholds of condition classes for biological indicators.

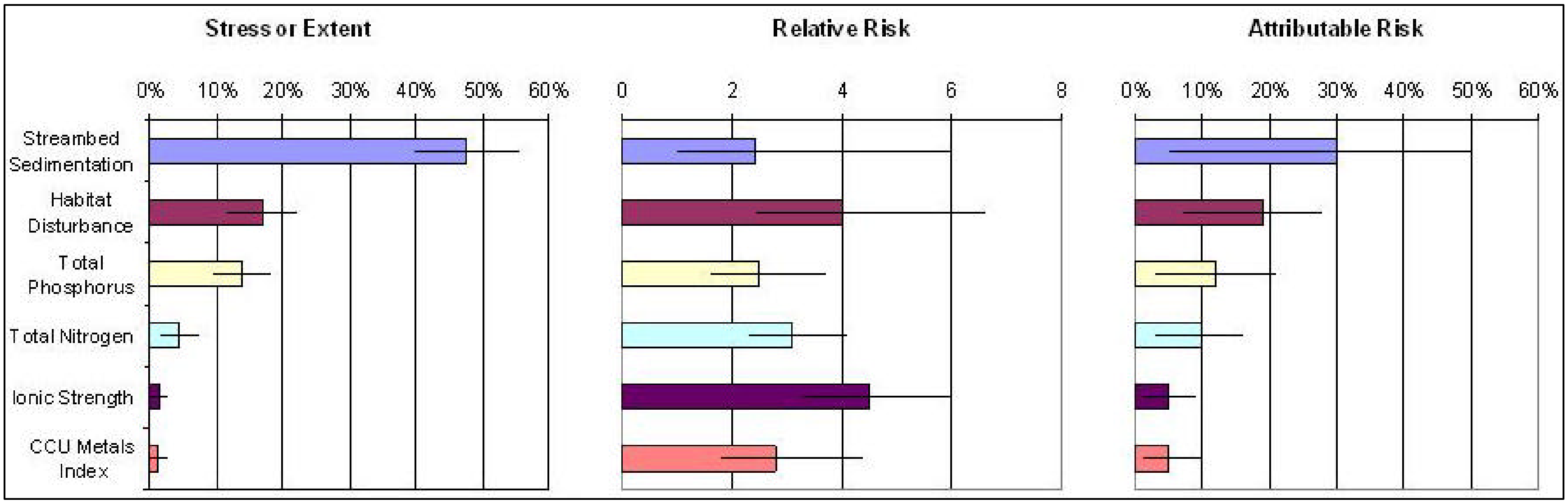
Response Parameters	Optimal	Suboptimal	Classification Reference
Virginia Stream Condition Index	>60	<50	(VDEQ 2009)
Coastal Plain Macroinvertebrate Index	>=16	<=14	(VDEQ 2009)

Table 2.4-9. Thresholds of condition classes for stressor indicators.

Stressor Parameters	Optimal	Suboptimal	Classification Reference
Total Nitrogen (mg/L)	<1	>2	(VDEQa 2006)
Total Phosphorus (mg/L)	<0.02	>0.05	(VDEQa 2006)
Habitat Degradation (unitless)	>150	<120	(USEPA 1999)
Streambed Sedimentation (unitless)	>-0.5	<-1.0	(Kaufmann 1999)
Ionic Strength (TDS mg/L)	<100	>350	(VDEQb 2006b)
Metals Water Column (unitless)	<1	>2	(Clements 2000)

Sediment metals, organic chemicals in sediment, and pH were also evaluated for increased risk to the biological community. Streams with elevated metals and organic chemicals in the sediment did not show an increased relative risk with respect to the benthic macroinvertebrate community. Similarly, low pH values were not found to increase the risk to the macroinvertebrate communities. Relative risk values that were less than 1.0, such pH or sediment metals, were not reported in this chapter.

Figure 2.4-10. Stressor extent, relative risk and attributable risk for major benthic macroinvertebrate stressors in Virginia streams. The horizontal lines associated with the parameters illustrate the confidence intervals. Stressor extent shows the frequency of the stressor in Virginia streams. Relative risk shows the number of times more likely a benthic macroinvertebrate community is to be scored in the suboptimal range if the parameter shown on the y-axis is degraded. Attributable risk illustrates the percent improvement in the benthic macroinvertebrate community scores if the stressor on the y-axis is removed.



The stressor that is considered most common across Virginia is streambed sedimentation. Based on the Stressor Extent figure above, ProbMon data estimates streambed sedimentation is considered suboptimal in 47.6% of Virginia streams. For Relative Risk, when stream sedimentation levels are suboptimal, they are 2.4 times more likely than streams with optimal sedimentation levels to not support a healthy benthic macroinvertebrate community. The Attributable Risk calculation for streambed sedimentation indicates that 29% of streams could have improved biological conditions if sedimentation stresses were eliminated. Just over 17% of Virginia streams had suboptimal habitat disturbance scores and suboptimal habitat disturbance scores increase the relative risk of a suboptimal aquatic community by a factor of 4.0. Attributable risk estimates 19% of suboptimal biological condition scores would improve with improved habitat conditions.

The two major nutrients found in Virginia streams are nitrogen and phosphorus; their relative risks are 3.1 and 2.5, respectively. Suboptimal phosphorus conditions occur in many more streams (13.8%) than elevated nitrogen (4.4%). Eliminating suboptimal levels of phosphorus could improve 12% of the suboptimal benthic macroinvertebrate communities, while normal nitrogen levels could improve 10% of the suboptimal aquatic communities. The highest Relative Risk is posed by ionic strength (as measured by total dissolved solids) with a relative risk of 4.5; however, suboptimal conditions were only found in 1.4% of Virginia streams. Dissolved metal concentrations that may cause adverse biological condition were found in 1.3% of Virginia streams; however, elevated metal concentrations increase the Relative Risk of having a suboptimal benthic macroinvertebrate community by 2.8.

2.4.6 Uses of Probabilistic Data

In addition to estimating the condition of all streams and rivers compared to established water quality criteria/screening values and identifying the major stressors to aquatic organisms, freshwater probabilistic data has many ancillary uses for water quality management programs. Examples of these uses are detailed in next several paragraphs.

One use of the freshwater ProbMon data is to describe the natural, or baseline, conditions of Virginia streams. By understanding the natural variability of Virginia streams, VDEQ hopes to be able to develop more regionally specific water quality criteria for the Commonwealth. This will provide VDEQ with better information to define reference conditions and select appropriate reference sites.

VDEQ is currently using ProbMon data to re-validate the CPMI. The intent is to utilize ProbMon data to identify new reference sites in the coastal plain, check ecoregion best standard values, and select potential metrics that would help the CPMI detect stresses to the benthic macroinvertebrate community created by human activity.

ProbMon data is now being used by the Biologist/Total Maximum Daily Load (TMDL) Staff Workgroup to create scientifically defensible screening values for Benthic Macroinvertebrate TMDL stressor analysis. Relative Bed Stability and metals in water column cumulative criterion unit (CCU) (Clements 2000) are examples of new tools that are applicable to biological TMDL stressor identification. Relative Bed Stability is used to quantify excessive streambed sedimentation (Kaufmann 1999). ProbMon data is being used to create stressor specific metrics for TMDL coordinators to identify stressor signals from impaired reaches and collect the appropriate water chemistry information. ProbMon data is especially useful in describing statewide in-stream conditions for those parameters that do not currently have water quality standards.

Another important use of ProbMon data is in the development of new water quality standards. One key to standards development is the integration of chemical and biological data. ProbMon provides information on chemical and biological interactions from a variety of streams. Perhaps more importantly, ProbMon allows managers to predict the effect of a proposed standard in terms of how many streams will likely violate a standard if it were to be implemented.

Yet another important use of ProbMon data has been its use as a test platform for new monitoring approaches. VDEQ is currently collecting periphyton and fish community data. The collection methodology was designed and tested in tandem with the USEPA's National Aquatic Resource Survey (NARS). VDEQ expects to have two new draft biological monitoring tools by 2012. Until VDEQ participated in the NARS sampling, sampling methodologies were not refined for large river habitat and biology. Now VDEQ is collecting complete ProbMon data sets for large rivers and plans to report on the condition of this valuable freshwater resource.

VDEQ has found that ProbMon provides an efficient design to develop and evaluate new biomonitoring assessment tools. ProbMon proved to be an indispensable source of information in the development of the VSCI by providing crucial data needed to fill in gaps. The use of ProbMon data allowed VDEQ to validate the VSCI and incorporate VSCI assessment results for the first time in the 2008 Integrated Report. ProbMon also aided in improving the biomonitoring program by identifying over 100 new biological references sites, doubling the number of reference sites in the Virginia reference database. ProbMon sites are being used to collect genus-level macroinvertebrate data and will provide the data necessary to create a genus-level database and multimetric assessment tool. ProbMon data will also be used to create a biological condition gradient for Virginia stream and rivers. The Biological Condition Gradient is a descriptive model that illustrates how increasing stress alters ecological attributes (Davies and Jackson 2006). A biological condition gradient defines expected conditions, like benthic macroinvertebrate community structure, for streams by stream order and ecoregion.

An important future application of ProbMon data is trend analysis. VDEQ plans to adjust the experimental design of ProbMon to accelerate its ability to detect trends. By revisiting a relatively small number of sites each year, VDEQ will be able to detect statewide trends. Perhaps the most important question a monitoring program answers is: are management initiatives effective? The ability of ProbMon to detect trends is critical to the goal of assessing the effectiveness of water quality management programs.

2.4.7 Conclusion

VDEQ reported the results of 43 water quality parameters with established water quality criteria and/or screening values in this chapter. Very few water quality parameters were observed in unacceptable levels in the environment; of the 36 parameters that have water quality standards/screening values, approximately 2% of all stream and river miles showed exceedences of applicable criteria. It is evident that many of Virginia's water quality management strategies and permits are successful with respect to the aforementioned parameters.

Benthic macroinvertebrate community scores exceeded water quality standards/screening values in a relatively high percentage of streams; suboptimal benthic macroinvertebrate scores are indicating widespread existence of stressors to aquatic life (Figure 2.4-2). Benthic macroinvertebrate communities were found to be suboptimal in 43.2% of the wadeable streams and rivers in Virginia. These communities respond to a variety of water quality stressors that have water quality standards (e.g., dissolved oxygen levels, pH, etc.) and parameters that do not have criteria like nutrients and sedimentation. VDEQ relative risk analyses indicate that additional work is necessary to control the following six stressors to aquatic organisms: streambed sedimentation, habitat disturbance, total phosphorus, total nitrogen, ionic strength (as shown by total dissolved solids data), and CCU Metals Index in the water column. Attributable risk calculations indicate that correcting streambed sedimentation and habitat disturbances problems would go the farthest to improve the health of benthic macroinvertebrate communities in Virginia (Figure 2.4-10). These six major stressors do not currently have water quality standards.

Presentations, posters, reports, and handouts about ProbMon are available for viewing and download at the following website: http://www.deq.virginia.gov/probmon/.

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