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WATER QUALITY MONITORING PROGRAM DESIGN

to be implemented by

CHESAPEAKE BAY LOCAL ASSISTANCE DEPARTMENT

in Polecat Creek

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CHESAPEAKE BAY LOCAL ASSISTANCE DEPARTMENT
WATER QUALITY MONITORING PROGRAM
VOLUME 1 - MONITORING PROGRAM DESIGN

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EXECUTIVE SUMMARY

In 1991 the Chesapeake Bay Local Assistance Department (CBLAD), the Virginia Water Control Board (VWCB), and the Virginia Council on the Environment (COE) submitted a joint grant proposal to the National Oceanographic and Atmospheric Administration (NOAA), Coastal Zone Management (CZM) Program. This grant requested monies to design a water quality monitoring program for CBLAD. COE was the lead agency on this project. The EcoMAP section of COE was given primary responsibility for the scope of work outlined in the grant proposal, and unless otherwise stated all aspects of the plan development were performed by EcoMAPS staff. The design criteria provided by CBLAD to COE were:

1) the program would be funded for ten years,

2) the project would be located in a small watershed in Chesapeake Bay drainage, currently rural but in which urban development would likely occur in the next three to five years,

3) CBLAD would select the study drainage, and

3) the primary goal of the monitoring program would be to describe the efficacy of emerging land use regulations and policies in protecting adjacent water quality during urban development activities.

Of course, the land use regulations and policies being tested are those developed by the CBLAD and the county governments in response to the Chesapeake Bay Preservation Act.

After the main goal of the program was set, it was determined from that goal what kinds of data were required to address the information needs. The project was divided into three main components and a list of objectives for each component was developed. The components were:

1) design a system of water quality monitoring networks that would provide quantitative information about chemical, physical, and biological parameters from a watershed in the Chesapeake Bay drainage;

2) develop a data base of land use activities and land cover characteristics in the watershed and monitor changes in each over the life span of the project; and

3) use a geographical information system (GIS) to develop a link between the water quality data, the land use and land cover data and digital geographic base map data. This component will be used to assess these data at the end of the project as well as to develop a nonpoint source pollution model for the watershed.

The Polecat Creek watershed which is in south-central Caroline County was determined to be the most appropriate watershed for this study. It was selected for several reasons:

1) Polecat Creek has diverse physiographic features. The headwaters rise in the piedmont, flow through the fall zone, and converge with the Mattaponi river in the coastal plain.

2) The drainage area is about 30,000 acres which is the size recommended for watershed projects by the EPA and the USDA.

3) Although the watershed is currently rural, it will likely undergo urban development in the next ten years. Currently, the predominant land cover in the watershed is forest, followed by open fields and pastureland, but about two thirds of the watershed is designated a primary growth area in the Caroline County comprehensive plan. Also, it is located on the Interstate 95 corridor between Richmond, Virginia and Washington, D.C.

To begin this project an extensive literature review on design of water quality monitoring systems was performed (these references are listed by subject later in this document). During the literature review process, a glossary was developed and is included in this document. The following statements were written by some of the foremost authors and researchers in water quality monitoring system design, and they were used to drive the design phase of the Polecat Creek Monitoring Program.

> "Water quality monitoring is an effort to obtain an understanding of the chemical, physical, and biological characteristics of water via statistical sampling. To achieve an understanding of chemical, physical, and biological characteristics of water, samples are collected; analyzed; data from the sample analysis are stored; the data are retrieved and analyzed statistically; reports are written describing the behavior of water quality variables; and the reports must then be read and understood (Sanders et al. 1983)."

> "If a management agency wants answers to water quality questions then the questions will have to be quantified and a monitoring system, including its statistical methods, designed before the data are collected (Loftis and Ward 1987)."

> "The exact procedures to be used in the day-to-day operation of the monitoring system need to be documented throughout the entire system. From preparation of sampling routes and specification of sampling protocols through identification of standard laboratory analysis methods to definition of data handling and storage procedures, the operating procedures need to be documented in detail. To leave portions of the monitoring system undefined or poorly defined, is to leave open the opportunity for inconsistent operation of the monitoring system. This permits introduction of variability into the data that comes from the operation of the monitoring system and not from the behavior of the water quality variables" (Ward 1989).

As stated above, all activities undertaken in a monitoring program must be documented. The Polecat Creek Water Quality Monitoring Program standard operating procedures (SOP's) are presented in several volumes and record the monitoring program design as well as SOP's used in the project.

Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 1: Introduction and Monitoring Program Design is the first volume of documentation and includes a review of water quality monitoring program design, the method used to design the Polecat Creek project, and a description of Polecat Creek watershed. Also, a glossary of important terms used in monitoring and a literature review of program design, project reports, statistical analysis methods, chemical analysis methods, field methods, and biological monitoring are included in this volume.

The second volume, *Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 2: Standard Operating Procedures - Sample Collection,* contains detailed methodologies for collecting water, sediment and fish tissue samples as well as methodologies for performing the EPA's Rapid Bioassessment Protocol III and the Index of Biotic Integrity. Of course, this includes all pertinent information concerning type, size and preparation of sampling containers, preservation, holding times, and quality assurance/quality control procedures. When sampling equipment is purchased, a schedule of maintenance, calibration, routine repair and replacement will be added to this document.

Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 3: Standard Operating Procedures - Chemical Analysis will document all chemical protocols, bench methodologies, calculations and calibrations performed by the selected analytical laboratory. These will adhere to the EPA's requirements outlined in *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater* and the American Public Health Association's *Standard Methods for the Examination of Water and Wastewater.* This document will be produced when CBLAD selects an analytical laboratory.

The fourth volume, *Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 4: Data Handling, Analysis, and Reporting* describes the software and data base management system, provides documentation for WQSTAT II and the EPA STORET data base, and documents the statistical methods used for reporting. Also included are methods of data interpretation and evaluation.

The GIS for the project is described in *Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 5: Geographic Information System.* So far this document contains a description of all GIS hardware and software, a digitizing protocol, and a dictionary of all data in the system.

Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 6: Land Use/Land Cover Data Base will be developed during the first year of the monitoring program. This volume will contain a dictionary (definition and description) of individual land uses and land covers, methodologies for delineating each, and a methodology for annually updating the data sets.

Chesapeake Bay Local Assistance Department, Polecat Creek Water Quality Monitoring Program, Volume 7: Special Studies will provide guidelines for development of special studies, including quality assurance project reports. It will also be a repository for special study project reports.

CHAPTER 1
Water Quality Monitoring System Design

"Water quality monitoring is an effort to obtain an accurate understanding of the chemical, physical, and biological characteristics of water through statistical sampling" (Sanders et al. 1983). To understand water quality conditions a number of tasks must be performed. Table 1.1 provides a schematic representation of these tasks and the information flow in a water quality monitoring system (Sanders et al., 1983).

For many years when a monitoring program was being designed, the focus of the design was on "what, where, and how". In other words, what water quality constituents or parameters to monitor, at what physical location in the stream, and how to collect those particular samples (Item 1, Table 1.1). During that time tremendous quantities of data were collected with little thought given to how those data would be used by management or how they would be statistically analyzed and interpreted. The focus on data collection led to a situation that Ward, Loftis and McBride (1986) referred to as the "data rich but information poor syndrome" in water quality monitoring.

Of course, collection activities are important to data quality of a monitoring program, but these activities alone do not constitute a viable monitoring program. During the last ten years a number of researchers have investigated and evaluated design of water quality monitoring programs (Brown, 1991; Loftis and Ward, 1987; McBride, 1987; Sanders et al., 1983; Ward, 1988; Ward, 1989; Ward et al., 1990; Ward and Loftis, 1989). As a result of this work, a new method of designing water quality monitoring programs has emerged. This method entails viewing the design process in an entirely new manner. The following is a brief description of the steps in the design of a water quality monitoring system. Table 1.2 provides an outline of this process and this is the template that was used to design the Polecat Creek Water Quality Monitoring Program.

In this format, Step 1 provides a list of tasks that must be addressed to define and describe the information expectations of the water quality monitoring program. Unfortunately, to some individuals defining goals and objectives sounds like a waste of time, that goals and objectives should be "understood" by anyone routinely involved in the monitoring program. Today, most researchers and program designers recognize this step as essential to the success of their monitoring programs. A concise and clear statement of goals and objectives will drive and direct all activities undertaken during the monitoring program. The goals and objectives dictate the statistical methods used, the location of monitoring stations, the parameters monitored, and the frequency of sampling, as well as the type of chemical analyses used and minimum acceptable analytical detection limits. Having a written statement of goals and objectives will allow each component of the monitoring program to be reviewed in a logical manner with subsequent decisions based on how each component fits into the overall management objective for the water quality monitoring program.

Table 1.1 **Schematic Representation of the Information Flow in a Water Quality Monitoring Information System.**

Sample Collection
- *Sample Techniques
- *Field Measurements
- *Sample Preservation
- *Sample Transport

Laboratory Analysis
- *Scheduling and Operational Procedures
- *Laboratory Analysis Procedures
- *Laboratory Quality Control
- *Data Recording

Data Handling
- *Screening and Verification
- *Computer Hardware
- *Data Base Management System
- *Storage and Retrieval

Data Analysis
- *Statistical Procedures
- *Statistical Software
- *Deterministic Modeling

Reporting
- *Formats
- *Frequency
- *Distribution

Information Utilization
- *Public
- *Policy Making
- *Administration
- *Technical

TABLE 1.2 Steps in the Design of a Water Quality Monitoring Information System (Ward et al. 1990).

STEP 1. Define Information Expectations

- Determine management and corresponding monitoring goals
- Define water quality for monitoring system design purposes
- Identify statistical methodology to be used by monitoring system
- State statistical conclusion to be drawn from data and discuss how these conclusions relate to management goals
- Describe means of reporting conclusions

STEP 2. Confirm Statistical Design Criteria

- Statistically characterize water quality "population" to be sampled
    - plot concentration and flow (and load, if appropriate) versus time
    - normality testing
    - variance homogeneity testing
    - independence testing
- State that assumptions of chosen statistical methodology are met

STEP 3. Design Monitoring Network

- Where to sample (from management/monitoring goals)
- What to measure (from water quality definition and management/monitoring goals)
- How frequently to sample (from needs of selected statistical methodologies)

STEP 4. Develop Operating Plans and Procedures

- Sampling routes, equipment, and employee training
- Field sampling and analysis procedures
- Sample preservation and transportation
- Laboratory analysis and quality control procedures
- Data verification protocols
- Data storage and retrieval hardware and software
- Data analysis software for chosen statistical methodology

STEP 5. Develop Information Reporting Procedures

- Type, format, and frequency of reporting
- Distribution of reports
- Automation of reporting
- Evaluation of information relative to expectations defined in Step 1

Step 2 of the design outline describes statistical design criteria. Again, this step should be addressed early in the monitoring program design. The first point in this procedure is to "statistically characterize the water quality population to be sampled", and includes a list of graphical and statistical tests which might be used to accomplish this. Each of these tests centers around understanding and describing the type of statistical analysis (parametric or nonparametric) that will be appropriate for use.

Robustness is a term used by statisticians to describe the resistance of a particular statistical test to giving "false positives". The robustness of parametric and nonparametric tests is dependent on different assumptions about the "water quality population" being tested. For parametric tests these assumptions are:

a) the underlying distribution should be normal,

b) the data should be independent (no serial or temporal correlation), and

c) the data should exhibit homogeneity of variance.

If any of these assumptions is violated, then the results of parametric tests can be very misleading. For nonparametric statistical tests, the only assumption is that the data are independent, since nonparametric tests are performed on ranks of data and therefore do not rely on any underlying distribution or homogeneity of variance. Water quality data rarely display a normal distribution pattern or homogeneity of variance, and it takes skill to ensure that data are independent. For these reasons nonparametric statistical tests provide the best available method of supplying information about many water quality parameters.

Also, knowing what statistical test will be used to analyze the resulting data will provide the information required to select an appropriate sampling frequency. Sample collection and analysis is very expensive and time consuming. Too few samples can waste years of effort, while too many samples can waste time and money that could be spent on more useful activities.

After the goals and objectives have been defined and the statistical methodology selected, Step 3 can be addressed. This is the time to decide "where, what, and how often". There are a number of factors to consider in determining where to monitor. First, the macrolocation should be selected. Macrolocations are river reaches which will be sampled within the river basin, and are a function of the specific objective of the sampling agency. Secondly, the microlocation will be selected. Microlocation is an actual station location which is located relative to unique or pertinent features within a river reach. The microlocation is a function of the hydraulics and mixing characteristics of the stream. The most important aspect of station selection is that each station be representative. That is each station must provide samples which will provide data relative to the management goals. For example, if the agency goal is to determine trends over time, then the stations should be placed to yield information characteristic of reaches of the river and, in composite with other stations, provide information characteristic of the condition of the river system in general (Keith 1991).

Secondly, during this step, each parameter must be defined and reasons for its selection documented. Also, a description of how each parameter will be used to reflect water quality must be provided (in essence, a justification for monitoring each constituent).

Finally, the frequency of sampling must be determined. Of course, if the protocol is followed, the frequency of sampling will have already been determined by the statistical test which was selected in Step 2.

As stated earlier "the exact procedures to be used in the day-to-day operation of the monitoring system need to be documented throughout the entire system. From preparation of sampling routes and specification of sampling protocols through identification of standard laboratory analysis methods to definition of data handling and storage procedures, the operating procedures need to be documented in detail. To leave portions of the monitoring system undefined or poorly defined is to leave open the opportunity for inconsistent operation of the monitoring system. This permits introduction of variability into the data that comes from the operation of the monitoring system and not from the behavior of the water quality variables" (Ward 1989). These activities are undertaken in Step 4 of the program design.

Developing standard operating procedures for collection of water quality samples and chemical analysis is typically the least difficult phase of designing a water quality monitoring program. Collection methodologies for surface water, sediment, fish, fish tissue, benthic macroinvertebrates, fecal coliform bacteria, rain water and ground water are well documented in the literature (see Literature Review - Collection Methodologies and Biological Monitoring). Also, private industry, wishing to make their equipment "user friendly", has developed SOP's for most of the commonly used monitoring equipment. As for chemical analysis and laboratory QA/QC, both the EPA and USGS have developed manuals and/or issued directives concerning both (see Literature Review - QA/QC and Laboratory Analysis).

Developing data handling and storage procedures is also a relatively simple, but time consuming task. Data handling, storage and retrieval methods are documented in several government publications. There are many commercial software packages available as well as several government-sponsored data base systems available for data storage and retrieval. This step simply involves selecting the software that is most useful, cost effective and usable by individuals in the monitoring program and subsequently acquiring the appropriate documentation manuals and training for monitoring personnel.

CHAPTER 2
NETWORK DESIGN - POLECAT CREEK PROJECT

The Polecat Creek water quality monitoring program networks are designed after the "wheel and axle" concept of water quality monitoring network design (Ward et al., 1990). What this actually means is that the monitoring program is comprised of two different types of station networks: network(s) of stations referred to as the "axle" network(s) and a series of special study networks referred to as "wheel" networks (Figure 2.1).

In this monitoring program design, the "axle" is a network(s) of stations that makes up the "back bone" of the monitoring program. It is data collected from these stations that are used to perform statistical trend analyses. These are fixed stations (station location does not change) at which samples are taken using standard operating procedures describing collection techniques at specific time intervals, using specific collection, preservation, and analytical techniques. These methodologies will not change over the life of the project (with the possible exception of chemical analytical methodologies).

"Wheels" are networks of stations that are actually special studies or intensive stream surveys. Typically, a special study network is an intensive sampling effort with a limited time frame and a specific information purpose related to a particular water quality problem that needs further definition. In other words, there are a relatively large number of stations over a fairly small area. These stations are monitored to observe a particular event or practice.

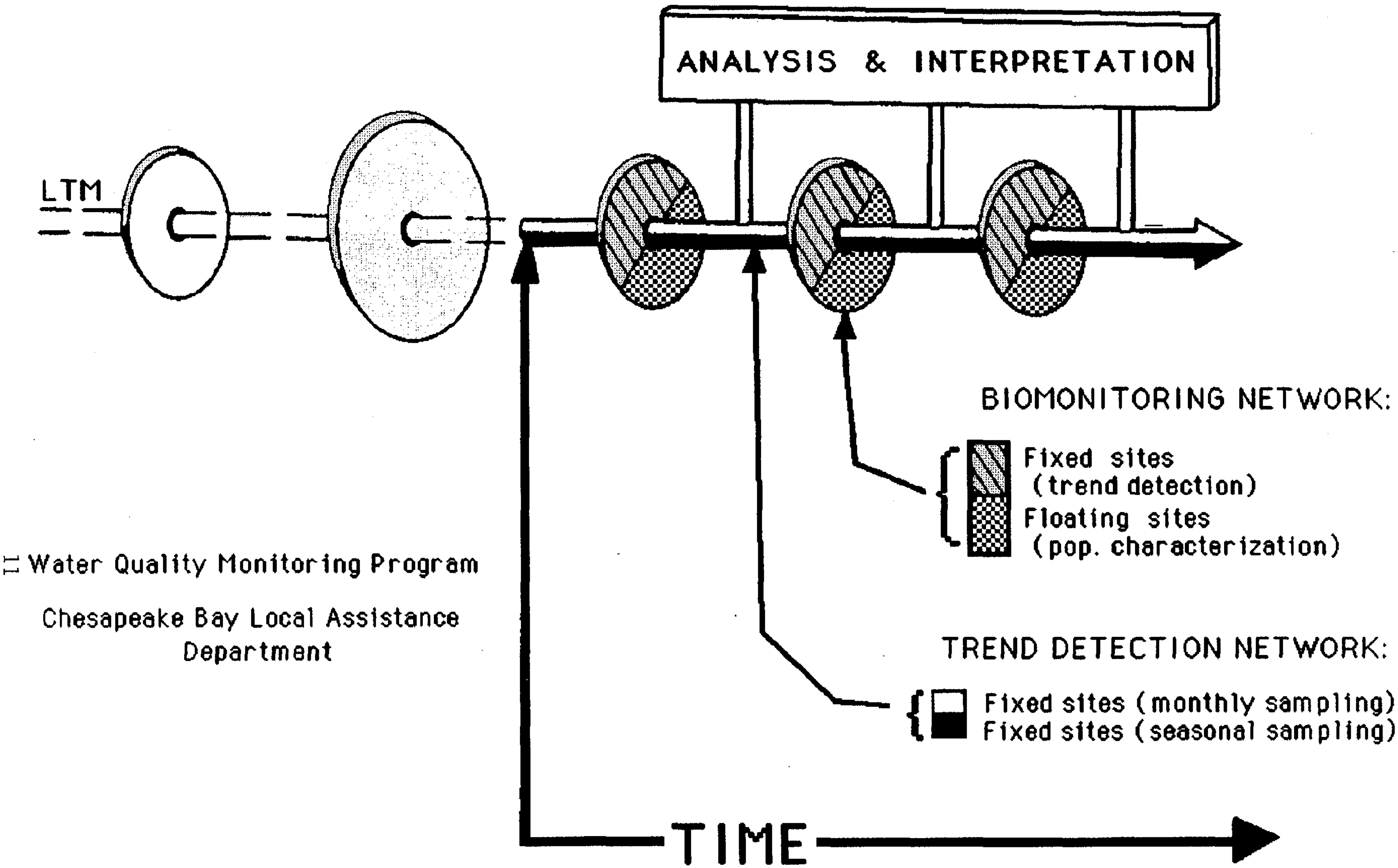
Section 1. The "Axle" or backbone of the Polecat Creek Project

The "axle" of the Polecat Creek Water Quality Monitoring Program consists of two networks of eight stations each (Figure 2.2). The first network, referred to as "Trend Network - Surface Water" will be comprised of an in-stream network of stations monitoring surface water conditions. Chemical, physical, and biological parameters will be monitored. The second network, "Trend Network - Rain Fall", will consist of an off-stream network monitoring quantity, quality, and intensity of rain fall. Each of these types of monitoring is essential in obtaining an accurate understanding of water quality conditions in the Polecat Creek watershed.

"Trend Network - Surface Water"

This network will monitor chemical, physical and biological parameters. Data from these stations will be used to identify long-term changes or trends in water quality.

In order to monitor physical and chemical parameters, each station will have a stream gage (weir), automatic sampler, and an automatic data logger. Flow data are essential in

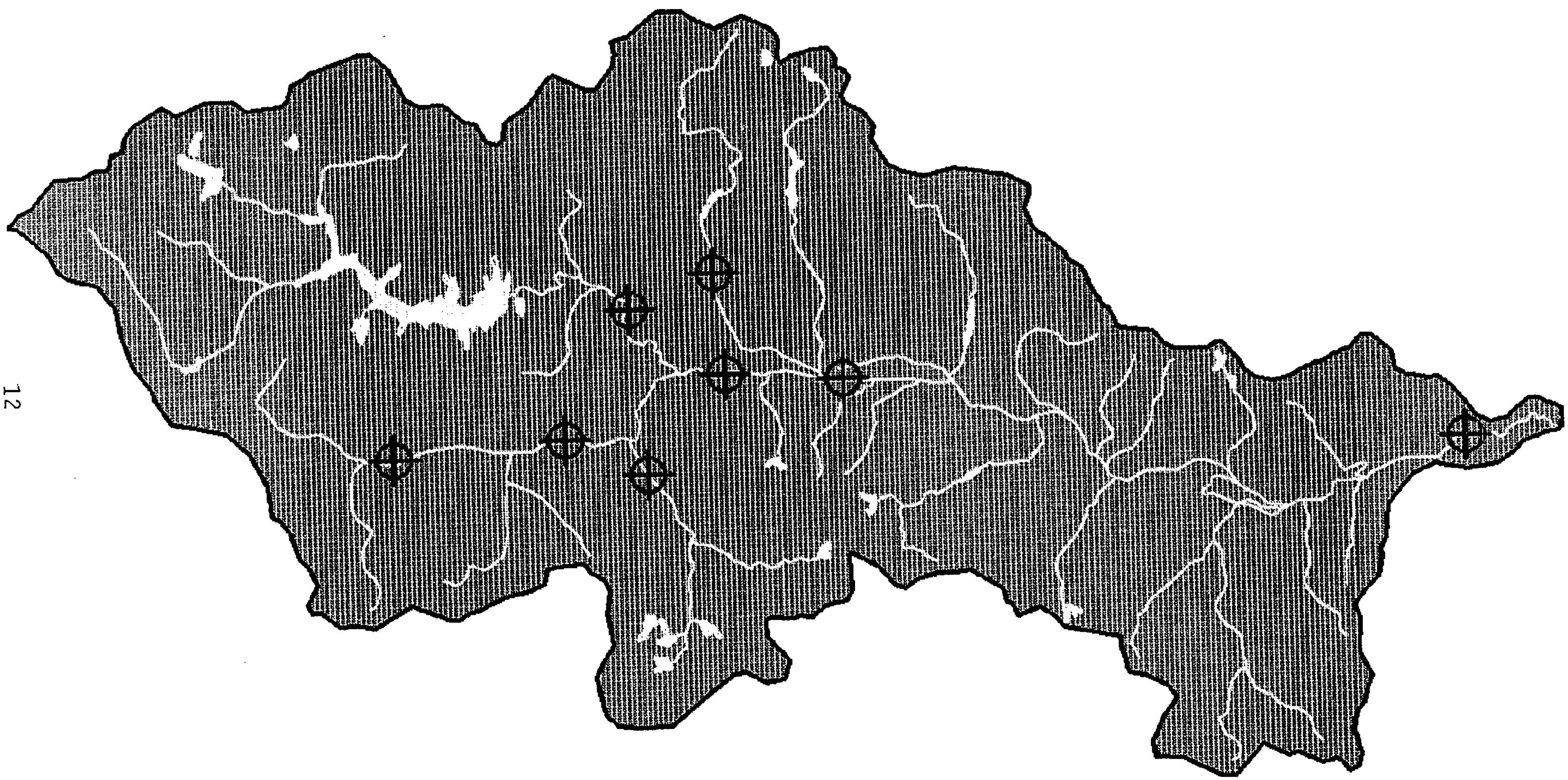


The conceptual "Wheel and Axle" design frame to be used for monitoring streams as part of the proposed long-term monitoring program designed to assess the efficacy of state and local landuse regulations in protecting water quality during urban development.

Prepared By: Virginia EcoMAP System, Council on the Environment

Figure 2.1

POLECAT CREEK



TREND MONITORING STATIONS

FIGURE 2.2

identifying long term trends in water quality data because they allow concentration data to be converted to loading data normalized for season.

Biomonitoring efforts will include monitoring benthic macroinvertebrate community structure (EPA's Rapid Bioassessment Protocol III) and fish community structure (Index of Biotic Integrity - IBI). These monitoring efforts will in the short-term describe biological community structures and in the long-term record any changes in the community structures. Biomonitoring is integral to any water quality monitoring program, but is particularly important to the Polecat Creek project since this project will assess the effectiveness of best management practices and land use regulations in the watershed. It has long been recognized that "assessing the integrated response of biological communities to highly variable pollutant inputs offers a particularly useful approach for monitoring nonpoint source impacts and the effectiveness of certain BMP's" (Plafkin, 1989).

"Trend Network - Rain Fall"

An off-stream network of rainfall gages in close proximity to the in-stream stations will record quality, quantity and intensity of rainfall. These data are required in an effective nonpoint source monitoring program for two reasons. Rain water is a potential source of nutrients as well as pH and temperature changes to surface water. Secondly, quantity and intensity of rain fall will describe how much and in what time frame water moves through the system. For example, two inches of rain falling over a time frame of two days has a tremendously different implication to surface water quality than does two inches of rain falling over a time frame of two hours.

Information Expectations for the "Axle" or Backbone Networks
Trend Network - Surface Water

Management Goal:Determine the efficacy of state and local land use regulations in protecting water quality during and after urban development

Monitoring Objective:	Detect and measure temporal trends in water quality
Definition of Water Quality:	Nutrients, sediments, temperature, pH, flow, oxygen, and bacteria
Statistical Methodology:	Seasonal Kendall Test
Statistical Hypothesis:	H_o: No trend exists H_a: Trend exists
Monitoring System Product:	Description of appearance or absence of a trend over time.
Reporting:	If there is a trend toward improved water quality or there is no discernible trend in water quality over time, then state and local land use regulations will remain unchanged. If there is a trend toward degraded water quality for those parameters associated with state and local land use regulations, then recommendations will be made to modify regulations to better protect water quality.

Trend Network - Surface Water
Parameters to be Monitored

STORET Parameter Code	Description
00010	Temperature (degree C)
00061	Flow, (ft3/sec)
00076	Turbidity (NTU)
00094	Conductivity, (micro-seimans/cm)
00300	Oxygen, dissolved (mg/L)
00301	Oxygen, dissolved (% saturated)
00310	BOD5
00400	pH, field (Standard Units)
00403	pH, lab (Standard Units)
00410	Alkalinity, lab (mg/L as $CaCO_3$)
00453	Bicarbonate, water dissolved, IT field (mg/L as HCO_3)
00940	Chloride
00500	Solids, total (mg/L)
00505	Solids, total volatile (mg/L)
00510	Solids, total fixed (mg/L)
00515	Solids, dissolved (mg/L)
00530	Residue, total at 105 degree C, suspended (mg/L)
00535	Residue, volatile, suspended (mg/L)
00540	Residue, fixed, nonfilterable (mg/L)

00545	Solids, settleable (mg/L)
00610	Nitrogen, Ammonia total (mg/L as N)
00613	Nitrogen, Nitrite dissolved (mg/L as N)
00615	Nitrogen, nitrite total (mg/L as N)
00618	Nitrogen, nitrate dissolved (mg/L as N)
00620	Nitrogen, nitrate, total (mg/L as N)
00625	Nitrogen, total Kjeldahl Ammonia + organic total (mg/L as N)
00665	Phosphorus, total (mg/L as P)
00666	Phosphorus, dissolved (mg/L as P)
00671	Phosphorus-ortho (PO4), dissolved (mg/L as P)
70507	Phosphorus-ortho (PO4), total (mg/L as P)
00680	Carbon, total organic (mg/L as C)
00900	Hardness, total (mg/l as CaC03)
00945	Sulfate, dissolved (mg/L as SO4)
80154	Sediment, suspended (mg/L)
31506	Bacteria, total coliform/100ml MPN
31616	Bacteria, fecal coliform/100ml MFM, M-FC broth, 44.5 deg C
31614	Bacteria, fecal coliform/100ml MPN, tube configuration
31618	Bacteria, fecal streptococci/100ml

Trend Network - Surface Water
Justification for each Parameter

Dissolved Oxygen

Dissolved oxygen is essential to aquatic life as well as to the breakdown of organic waste materials that may be present in a stream. The US EPA (1986) "Gold Book" established a concentration of 5.0 milligrams of oxygen per liter of water to be the minimum level for adequate maintenance of a varied fish population.

Temperature

Temperature has a significant effect on chemical reactions in water. It can effect the solubility of chemicals, the rate of reactions, and the metabolic rate of biota. Besides the obvious seasonal variations there are other factors that can effect water temperature. These include, but are not limited to the removal of riparian vegetation and the input of heated waste water.

Flow

Flow data are essential in performing statistical tests for trend analysis. Having this data available allows for seasonal variations to be accounted for during data analysis.

Biochemical Oxygen Demand

"The use of dissolved oxygen during the metabolism of organisms and the oxidation of biologically oxidizable organic material in water can be measured by a 5-day biological oxygen demand test (BOD5). The BOD5 is useful to evaluate the amount of oxidizable organic material in the water. BOD5 values of 1 to 8 are common for streams moderately contaminated with domestic waste water.

pH

"The pH of water is fundamental to the nature of the chemical reactions that occur in the water. In general, aquatic life requires pH to be within a range of 6.5 to 9 units (US EPA 1986). Low pH values can increase the solubility of materials toxic to aquatic life and cause detrimental effects. Consumption of carbon dioxide by algae causes a decreased acidity, causing pH to rise."

Alkalinity

"Alkalinity buffers acidity of water reducing changes in pH that may occur, for example, in response to algae activity, acid precipitation, and waste water discharges. The bicarbonate ion can be a major contributor to the alkalinity of water. Because bicarbonate can reduce the toxicity of certain metals to aquatic life, the US EPA recommends a minimum of 20 mg/L of alkalinity as $CaCO_3$ (1986). "

Bicarbonate

The US Forest Service recommends monitoring bicarbonate (HCO_3) when assessing impacts from the use of fertilizers.

Hardness

"Hardness in the water is caused by polyvalent cations, primarily calcium and magnesium, and to a lesser extent, strontium, ferrous iron, and the manganous ion. Hardness is generally dependent on contact of the water with certain chemicals and minerals in soils and local rock formations. In addition, calcium and magnesium are abundant in seawater, so hardness generally increases with increased mixing of freshwater with seawater. Many of the aquatic life criteria (US EPA 1986) vary depending on the water hardness because toxicity of metals and other constituents to aquatic life increase as water hardness decreases."

Suspended Sediment

"Sediment is the solid material transported by stream discharge, either in suspension or along the stream bottom, and consists primarily of fragmental material that originates from weathering of rocks and includes soils and organic debris. Many nutrients, metals, and synthetic organic materials, such as pesticides are readily sorbed and transported by sediment particles."

Turbidity

"Turbidity is caused by suspended material in water. High turbidity reduces sunlight penetration and may limit algal growth capacity."

Solids, (Total, Suspended, and Dissolved)

"The matter that remains as residue after a water sample is evaporated is generally referred to as total solids. This residue can be further defined by measurements to determine (1) dissolved solids, which is primarily inorganic salts, and (2) suspended solids, which is undissolved constituent generally comparable to suspended sediment. Solids can be further subdivided into volatile and nonvolatile fractions. The volatile fraction is primarily the organic material in the sample; the nonvolatile fraction of the residue is primarily the inorganic material in the sample. Dissolved solids, reported in milligrams per liter, is mostly used in reference to freshwater quality. The amount of dissolved material in water is environmentally important because it helps managers determine the ultimate use or treatment of water and plays a critical role in the types of aquatic life that populate the waters.

Chloride

"Chloride is one of the major constituents of dissolved solids in seawater. Locally, trends detected in chloride are expected to be similar to those seen for dissolved solids and salinity. The US Forest Service recommends monitoring chloride (Cl) when assessing impacts from the use of fertilizers.

Sulfate (SO4)

The US Forest Service recommends monitoring sulfate when assessing impacts from the use of fertilizers.

Specific conductance

"Specific conductance is a measure of the ability of water to conduct electric current and is measured in uS/cm (microsiemens per centimeter at 25 degrees C). Specific conductance is dependent upon the number and types of ions dissolved in the water and is, therefore, useful as an indirect measure of the relative amounts of chemical ions in solution."

Macronutrients (Carbon, Nitrogen, and Phosphorus)

Carbon, nitrogen, and phosphorus are primary chemical elements required by plants for growth. Eutrophication, the enrichment of a body of water with nutrients, is normally associated with increases in algal populations. The accumulation of organic matter caused by growth and decomposition of algae in turn provides habitats and ample food supplies for bacteria and other aquatic organisms. These effects are usually most pronounced in lakes and estuaries where accumulation of nutrients may result in particularly high concentrations of algae.

Carbon - A range of 5 to 15 mg/L total organic carbon (TOC) is characteristic of the upstream edge of the tidal zone of river and estuary waters of Chespeake Bay. However, TOC concentrations in swamps and bogs, which can be relatively high generally range from 30 to 40 mg/L. Because carbon is readily available in the environment as carbon dioxide or bicarbonate, it is unusual that carbon would limit the growth of algae.

Nitrogen - "Nitrogen is critical in the growth of algae. Total nitrogen concentrations larger than 0.3 mg/L indicate potential for nuisance growth of algae. The oxidation of reduced forms of nitrogen (ammonia and organic nitrogen) in surface waters is readily accomplished by aerobic aquatic biota that produce nitrite and nitrate nitrogen. Because natural processes oxidize reduced nitrogen, concentrations of reduced nitrogen are transient in surface water" (USGS, 1990).

Phosphorus - "Phosphorus is the third major nutrient essential to algal growth. The National Technical Advisory Committee (1968) recommends 0.05 mg/L total phosphorus (as P) as the maximum limit for waters entering impoundments. Other sources note that total phosphorus concentrations in lakes above 0.01 mg/L promote nuisance algal growth. A concentration below 0.1 mg/L is recommended to prevent algal blooms in streams (USGS 1990). Phosphorus undergoes seasonal and other cycles in the abundance of its organic and inorganic forms due to biological activity and physical cycles. Thus, total phosphorus (which represents all forms: dissolved, particulate, organic and inorganic) is believed to better indicate phosphorus enrichment or reduction in ecological assessments rather than its soluble nutrient forms. Orthophosphate is the form of phosphorus which is most available for plant growth.

Carbon:nitrogen:phosphorus ratios - Ratios of carbon to nitrogen to phosphorus can be used to evaluate which nutrient is limiting algal growth. A comparison of the measured ratios to an average plant tissue composition carbon:nitrogen:phosphorus ratio of 47:7:1 can show which nutrient is in relatively limited supply. It is important to note that nutrient ratios based strictly on observed water column concentrations of nutrients do not always clearly indicate the limiting nutrient. In particular, seasonal variation in nutrient limitation and limits of nutrient chemical forms available to phytoplankton are not reflected in a simple nutrient ratio comparison.

Biological Characteristics

"Bacteria - Fecal coliform bacteria commonly live in the gut and feces of warmblooded animals. Although all species of this group are not human pathogens, the occurrence of fecal coliform bacteria indicates probable fecal contamination and possible presence of pathogenic species. The US EPA raw-water criteria for body contact is a geometric mean of 200 fecal coliform colonies per 100 milliliters of water. Fecal streptococci bacteria also indicate fecal contamination from warmblooded animals. The ratio of fecal coliforms to fecal streptococci is sometimes used to identify the origin of bacterial contamination. Ratios greater than 4.0:1 indicate contamination primarily of human origin, whereas ratios less than 0.6:1 indicate animal origin."

Information Expectations for the "Axle" or Backbone Networks
Benthic Macroinvertebrate Network

Management Goal:Determine the efficacy of state and local land use regulations in protecting water quality during and after urban development

Monitoring Goal:	Characterize the biotic component of the watershed and subsequently describe existence and severity of any identified impairment.
Definition of Water Quality:	Benthic macroinvertebrate community structure.
Statistical Methodology:	Rapid Bioassessment Protocol III, Plafkin, 1989.
Statistical Hypothesis:	H_o: the community is not impacted by land use activities H_a: the community is impacted by land use activities
Monitoring System Product:	Description of status and trends in the benthic macroinvertebrate community structure.
Reporting:	Identification of use impairment through biological monitoring will initiate special studies to identify the specific agents causing the impact. These special studies might include intensive surveys of water chemistry, fish tissue, sediment, and/or toxicity testing. Results of special studies will be used to determine and limit (or eliminate) specific sources.

Information Expectations for the "Axle" or Backbone Networks
IBI (Fish Community Structure) Network

Management Goal: Determine the efficacy of state and local land use regulations in protecting water quality during and after urban development

Monitoring Goal:	Description of status and identification of changes in fish community structures.
Definition of Water Quality:	Fish community structure as defined by the Index of Biotic Integrity (IBI).
Statistical Methodology:	IBI Metrics (Karr 1981; Angermeier and Karr 1986; Angermeier and Schlosser, 1987)
Statistical Hypothesis:	H_o: the fish community structure is not impacted by land use activities. H_a: the fish community structure is impacted by land use activities.
Monitoring System Product:	Description of status and trends in the fish community structure.
Reporting:	Identification of use impairment through biological monitoring will initiate special studies to identify the specific agents causing the impact. These special studies might include intensive surveys of water chemistry, fish tissue, sediment, and/or toxicity testing. Results of special studies will be used to determine and limit (or eliminate) specific sources.

Information Expectations for the "Axle" or Backbone Networks
Trend Network - Rain Fall

Management Goal:	Determine the efficacy of state and local land use regulations in protecting water quality during and after home construction activities.
Monitoring Goal:	Characterize rain fall patterns, rain water quantity, quality, and intensity.
Definition of Water Quality:	pH, nitrogen, phosphorus, sulfate
Statistical Methodology:	Seasonal Kendall Test
Statistical Hypothesis:	H_o: there is no trend in rain water quality. H_a: there is a trend in rain water quality
Monitoring System Product:	Description of status and trends in rain water quality.
Reporting:	These data will be used in conjunction with data from the trend network - surface water. They will be used primarily to eliminate or identify rain water as a source of pH or nutrient trends in surface water and to identify times of high surface runoff. These data will be reported to the Chesapeake Bay Local Assistance Board and to the EPA Chesapeake Bay Program.

Trend Network - Rain Fall
Parameters to be Monitored

STORET Code	Description
00400	pH (field), standard units
00610	Nitrogen, Ammonia total (mg/L as N)
00613	Nitrogen, Nitrite dissolved (mg/L as N)
00615	Nitrogen, nitrite total (mg/L as N)
00618	Nitrogen, nitrate dissolved (mg/L as N)
00620	Nitrogen, nitrate, total (mg/L as N)
00625	Nitrogen, total Kjeldahl Ammonia + organic total (mg/L as N)
00665	Phosphorus, total (mg/L as P)
00666	Phosphorus, dissolved (mg/L as P)
00671	Phosphorus-ortho (PO4), dissolved (mg/L as P)
70507	Phosphorus-ortho (PO4), total (mg/L as P)
00945	Sulfate, dissolved (mg/L as SO4)

Trend Network - Rain Fall
Justification for Monitoring each Parameter

pH

There is ample evidence in the scientific literature to support the contention that some areas of the country are impacted by "acid rain". It is essential to the Polecat Creek project to eliminate or identify rain water as a source of pH changes in surface water.

Nitrogen

There is evidence to indicate that rain water can be a source of nutrients to surface water. This phenomenon has been reported in the Chesapeake Bay drainage. It is essential to the Polecat Creek project to eliminate or identify rain water as a source of nitrogen to surface water.

Phosphorus

There is evidence to indicate that rain water can be a source of nutrients to surface water. This phenomenon has been reported in the Chesapeake Bay drainage. It is essential to the Polecat Creek project to eliminate or identify rain water as a source of phosphorus to surface water. Total phosphorus (which represents all forms: dissolved, particulate, organic and inorganic) is believed to better indicate phosphorus enrichment or reduction in ecological assessments rather than its soluble nutrient forms.

Sulfate

There is evidence to indicate that rain water can be a source of sulfate to surface water. It is essential to the Polecat Creek project to eliminate or identify rain water as a source of sulfate to surface water.

Section 2. The "Wheels"; Special Studies and Intensive Stream Surveys.

As noted before, "wheels" are networks of stations that are actually special studies or intensive stream surveys. The "wheels" or special studies of the Polecat Creek program will be used to determine the potential sources or reasons for the changes in water quality.

An outline of the requirements for a special study design follows, with each special study having a sampling plan and quality assurance work plan which will provide the following:

1. Describe the environmental problems and concerns that led to the initiation of the monitoring project. This should include information on specific environmental concerns, general history and project background, the current situation, and the projected impacts to the environment if no action is taken.

2. Define what the environmental goals (management and monitoring) are, and how the goals can be achieved.

3. Define acceptable confidence (including confidence interval) and power, and state a statistical methodology and hypothesis.

4. Describe information expectations.

5. Describe any regulatory requirements.

6. Define data quality objectives (these are qualitative and quantitative statements of the quality of data which is needed to support specific decisions or actions). The quality of the data must be compatible with the decision making requirement. This should include specific standard operating procedures used to assess data precision, accuracy, representativeness, completeness, and comparability.

7. Provide a list of parameters which will be monitored and a written justification for each parameter.

8. Describe how the data will be used and a reporting format.

9. Provide standard operating procedures for collection and chemically analyzing data.

10. Describe data reduction, validation and reporting procedures.

11. Describe Quality Assurance/Quality Control procedures including: internal quality control checks, performance and system audits, and preventive maintenance with a description of the required corrective action and QA reporting procedures for problem situations.

Examples of some special study networks might include:

1) pre-construction or pre-logging monitoring (development of "base-line" data set) which will require monitoring during base-flow and high-flow events,

2) monitoring a high flow event after logging or construction activities,

3) monitoring high flow events near potential agricultural, commercial, or industrial nonpoint sources, and

4) monitoring the influence of nearby septic systems on stream water quality.

All special study project plans and reports will be kept in *Chesapeake Bay Local Assistance Department, Water Quality Monitoring Program, Volume 7, Special Studies.*

CHAPTER 3
DESCRIPTION OF THE POLECAT CREEK DRAINAGE

The Polecat Creek watershed which is in south-central Caroline County (Figure 3.1) was determined to be the most appropriate watershed for this study. It is in the headwaters of the Mattaponit River which is in the York River system. Polecat Creek was selected as the study area for several reasons:

1) Polecat Creek has diverse physiographic features. The headwaters rise in the piedmont, flow through the fall zone, and converge with the Mattaponi river in the coastal plain.

2) The drainage area is about 30,000 acres which is the size recommended for watershed projects by the EPA and the USDA.

3) Although the watershed is currently rural, it will likely undergo urban development in the next ten years. Currently, the predominant land cover in the watershed is forest, followed by open fields and pastureland, but about two thirds of the watershed is designated a primary growth area in the Caroline County comprehensive plan. Also, it is located on the Interstate 95 corridor between Richmond, Virginia and Washington, D.C.

The 1990 US Census reported 5,569 individuals living in the Polecat Creek watershed. Most of these individuals live in the Lake Caroline or the Lake Heritage developments. Both these impoundments are located on the Stevens Mill Run tributary to the Polecat Creek. There are about 144 miles of paved roads in the drainage including a section of Interstate 95 which bisects the drainage in the fall zone (Fig 3.2).

Some of the environmentally sensitive areas in the drainage include wetlands and potential habitat for endangered species. Approximately 2,433 acres of wetlands and waterbodies occur in the drainage (Fig 3.3). There are about 5,234 acres of Chesapeake Bay Preservation Areas (Resource Protection Areas) buffering these wetlands and waterbodies (Fig 3.4). The Polecat Creek watershed presents the habitat requirements for three plant species listed as federal endangered or threatened species. A list of these species with a short description of habitat requirements and threats to the species follows (DGIF 1992).

> "Small whirled pogonia, *Isotria medeoloides (Pursch) Rafinesque,* is extremely rare in Virginia...It occurs in third-growth upland forests with open understories. The population is threatened by urban development and by deer grazing."

> "Swamp pink, *Helonias bullata,* is extremely rare in Virginia. It occurs along small watercourses, in springy ground, or in other areas where water conditions are stable and

rarely subject to flooding. The swamp pink is vulnerable to damage from logging, roadbuilding, trampling, or drainage at the few unprotected sites."

"New Jersey Rush, *Juncus caesariensis*, is extremely rare in Virginia. It has been reported from five Coastal Plain counties, where it occurs in very acidic usually sphagnous, hardwood swamps, seeps, swales, or pond margins. Ditching, ponding, or clearcutting of the overstory will result in the elimination of this species."

The following describes the current water quality conditions of the Polecat Creek and was taken from the Virginia Water Control Board's 1990 Section 305(b) Report: "The Polecat Creek waterbody encompasses an area of approximately 50 square miles in Caroline County. It includes the mainstem and tributaries, from its confluence with the Mattaponi River to the headwaters. The Polecat Creek station (8-PCT002.29) near Rt. 601 is monitored monthly for state water quality standards. Sediment and water column samples were analyzed for metals, but less frequently than for the state standards. There were no violations of the standards or exceedences of criteria for metals. This station serves as a biological monitoring station as well as an ambient water quality monitoring station. The benthic macroinvertebrate community at this station was rated fair, showing no improvement from the last 305(b) reporting period. The fair rating is similar to the current bioassessment rating of moderately impaired. The habitat and substrate limitations at this station may restrict the sensitive portions of the benthic community.

Several municipal facilities, including the Caroline County Regional STP and one industrial facility, Pilot Oil Corp. #291, discharge into this waterbody. A stream survey was conducted in February 1988 to determine the impacts of the sewage treatment facilities and low stream flows. Results indicated that there was nutrient overload in this stream.

Based on the results of the stream survey, six miles of this segment partially support the Clean Water Act (CWA) goal for swimmable waters. Polecat Creek partially supports the CWA goal for fishable waters in 5.50 miles due to the moderately impaired rating of the benthic community. The remainder of the waterbody fully supports the CWA goal for fishable and swimmable waters."

POLECAT CREEK

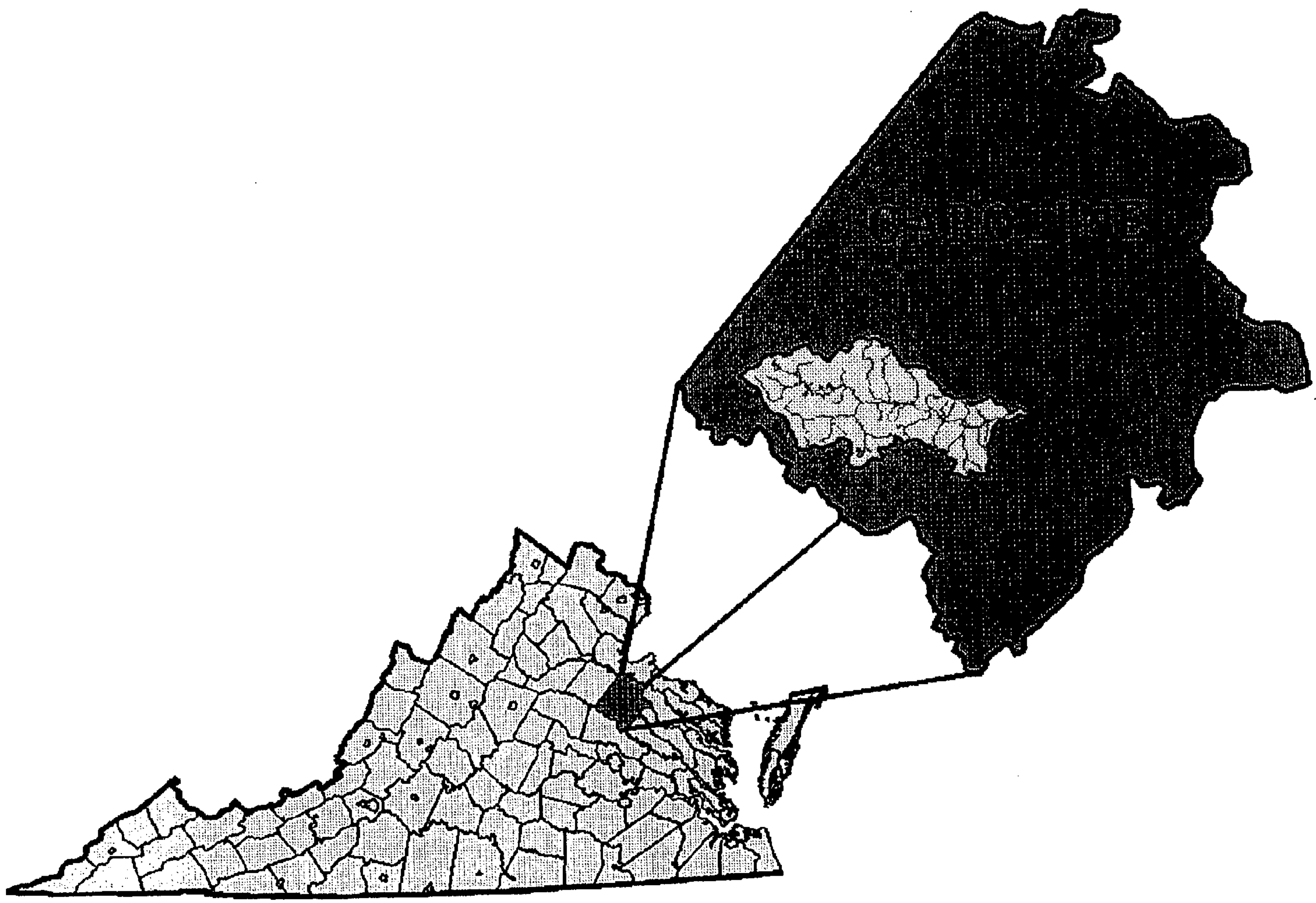
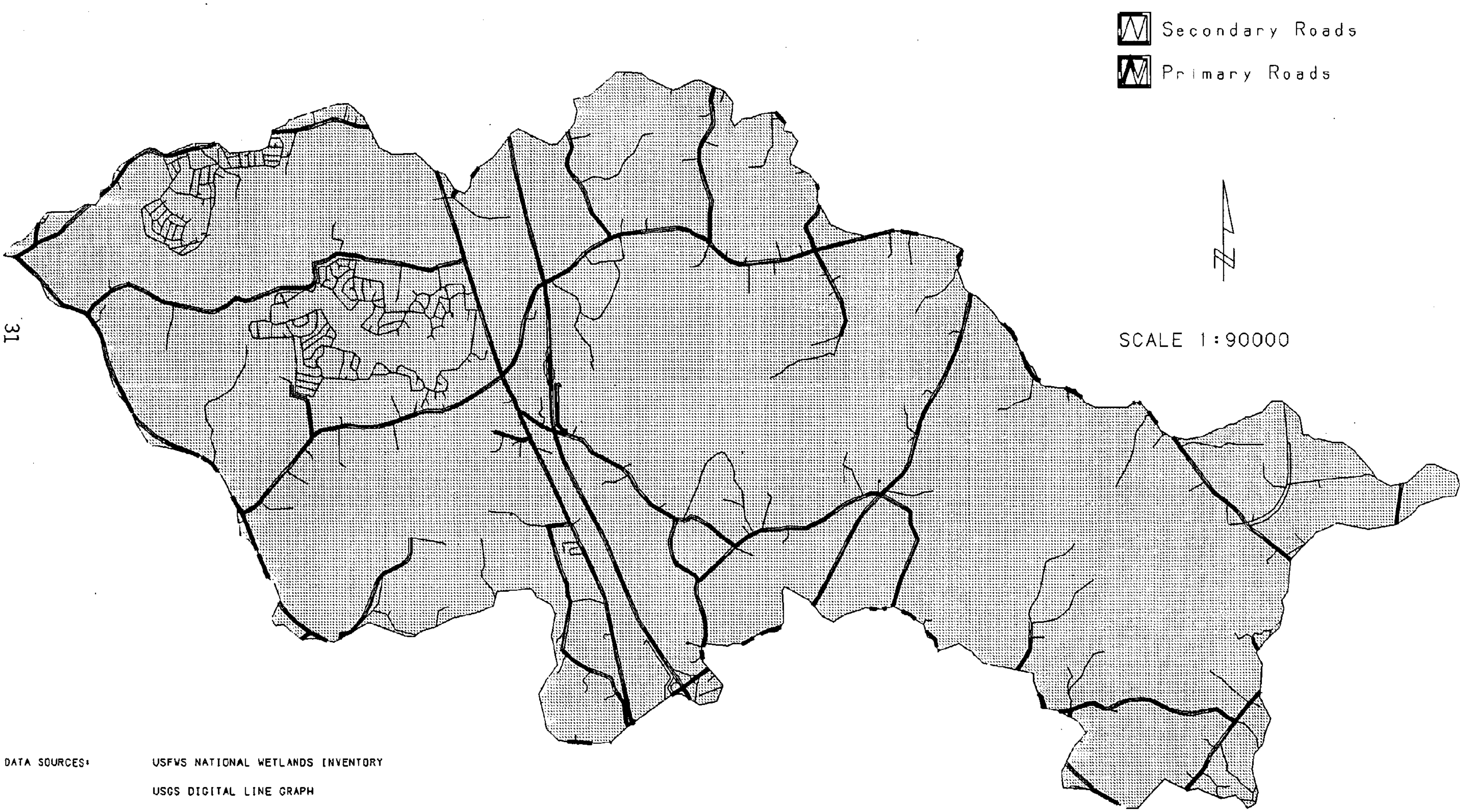


FIGURE 3.1

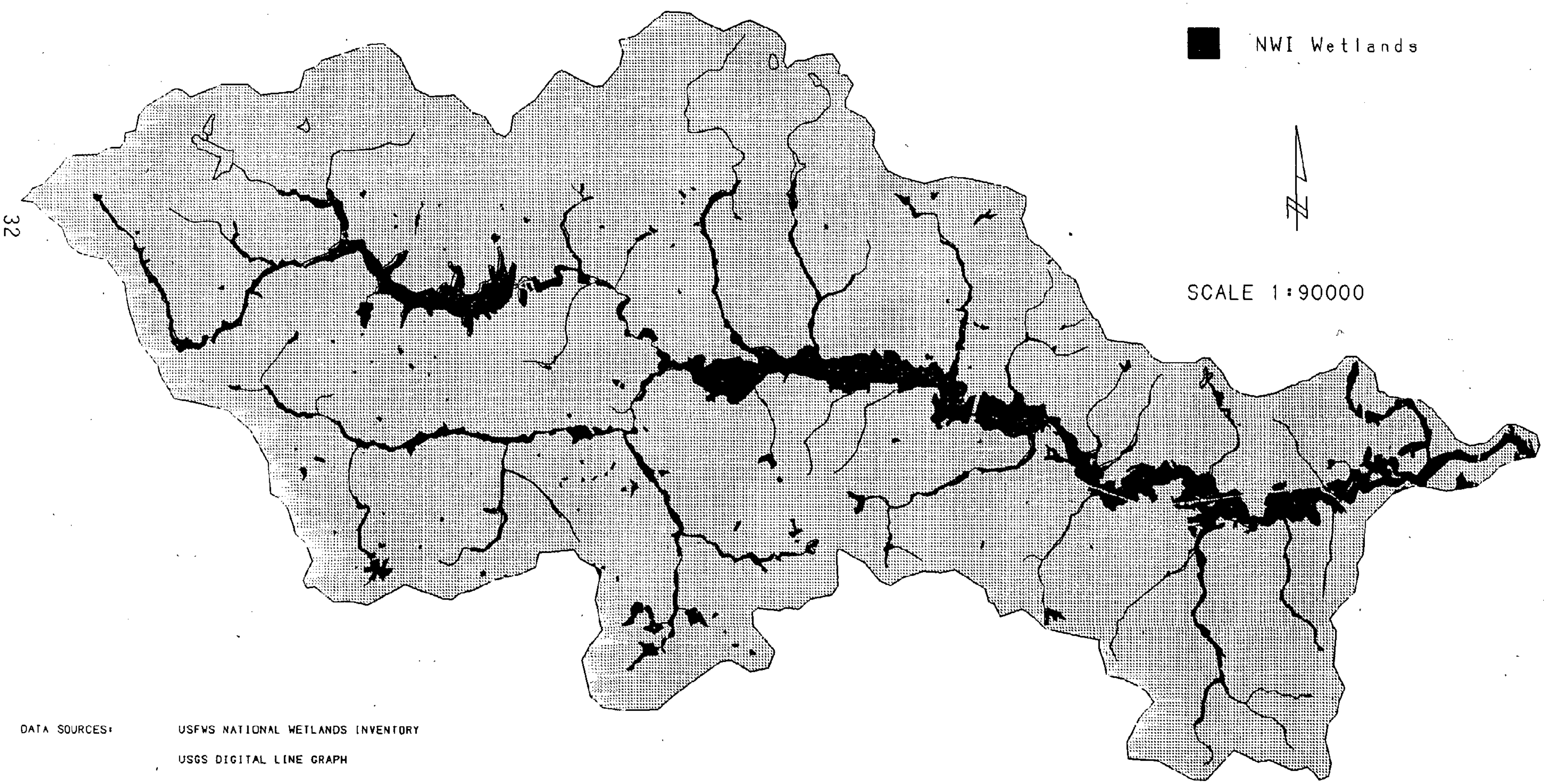
POLECAT CREEK PRIMARY AND SECONDARY ROADS



DATA SOURCES: USFWS NATIONAL WETLANDS INVENTORY
USGS DIGITAL LINE GRAPH
VIRGINIA DEPARTMENT OF CONSERVATION AND RECREATION
PREPARED BY VIRGINIA ECOMAP PROGRAM

FIGURE 3.2

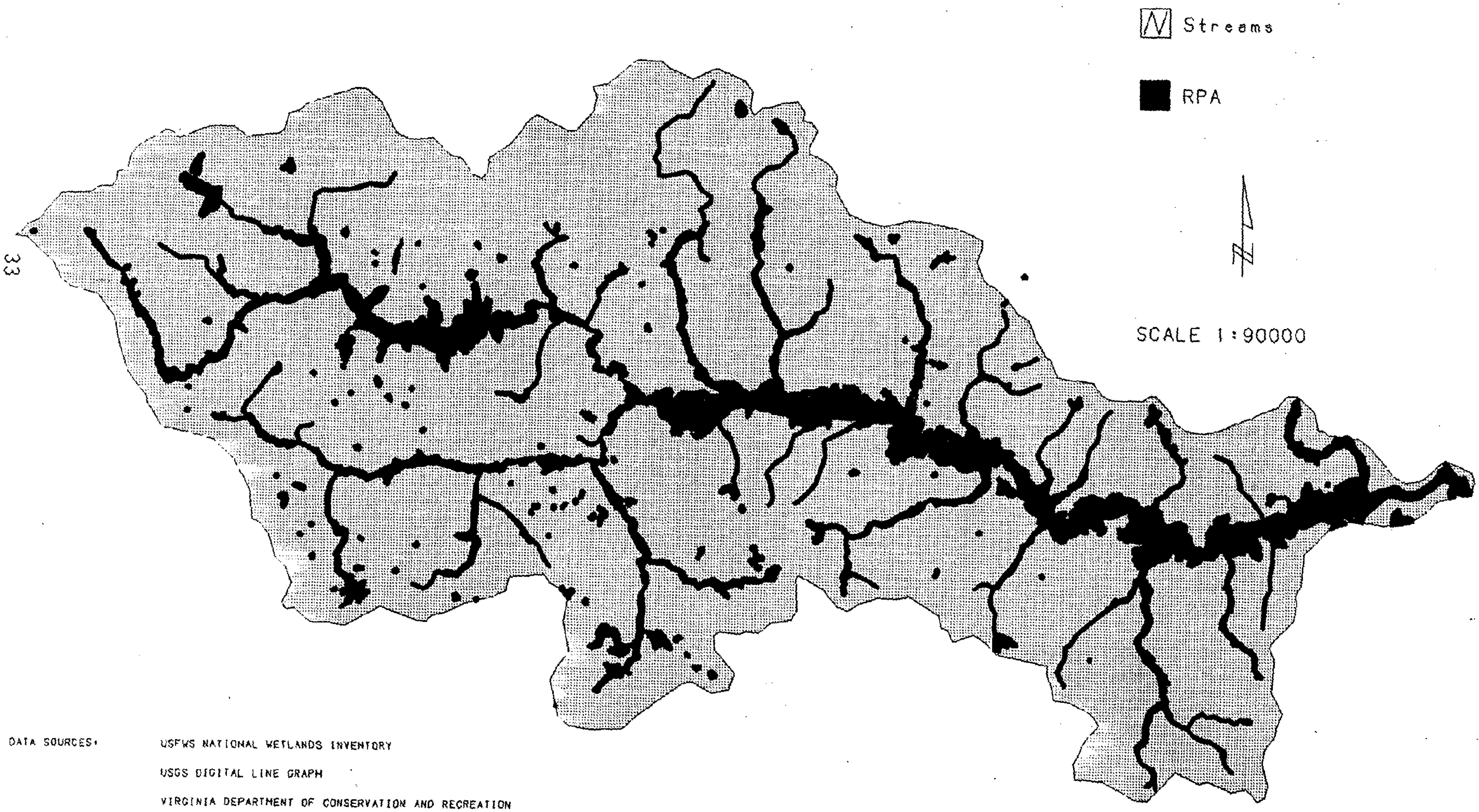
POLECAT CREEK STREAMS AND WETLANDS



DATA SOURCES: USFWS NATIONAL WETLANDS INVENTORY
USGS DIGITAL LINE GRAPH
VIRGINIA DEPARTMENT OF CONSERVATION AND RECREATION
PREPARED BY VIRGINIA ECOMAP PROGRAM

FIGURE 3.3

POLECAT CREEK RESOURCE PROTECTION AREAS



DATA SOURCES: USFWS NATIONAL WETLANDS INVENTORY
USGS DIGITAL LINE GRAPH
VIRGINIA DEPARTMENT OF CONSERVATION AND RECREATION
PREPARED BY VIRGINIA ECOMAP PROGRAM

GLOSSARY

Absolute Method - a method in which characterization is based entirely on physically (absolute) defined standards (Taylor, 1987).

Accuracy - "is a measure of the degree of agreement of a measured value with an accepted reference or true value. It is usually expressed in terms of percent recovery of the true value and is an expression of the amount of bias in the data" (Dillaha et al. 1988).

Aliquant - A divisor that does not divide a sample into a number of equal parts without leaving a remainder; a sample resulting from such a divisor (Taylor, 1987).

Aliquot - A divisor that does divide a sample into a number of equal parts without leaving a remainder; a sample resulting from such a divisor (Taylor, 1987).

Analyte - the specific component measured in a chemical analysis (Taylor, 1987).

Autocorrelation - is a measure of how data points are related in time. Values of the autocorrelation range from - 1 to + 1. Plus (+) 1 = a perfect relationship, while 0 = independent distribution. Autocorrelation may result from seasonality, trend, or serial correlation. Seasonality will appear as a cyclic pattern.

Benthos - the community of organisms living in or on the bottom or other substrate in an aquatic environment.

Bias - A systematic error inherent in a method or caused by some artifact or idiosyncrasy of the measurement system. Temperature effects and extraction inefficiencies are examples of this first kind of bias. Blanks, contamination, mechanical losses and calibration errors are examples of the latter kinds. Bias may be both positive and negative, and several kinds can exist concurrently, so net bias is all that can be evaluated except under special conditions (Taylor, 1987).

BLANKS - matrices that have negligible or unmeasurable amounts of the substance of interest. Wherever a possibility exists for introducing extraneous material into a collection, treatment, or analytical procedure, a blank should be devised to detect and measure the extraneous material.

Field blanks - samples of analyte free media similar to the sample matrix. They are transferred from one vessel to another or exposed to the sampling environment at the sampling site.

Trip blanks - are test samples of analyte-free media taken from the laboratory to the sampling site and returned to the laboratory unopened.

Background samples (matrix blanks or control samples) - are samples of the media similar to the test sample matrix and are taken near to the time and place where the analytes of interest may exist at background levels.

Equipment blanks - are samples of analyte-free media that have been used to rinse the sampling equipment. They document adequate decontamination of the sampling equipment after its use.

Field Spike Samples - selected field samples to which a known amount of the analytes of interest are added during their collection in the field. In the event that background samples are not practical to collect, field spiked samples can provide a reasonable substitute that will help to estimate matrix effects; however, field spiked samples may have higher extraction efficiencies than unspiked test samples.

Material blanks - are samples of construction materials such as those used in groundwater wells, pump and flow testing, etc. They document the decontamination (or measure artifacts from use of the materials.

Blind Sample - a sample submitted for analysis whose composition is known to the submitter but unknown to the analyst. A blind sample is one way to test proficiency of a measurement process (Taylor, 1987).

Calibrant - a substance used to calibrate or establish the analytical response of a measurement system (Taylor, 1987).

Calibration - comparison of a measurement standard or instrument with another standard or instrument to report or eliminate by adjustment any variation (deviation) in the accuracy of the item being compared (Taylor, 1987).

Central Limit Theorem - For large sample sizes the sample means will tend to be normally distributed, regardless of the underlying distribution of the random variable, X.

Chance cause - a cause for variability of a measurement process that occurs unpredictably, for unknown reasons, and believed to happen by chance (Taylor, 1987).

Check standard - in physical calibration, an artifact measured periodically, the results of which typically are plotted on a control chart to evaluate the measurement process (Taylor, 1987).

Coefficient of Variability - the standard deviation divided by the mean multiplied by 100 $(s/Y)100$. This is a measure of relative dispersion about the mean and is applicable only when the mean is not equal to zero.

Coefficient of Variation - the standard deviation divided by the value of the parameter measured (Taylor, 1987).

Comparability - "expresses the confidence with which one data set, measuring system, or piece of equipment can be compared with another. Data can be considered comparable if they are similar to those reported by others in the literature or if the analysis procedures produce results similar to those of other laboratories from split samples" (Dillaha et al. 1988).

Completeness - "is a measure of the amount of valid data obtained from a measurement system compared to the amount expected to be obtained under correct normal conditions. For example, analysis of a water sample for total phosphorus will not be complete unless the sample is totally digested. Completeness is usually expressed as a percent of the true value" (Dillaha et al. 1988).

Confidence Interval - That range of values, calculated from an estimate of the mean and the standard deviation, which is expected to include the population mean with a stated level of confidence. Confidence intervals in the same context may also be calculated for standard deviations, lines, slopes, and points (Taylor, 1987).

Confidence Level - "There is a certain probability $(1 - \alpha)$ that the population mean of a random variable will lie within a certain interval (the confidence interval) about the sample mean." A small confidence interval width indicates a small degree of uncertainty in the estimate of the mean. Similarly, a small confidence interval width indicates that a large amount of information is contained in the estimate of the mean.

Control Sample - a material of known composition that is analyzed concurrently with test samples to evaluate a measurement process (Taylor, 1987).

Composite Sample - a sample composed of two or more increments selected to represent a population of interest (Taylor, 1987).

Data Quality Objectives - data quality is a measure or description of the type and amount of the error associated with a set of data.

Detection Limit - the smallest concentration/amount of some component of interest that can be measured by a single measurement with a stated level of confidence (Taylor, 1987).

Double Blind Sample - a sample known by the submitter but submitted to an analyst in such a way that neither its composition nor its identification as a check sample are known to the latter (Taylor, 1987).

Duplicate Measurement - a second measurement made on the same (or identical) sample of material to assist in the evaluation of measurement variance (Taylor, 1987).

Duplicate Sample - a second sample randomly selected from a population of interest to assist in the evaluation of sample variance (Taylor, 1987).

Error - the difference between the true or expected value and the measured value of a quantity or parameter (Taylor, 1987).

Frequency distribution - a plot of the number of observations occurring within each of several specified class intervals.

Holding Time - the length of time a sample can be stored, after collection and preservation and before preparation and analysis, without significantly affecting the analytical results.

Homogeneity - the degree to which a property or substance is randomly distributed throughout a material. Homogeneity depends on the size of the subsample under consideration. Thus a mixture of two minerals may be nonhomogeneous at the molecular or atomic level but homogeneous at the particulate level (Taylor, 1987).

Intercalibration - the process, procedures, and activities used to ensure that the several laboratories engaged in a monitoring program can produce compatible data. When compatible data outputs are achieved and this situation is maintained, the laboratories can be said to be intercalibrated (Taylor, 1987).

Limiting Mean - the value approached by the average as the number of measurements made by a stable measurement process increases indefinitely (Taylor, 1987).

Limit of Linearity (LOL) - the upper limit of concentration or amount of substance for which incremental additions produce constant increments of response (Taylor, 1987).

Limit of Quantitation (LOQ) - the lower limit of concentration or amount of substance that must be present before a method is considered to provide quantitative results. By convention, LOQ=10so, where so is the estimate of the standard deviation at the lowest level of measurement (Taylor, 1987).

Macroinvertebrates - invertebrates which are large enough to be seen by the unaided eye and which can be retained by a U.S. Standard No. 30 sieve (28 meshes per inch, 0.595 mm openings) and live at least part of their life cycles within or upon available substrates in a body of water or water transport system.

Map Content Accuracy - determination of whether a map accurately depicts the true situation on the ground. This is determined by ground checking and relating this to a specific statistical reliability (e.g. 95% +/- 3%).

Map Projection - used to portray all or part of the round earth on a flat surface. This cannot be done without some distortion. It is important to note the map projection when making a map.

Map Scale - a ratio of distance on the map to the corresponding distance on the ground. For example, a USGS 1:24000 scale map indicates that one unit of measurement on the map is equal to 24000 units of measurement on the ground. So long as the both the numerator and the denominator of the ratio represent the same unit (inches, feet, centimeters) the scale is valid. If different units of measurement are to be used, the appropriate conversion must be made. For example, a map scale 1:24000 measured in inches can be converted to 1 inch on the map is equal to 2,000 feet on the ground.

Map resolution - this is the smallest unit shown on a map (ie. 1 acre).

Monotonic - regression (either increasing or decreasing) which goes in one direction, but not in a straight line.

Outlier - "an observation which deviates so much from other observations as to arouse suspicions that it was generated by a different mechanism" (Magnien et al. 1991).

Phi Grade Scale - a logarithmic transformation of the Wentworth grade scale for size classifications of sediment grains based on their negative logarithm to the base 2 of the particle diameter. $\phi = \log^2 d$

Population - a generic term denoting any finite or infinite collection of individual things, objects or events; in the broadest concept, an aggregate determined by some property that distinguishes things that do and do not belong.

Positional Accuracy - the extent to which the location of features shown on a map accurately reflects their true location. This is determined by field checking against National Map Standards.

Power - The ability of a statistical test to determine whether the null hypothesis is false (1 - β). The power of a test is the probability of not committing a Type II error (β). The more powerful the test, the more likely it is to show, statistically an effect that exists. A Type II error (β) means that we have accepted an invalid null hypothesis. Also, this is called "sensitivity"; the ability of a test to find differences in the data when differences are actually present, the greater the power, the smaller the changes that can be discerned; power is dependent on 1) the variability within the data set, 2) the length of the data set, and 3) the statistical test used (Magnien et al. 1991).

Precision - "is a measure of the degree of agreement between independent measurements of some property. It is concerned with the closeness of the results and is best expressed in terms of standard deviation" (Dillaha et al. 1988).

Probability - the likelihood of the occurrence of any particular form of an event, estimated as the ratio of the number of ways or times that the event may occur in that form to the total number of ways that it could occur in any form (Taylor, 1987).

Probability Function - this is a function that assigns probabilities to the various events in the sample space. This mathematically expresses how probabilities of occurrence are distributed over the possible range of values and can be utilized to estimate the probability that a specified event will or will not occur. Probability density function describe continuous random variables. Probability Mass Function describe discrete random variables.

Quality - an estimation of acceptability or suitability for a given purpose of an object, item, or tangible or intangible thing.

Quality Assessment - the overall system of activities whose purpose is to provide assurance that the quality control activities are done effectively. It involves a continuing evaluation of performance of the production system and the quality of the products produced (Taylor, 1987).

Quality Assurance (QA) - "can be defined as a system of activities designed to assure sponsors, researchers, and other data users that quality control activities are being accomplished and that data of known quality are being generated. Quality assurance is primarily a process of documenting the quality control activities that are being followed. The documentation should be verifiable and defensible" (Dillaha et al. 1988). "The term quality assurance refers to the quality control functions and involves totally integrated program for ensuring the reliability of monitoring data." EPA 1990.

Quality Control (QC) - "activities include data collection operations which are undertaken in the field and laboratory and in the processing of data to ensure that quality data are being collected which meet the needs of data users. The quality of data can be expressed in terms of its precision, accuracy, representativeness, comparability, and completeness (PARCC)" (Dillaha et al. 1988). "refers to the routine application and procedures for obtaining prescribed standards of performance and for controlling the measurement process (EPA 1990).

Random sampling - simple random sampling is a method of selecting n units out of a total population in such a way that each unit of the population has an equal probability of being selected.

Reduction - the process of preparing one or more subsamples from a sample (Taylor, 1987).

Reference material (RM) - a material or substance, one or more properties of which are sufficiently well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for the assignment of values to materials (Taylor, 1987).

Relative standard deviation - the coefficient of variation expressed as a percentage (coefficient of variation is the standard deviation divided by the value of the parameter measured).

Replicate Sample - a counterpart of another, usually referring to an analytical sample or a measurement. It is the general case for which duplicate is the special case consisting of two samples or measurements.

Representativeness - "is a measure of the degree to which data accurately and precisely represent the characteristic of the population which is being monitored. For example, collection and analysis of a single grab sample collected from the surface of a stream will not be representative of the mean sediment concentration of the stream because sediment concentrations in the stream will vary at different places in the cross-section" (Dillaha et al. 1988).

Robustness - This is a term used by statisticians which means that some of the assumptions about a population can be violated somewhat and the technique can still be used. The assumptions being: 1) independence between observations or groups, 2) the sample means have a normal distribution, (3) and the groups should have nearly equal variances, called homogeneity of variance (Cody and Smith, 1991). "Degree of susceptibility to "false alarms"; the resistance of a test to giving "false" positives, that is saying there is a difference when there is not; robustness is dependent on the statistical test used (Magnien, et al. 1991).

Sample - a portion of a population or lot. It may consist of an individual or groups of individuals. It may refer to objects, materials, or measurements, conceivable as part of a larger group that could have been considered (Taylor, 1987).

Selectivity - the ability of methodology or instrumentation to respond to a desired substance or constituent and not to others.

Sensitivity - capability of methodology or instrumentation to discriminate between samples having differing concentrations or containing differing amounts of an analyte.

Serial Correlation - the tendency of an observation to be closely related to those around it. Serial correlation is significant autocorrelation remaining after seasonality and trend are removed.

Significance level - α (alpha).

Skewness - the third statistical moment. The mean divided by the cube of the standard deviation. Skewness is a dimensionless parameter which measures asymmetry of the probability density function.

Special studies (surveys) - monitoring efforts which have a designated termination data.

Spiked sample - using a similar analyte (surrogate) or the same analyte (standard addition) are used to estimate interference bias when expected confidence limits of percent recovery are exceeded.

Split Sample - a replicate portion or subsample of a total sample obtained in such a manner that it is not believed to differ significantly from other portions of the same sample (Taylor, 1987).

Standard Deviation - is the square root of the variance. Describes the distribution of individuals. This is a description of the "spread" of the individuals. The variance or mean square (σ^2 or s^2) is defined in terms of squared deviations.

Standard Error - is the standard deviation of a mean.

Stratified Random Sampling - In stratified random sampling the total population is divided into subpopulations referred to a strata. Then, a simple random sample is taken independently from each strata.

Suspended load sampler - is a sampler which attempts to secure a sample of the water with its sediment load without separating the sediment from the water.

Systematic Sampling - consists of selecting a unit at random from 1 to k and then selecting every k^{th} unit thereafter.

Tolerance Interval - the range of values, calculated from an estimate of the mean and standard deviation, within which a specified percentage of individual values of a population (measurements of sample) are expected to lie with a stated level of confidence (Taylor, 1987).

Trend - a monotonic change in time, occurring as either an abrupt or a gradual change in concentration.

Type I Error - the probability of declaring a valid null hypothesis false, referred to as the α (alpha) level.

Type II Error - the probability of accepting an invalid null hypothesis, referred to as the β (beta) level.

Uncertainty - the range of values within which the true value is estimated to lie. it is a best estimate of possible inaccuracy due to both random and systematic error.

Validation - the process by which a sample, measurement method, or a piece of data is deemed useful for a specified purpose (Taylor, 1987).

Variance - the value approached by the average of the sum of the squares of deviations of individual measurements from the limiting mean. The second statistical moment about the mean. A measure of the amount of dispersion about the mean of a population of data. $var(x) = s^2/n$ (the population variance is equal to the sample variance divided by the number of observations).

LITERATURE CITED
DATA ANALYSIS

Alden, R.W., D.M. Jones, and J.C. Seibel. 1992. *An Analysis of the Chesapeake Bay Program Monitoring Design for Detecting Water Quality and Living Resource Trends.* Old Dominion University AMRL Technical Report No. 747. Submitted to the Virginia State Water Control Board. 63pp.

Alley, W.M. 1988. Using Exogenous Variables in Testing for Monotonic Trends in Hydrologic Time Series. Water Resources Research. 24(11):1955-1961.

Berryman, D., B. Bobee, D. Cluis, and J. Haemmerli. 1988. Nonparametric tests for trend detection in water quality time series. Water Resources Bulletin. 24(3):545-556.

Bliss, C.I. and R.A. Fisher. 1953. Fitting the Negative Binomial Distribution to Biological Data. Biometrics. 6:176-200.

Bowker, A.H. and G.J. Liberman. 1972. *Engineering Statistics.* Prentice Hall Inc., Englewood Cliffs, New Jersey. 641 pp.

Conover, W.J. 1980. *Practical Nonparametric Statistics.* Second Edition. John Wiley and Sons, New York.

Crawford, C.G., J.R. Slack, and R.M. Hirsch. 1983. Nonparametric Tests for Trends in Water-Quality Data Using the Statistical Analysis System. USGS Open File Report 83-550. 102pp.

El-Shaarawi, A.H. 1989. Inferences about the Mean from Censored Water Quality Data. Water Resources Research. 25(4):685-690.

El-Shaarawi, A.H. and E. Damsleth. 1988. Parametric and Nonparametric Tests for Dependent Data. Water Resources Bulletin 24(3):513-519.

Gerrodette, T. 1987. A Power Analysis for Detecting Trends. Ecology. 68(5):1364-1372.

Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring.* Van Nostrand Reinhold. New York, New York. 320pp.

Gilliom, R.J., R.M. Hirsch, and E.J. Gilroy. 1984. Effect of censoring trace-level water-quality data on trend detection capability. Environmental Science and Technology. 18(7):530-535.

Green, R.H. 1989. Power Analysis and Practical Strategies for Environmental Monitoring. Environmental Research. 50:195-205.

Haas, C.N. and P.A. Scheff. 1990. Estimation of Averages in Truncated Samples. Environmental Science and Technology. 24:912-919.

Harris, J., J.C. Loftis, R.H. Montgomery. 1987. Statistical Methods for Characterizing Ground Water Quality. Ground Water. 25(2):185-193.

Helsel, D.R. 1987. Advantages of Nonparametric Procedures for Analysis of Water Quality Data. Hydrological Sciences. 32(2):179-190.

Helsel, D.R. 1990. Less than Obvious: Statistical Treatment of Data Below the Detection Limit. Environmental Science and Technology. 24(12):1766-1774.

Helsel, D.R. and T.A. Cohn. 1988. Estimation of Descriptive Statistics for Multiply Censored Water Quality Data. Water Resources Research. 24(12):1997-2004.

Hipel, K.W., A.I. McLeod, and R.R. Weiler. 1988. Data analysis of water quality time series in Lake Erie. Water Resources Bulletin. 24(3):533-544.

Hipel, K.W. 1988. Nonparametric approaches to environmental impact assessment. Water Resources Bulletin. 24(3):487-492.

Hirsch, R.M. 1988. Statistical methods and sampling design for estimating step trends in surface-water quality. Water Resources Bulletin. 24(3):493-503.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. Techniques of trend analysis for monthly water quality data. Water Resources Research. 18(1):107-121.

Hirsch, R.M. and J.R. Slack. 1984. A nonparametric test for seasonal data with serial dependence. Water Resources Research. 20(6):727-732.

Hughes, J.P. and S.P. Millard. 1988. A tau-like test for trend in the presence of multiple censoring points. Water Resources Bulletin. 24(3):521-531.

Lettenmaier, D.P. 1976. Detection of trends in water quality data from records with dependent observation. Water Resources Research. 12(5):1037-1046.

Lettenmaier, D.P. 1988. Multivariate nonparametric tests for trend in water quality. Water Resources Bulletin. 24(3):505-512.

Loftis, J.C., R.C. Ward, R.D. Phillips, and C.H. Taylor. 1989. *Project Summary: An Evaluation of Trend Detection Techniques for Use in Water Quality Monitoring*

Programs. United States Environmental Protection Agency, Center for Environmental Research. Cincinnati, Ohio. EPA/600/S3-89/037.

Loftis, J.C. and R.C. Ward. 1981. Evaluating stream standard violations using a water quality data base. Water Resources Bulletin. 17(6):1071-1078.

Loftis, J.C., J. Harris, and R.H. Montgomery. 1987. Detecting changes in ground water at regulated facilities. Ground Water Review. 72-76.

Loftis, J.C.,R.C. Ward. R.D.,Phillips, and C.H. Taylor. 1988. *Detecting Trends In T.I.M.E. Data Series*. Final report to the U.S. Environmental Protection Agency, Corvallis, Oregon. July.

Loftis, J.C., G.B. McBride, and J.C. Ellis. 1991. Considerations of scale in water quality monitoring and data analysis. Water Resources Bulletin. 27(2):255-264.

Loftis, J.C., C.H. Taylor, and P.L. Chapman. 1991. Multivariate tests for trend in water quality. Water Resources Research. 27(7):1419-1429.

Magnien, R., R. Eskin, R. Alden, R. Batiuk, S. Bieber, S. Brunenmeister, C. Haywood, R. Hoffman, M. Olsen, and D. McCall. 1991. *Guidance for the Analysis of Water Quality Trends*. DRAFT. Prepared by the Data Analysis Workgroup of the Chesapeake Bay Program Monitoring Subcommittee. Baltimore, Maryland.

McLeod, A.I., K.W. Hipel, and F. Comancho. 1983. Trend assessment of water quality time series. Water Resources Bulletin. 19(4):537-547.

Millard, S.P. 1987. Environmental monitoring, statistics, and the law: Room for improvement. The American Statistician. 41(4):249-253.

Millard, S.P., and S.J. Deverel. 1988. Nonparametric statistical methods for comparing two sites based on data with multiple nondetect limits. Water Resources Research. 24(12):2087-2098.

Millard, S.P. and D.P. Lettenmaier. 1986. Optimal design of biological sampling programs using the analysis of variance. Estuarine, Coastal and Shelf Science. 22:637-656.

Montgomery, R.H. and J.C. Loftis. 1987. Applicability of the t-test for detecting trends in water quality variables. Water Resources Bulletin. 23(4):653-662.

Montgomery, R.H. and K.H. Reckhow. 1984. Techniques for detecting trends in lake water quality. Water Resources Bulletin. 20(1):43-52.

Newman, M.C., P.M. Dixon, B.B. Looney, and J.E. Pinder. 1989. Estimating mean and variance for environmental samples with below detection limit observations. Water Resources Bulletin. (4):905-916.

Parkin, T.B., S.T. Chester, and J.A. Robinson. 1990. Calculating confidence intervals for the mean of a lognormally distributed variable. Soil Sciences Society of America Journal. 54:321-326.

Parkinson, E.A. J. Berkowitz, and C.J. Bull. 1988. Sample size requirements for detecting changes in some fisheries statistics from small trout lakes. North American Journal of Fisheries Management. 8:181-190.

Peterman, R.M. 1990. The importance of reporting statistical power: the forest decline and acidic deposition example. Ecology. 71(5):2024-2027.

Peterman, R.M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences. 47:2-15.

Rotenberry, J.T. and J.A. Wiens. 1985. Statistical power analysis and community wide patterns. American Naturalist. 125:164-168.

Sachs, L. 1984. *Applied Statistics: A Handbook of Techniques*. Springer-Verlag, New York. 707 pp.

Schemper, M. 1984. Exact test procedures for generalized Kendall correlation coefficients. Biom. J. 26(4):399-406.

Snedecor, G.W. and W.G. Cochran. 1980. *Statistical Methods*. The Iowa State University Press. Ames, Iowa. 507 pp.

Steele, R.G.D. and J.H. Torrie. 1980. *Principles and Procedures of Statistics: A Biometrical Approach*. McGraw-Hill, Inc. New York, New York. 633 pp.

Taylor, C.H. and J.C. Loftis. 1989. Testing for trend in lake and ground water quality time series. Water Resources Bulletin. 25(4):715-726.

Toft, C.A. and P.J. Shea. 1983. Detecting community-wide patterns: estimating power strengthens statistical inference. American Naturalist. 122:618-625.

Travis, C.C. and M.L. Land. Estimating the mean of data sets with nondectable values. Environmental Science and Technology. 24(7):961-965.

van Belle, G. and J.P. Hughes. 1984. Nonparametric tests for trend in water quality. Water Resources Research. 20(1):127-136.

Ward, R.C., J.C. Loftis, H.P. DeLong, and H.F. Bell. 1988. Groundwater quality: a data analysis protocol. Journal of the Water Pollution Control Federation. 60(11): 1938-1945.

Whitfield, P.H. and P.F. Woods. 1984. Intervention analysis of water quality records. Water Resources Bulletin. 20(5):657-667.

LITERATURE CITED
PROJECT REPORTS

Alexander, R.B. and R.A. Smith. 1988. Trends in lead concentrations in major U.S. rivers and their relation to historical changes in gasoline-lead consumption. Water Resources Bulletin. 24(3):557-569.

Bishop, J.W. 1988. Protocol for analyses of tributary monitoring data. University of Richmond, Department of Biology. Richmond, Virginia.

Hall, J.D., M.L. Murphy, and R.S. Aho. 1978. An improved design for assessing impacts of watershed practices on small streams. Verh. Internat. Verein. Limnol. 20:1359-1365.

Harned, D.A. and M.S. Davenport. 1990. Water quality trends and basin activities and characteristics for the Albemarle-Pamlico estuarine system, North Carolina and Virginia. US Geological Survey Open-File Report 90-398. 164pp.

Klein, R.D. 1979. Urbanization and stream quality impairment. Water Resources Bulletin. 15(4):948-963.

McClellan, P.W. U. Tim, S. Mostaghimi, J.C. Carr, and R.K. Byler. 1989. Water quality and nutrient dynamics in Virginia's Owl Run watershed. A paper presented at the American Society of Agricultural Engineers in St. Joseph, Missouri.

Ott, A.N. 1990. Nutrient loading status of the Conestoga River basin 1985-1989. Susquehanna River Basin Commission, Resource Quality Management and Protection Division. Harrisburg, Pa. Publication No. 133.

Scanlan, M. 1989. Nitrate trends in the upper Roanoke River subarea. Virginia State Water Control Board, West Central Regional Office. Roanoke, Virginia.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987. Water quality trends in the nations's rivers. Science. 235:1607-1615.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987. Analysis and interpretation of water-quality trends in major U.S. rivers, 1974-81. U.S. Geological Survey Water-Supply Paper 2307. 25pp.

Spooner, J, R.L. Huffman, D.E. Line, J.A. Gale, G.D. Jennings, S.W. Coffey, J.A. Arnold, L. Wyatt, D.L. Osmond, and S.K. Haseeb. 1992. Nonpoint sources. Water Environment Research. 64(4):503-514.

US EPA. 1991. *Dissolved Oxygen Trends in the Chesapeake Bay (1984-1990).* United States Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland. CBP/TRS 66/91.

US EPA. 1991. *Trends in Phosphorus in the Chesapeake Bay (1984-1990).* United States Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland. CBP/TRS 67/91.

LITERATURE CITED
PROGRAM DESIGN

Austin, S.H. 1992. *Highlights of Virginia Department of Forestry Water Quality Studies 1990-1991*. Virginia Department of Forestry, Charlottesville, Virginia.

Brown, G.W. 1991. *Forestry and Water Quality*. Oregon State University (O.S.U.) Bookstores, Inc. Corvallis, Oregon.

Chapman, P.M., G.P. Romberg, and G.A. Vigers. 1982. Design of monitoring studies for priority pollutants. Journal of the Water Pollution Control Federation. 54(3):292-297.

Green, R.H. 1989. Power analysis and practical strategies for environmental monitoring. Environmental Research. 50:195-205.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54(2):187-211.

Loftis, J.C. and R.C. Ward. 1980. Sampling frequency selection for regulatory water quality monitoring. Water Resources Bulletin. 16(3):501-507.

Loftis, J.C. and R.C. Ward. 1980. Water quality monitoring - some practical sampling frequency considerations. Environmental Management. 4(6):521-526.

Loftis, J.C. and R.C. Ward. 1982. Water quality monitoring: what directions should new programs take?. Environmental Management. 6(4):279-282.

Loftis, J.C. and R.C. Ward. 1987. Designing systems to monitor water quality impacts due to non-point sources. Paper presented at the U.S. Committee on Irrigation and Drainage, Denver Regional Meeting on Water Management, September 2-4, Denver, Colorado.

McBride, J.B. 1987. *Proposal for National Water Quality Monitoring Programme in New Zealand*. DRAFT. Ministry of Works and Development, Water Quality Centre. Hamilton, New Zealand.

Noether, G.E. 1987. Sample size determination for some common nonparametric tests. Journal of the American Statistical Association. 82:645-647.

Perry, J.A. and R.C. Ward. 1984. Survey of state water quality monitoring programs. Environmental Management. 8(1):21-26.

Peterson, R.C. 1992. The RCE: A riparian, channel, and environmental inventory for small streams in the agricultural landscape. Freshwater Biology. 27:295-306.

Platts, W.S., W.F. Megahan, and G.W. Minshall. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138. US Forest Service.

Ponce, S.L. 1980. *Water Quality Monitoring Programs*. United States Department of Agriculture, Forest Service, Watershed Systems Development Group. Fort Collins, Colorado. WSDG Technical Paper, WSDG-TP-00002.

Sanders, T.G., R.C. Ward, J.C. Loftis, T.D. Steele, D.D. Adrian, and V. Yuvjevich. 1983. *Design of Networks for Monitoring Water Quality*. Water Resources Publications, Littleton, Colorado. 328 pp.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time?. Ecology. 67(4):929-940.

US EPA. 1990. *Draft Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters*. United States Environmental Protection Agency, Office of Marine and Estuarine Protection. Washington, D.C. EPA-503-8-90/002.

US EPA. 1991. *Watershed Monitoring and Reporting for Section 319 National Monitoring Program Projects*. United States Environmental Protection Agency, Assessment and Watershed Protection Division, Office of Wetlands, Oceans, and Watersheds. Washington, D.C.

Ward, R.C., and J.C. Loftis. 1986. Establishing statistical design criteria for water quality monitoring systems: Review and synthesis. Water Resources Bulletin. 22(5):759-767.

Ward, R.C. 1988. Water quality monitoring as an information system. Paper presented at the U.S. Environmental Protection Agency's nation Symposium on Water Quality Assessment, June 1-3, Annapolis, Maryland.

Ward, R.C. 1989. Future directions for water quality monitoring in Virginia. Prepared for the Virginia Water Control Board, Office of Water Resources Managment. Richmond, Virginia. Contract Number 414-S-90-002.

Ward, R.C. 1989. Water quality monitoring - a systems approach to design. A paper presented at the International Symposium on the Design of Water Quality Information Systems, June 7-9, 1989. Fort Collins, Colorado.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1986. The "data-rich but information-poor" syndrome in water quality monitoring. Environmental Management. 10(3):291-297.

Ward, R.C., J.C. Loftis, and G.B. McBride (Eds.). 1989. *Proceedings of the International Symposium on the Design of Water Quality Information Systems*. Information Series No. 61. Colorado Water Resources Research Institute. Fort Collins, Colorado.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1990. *Design of Water Quality Monitoring Systems*. Van Nostrand Reinhold. New York, New York. 231 pp.

Ward, R.C. and J.C. Loftis. 1989. Monitoring systems for water quality. Critical Reviews in Environmental Control. 19(2):101-118.

Ward, R.C., J.C. Loftis, K.S. Nielsen, R.D. Anderson. 1979. Statistical evaluation of sampling frequencies in monitoring networks. Journal of the Water Pollution Control Federation. 51(9):2292-2300.

Whitfield, P.H. 1988. Goals and data collection designs for water quality monitoring. Water Resources Bulletin. 24(4):775-780.

LITERATURE CITED
ANALYTICAL METHODS AND PROTOCOLS

Currie, L.A. 1968. Limits for qualitative detection and quantitative determination: application to radiochemistry. 40(3):586-593.

D'Elia, C.F., J.G. Sanders, and D.G. Capone. 1989. Analytical chemistry for environmental scientists: a question of confidence. Environmental Science and Technology. 23(7):768-774.

D'Elia, C.F., K.L. Webb, D.V. Shaw, and C.W. Keefe. 1986. *Methodological Comparisons for Nitrogen and Chlorophyll Determinations in Estuarine Water Samples.* United States Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland.

Franson, M.A. (ed). 1989. *Standard Methods for the Examination of Water and Wastewater.* 17th edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Washington, D.C.

Hites, R.A. and W.L. Budde. 1991. EPA's analytical methods for water: the next generation. Environmental Science and Technology. 25(6):998-1006.

Horwitz, W. 1982. Evaluation of analytical methods used for regulation of foods and drugs. Analytical Chemistry. 54(1):67-76.

Keith, L.H. and W.A. Telliard. 1979. Priority Pollutants: I - a perspective view. Environmental Science and Technology. 13(4): 416-423.

Keith, L.H., W. Crummett, J. Deegan, R.A. Libby, J.K. Taylor, and G. Wentler. 1983. Principles of environmental analysis. Analytical Chemistry. 55:2210-2218.

Magnien, R. 1986. *A Comparison of Estuarine Water Chemistry Analysis on the Filtrate from two Types of Filters.* Maryland Office of Environmental Programs, Ecological Modeling and Analysis Division. Baltimore, Maryland. 12 pp.

Oppenheimer, L., T.P. Capizzi, R.M. Weppelman, and Hina Mehta. 1983. Determining the lowest limit of reliable assay measurement. Analytical Chemistry. 55:638-643.

Porter, P.S., R.C. Ward, and H.F. Bell. 1988. The detection limit. Environmental Science and Technology. 22(8):856-861.

Rogers, L.B. 1986. The inexact imprecise science of trace analysis. Journal of Chemical Education. 63(1):3-6.

Siegfried, R.C. 1987. *Comparison of Preservation Techniques for Organic Carbon Analysis in Estuarine Water Samples.* US Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland. CBP/TRS 5/87.

US EPA. 1982. *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater.* United States Environmental Protection Agency. Cincinnati, Ohio. EPA 600/4-82-057. NTIS No. PB83-201798.

LITERATURE CITED
QUALITY ASSURANCE/QUALITY CONTROL

Dillaha, T.A., S. Mostaghimi, C.D. Eddleton, and P.W. McClellan. 1988. Quality control/quality assurance for water quality monitoring. A paper presented at the winter meeting of the American Society of Agricultural Engineers. December 13-16, 1988 Chicago, Illinois.

Horowitz, W., L.R. Kamps, and K.W. Boyer. 1980. Quality assurance in the analysis of foods for trace constituents. Journal of the Association of Analytical Chemists. 63(6):1344-1354.

Taylor, J.K. 1987. *Quality Assurance of Chemical Measurements.* Lewis Publishers, Chelsea, Michigan. 328pp.

US EPA. 1980. *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* Office of Monitoring Systems and Quality Assurance, Office of Research and Development. Washington, D.C. QAMS-005/80.

US EPA. 1982. *Handbook for Analytical Quality Control in Water and Wastewater Laboratories.* United States Environmental Protection Agency. Cincinnati, Ohio. EPA 600/4-79-015. NTIS No. PB-297-451.

US EPA. 1984. *Guidance for Preparation of Combined Work/Quality Assurance Project Plans for Environmental Monitoring.* United States Environmental Protection Agency, Office of Water Regulations and Standards. Washington, D.C. EPA-OWRS/QA-1.

US EPA. 1990. *Chesapeake Bay Coordinated Split Sample Program Annual Report, 1989.* United States Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland. CBP/TRS 51/90.

US EPA. 1991. *Chesapeake Bay Coordinated Split Sample Program Implementation Guidelines - Revision 3.* United States Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland. CBP/TRS 58/91.

LITERATURE CITED
FIELD COLLECTION METHODOLOGIES

Bros, W.E. and B.C. Cowell. 1987. A technique for optimizing sample size (replication). Journal of Experimental Marine Biology and Ecology. 114:63-71.

Brydon, G.W. and L.R. Smith. 1989. Sampling for environmental analysis: part 1: planning and preparation. American Laboratory. July:30-39.

Brydon, G.W. and L.R. Smith. 1989. Sampling for environmental analysis: part 2: sampling methodology. American Laboratory. September:19-24.

Casey, D., P.N. Nemetz, and D.H. Uyeno. 1983. Sampling frequency for water quality monitoring: measures of effectiveness. Water Resources Research. 19(5): 1107-1110.

Cowan, C.E. and R.G. Riley. 1987. *Guidance for Sampling of and Analyzing for Organic Contaminants in Sediments.* Prepared for United States Environmental Protection Agency, Criteria and Standards Division, Washington, D.C.

Keith, L.H. 1990. Environmental sampling: a summary. Environmental Science and Technology. 24(5):610-617.

Keith, L.H. 1991. *Environmental Sampling and Analysis: A Practical Guide.* Lewis Publishers. Chelsea, Michigan.

Rutherford, J.E. and R.J. Mackay. 1985. The vertical distribution of hydropsychid larvae and pupae (Tricoptera: Hydropsychidae) in stream substrates. Canadian Journal of Zoology. 63:1306-1315.

Schmitt, C.J. J.L. Zajicek, and M.A. Ribick. 1985. National pesticide monitoring program: residues of organochlorine chemicals in freshwater fish, 1980-81. Archives of Environmental Contamination and Toxicology. 14:225-260.

US EPA 1980. *Interim Methods for the Sampling and Analysis of Priority Pollutants in Ssediments and Fish Tissue.* Second Edition. Environmental Analysis Section, US Environmental Protection Agency. Washington, D.C.

US EPA. 1982. *Handbook for Sampling and Sample Preservation of Water and Wastewater.* United States Environmental Protection Agency. Cincinnati, Ohio. EPA 600/4-82-029. NTIS No. PB83-124503.

US EPA. 1985. *EPA Region III Guidance on Sampling Aquatic Organisms for Tissue Analyses During FY 1986.* Environmental Services Division, US Environmental Protection Agency. Washington, D.C.

VWCB. 1984. *Procedures for Collecting and Preserving Samples for Toxic Pollutant Analysis in Water, Sediment, and Fish.* Toxics Monitoring Program, Office of Environmental Research and Standards, Virginia Water Control Board. Richmond, Virginia.

VWCB. 1988. *Water Quality Assessment Operating Procedures Manual.* Office of Water Resource Management, Virginia Water Control Board. Richmond, Virginia. Revised June, 1991.

Welton, J.S. and M. Ladle. 1979. Two sediment trap designs for use in small rivers and streams. Limnol. Oceanogr. 24(3):588-592.

LITERATURE CITED
BIOLOGICAL MONITORING

Angermeier, P.L. and J.R. Karr. 1986. Applying an index of biotic integrity based on stream-fish communities: considerations in sampling and interpretation. North American Journal of Fisheries Management. 6:418-429.

Angermeier, P.L. and R.J. Neves. 1987. *Project Report: Virginia Warmwater Stream Classification and Survey*. Project Number: F-47-R. Virginia Polytechnic and State University, Blacksburg, Virginia.

Angermeier, P.L. and I.J. Schlosser. 1987. Assessing biotic integrity of the fish community in a small Illinois stream. North American Journal of Fisheries Management. 7:331-338.

Berkman, H.E., C.F. Rabeni, and T.P. Boyle. 1986. Biomonitors of stream quality in agricultural areas: fish versus invertebrates. Environmental Management. 10(3):413-419.

DGIF. 1991. *Endangered Species of Virginia*. (ed. Karen Terwilliger). Virginia Department of Game and Inland Fisheries, Endangered Species Program. Richmond, Virginia.

Fausch, K.D., J. Lyons, J.R. Karr, and P.L Angermeier. 1990. Fish communities as indicators of environmental degradation. American Fisheries Society Symposium. 8:123-144.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. The Great Lakes Entomologist. 20(1):31-39.

Hughes, R.M. 1985. Use of watershed characteristics to select control streams for estimating effects of metal mining wastes on extensively disturbed streams. Environmental Management. 9(3):253-262.

Hughes, R.M., D.P. Larsen, and J.M. Omernik. 1986. Regional reference sites: a method for assessing stream potentials. Environmental Management. 10(5):629-635.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries. 6(6):21-27.

Miller, D.L. et seq. 1988. Regional applications of an index of biotic integrity for use in water resource management. Fisheries. 13(5): 12-20.

Scott, J.B., C.R. Steward, and Q.J. Stober. 1986. Effects of urban development on fish population dynamics in Kelsey Creek, Washington. Transactions of the American Fisheries Society. 115:555-567.

Steedman, R.J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Canadian Journal of Fisheries and Aquatic Science. 45:492-501.

US EPA. 1989. *Rapid Bioassessment Protocols for Use in Streams and Rivers.* United States Environmental Protection Agency, Assessment and Watershed Protection Division. Washington, D.C. EPA-440-4-89/001.

US EPA. 1990. *Biological Criteria: National Program Guidance for Surface Waters.* United States Environmental Protection Agency, Regulations and Standards Division. Washington, D.C. EPA-440/5-90-004.

US EPA. 1990. *Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters.* United States Environmental Protection Agency, Office of Research and Development. Washington, D.C. EPA/600/4-90-030.

Walsh, J.B.S. 1992. *Effects of Timber Harvesting on Benthic Macroinvertebrate Populations in Southwestern Virginia.* Virginia Department of Forestry, Charlottesville, Virginia.

LITERATURE CITED
COMPUTER SOFTWARE DOCUMENTATION AND MODELING

Cody, R.P. and J.K. Smith. 1991. *Applied Statistics and the SAS Programming Language.* Elsevier Science Publishing Company, New York, New York. 403pp.

Dortch, M.S., C.F. Cerco, D.L. Robey, H.L. Butler, and B.H. Johnson. 1988. Work plan for three-dimensional time-varying, hydrodynamic and water quality model of Chesapeake Bay. U.S. Army Corps of Engineers. Baltimore, Maryland.

Engman, E.T. and A.S. Rogowski. 1974. A partial area model for storm flow synthesis. Water Resources Research. 10(3):464-472.

Freeze, R.A. 1980. A stochastic-conceptual analysis of rainfall-runoff processes on a hillslope. Water Resources Research. 16(2):391-408.

Haddad, K.D. and G.A. McGarry. 1989. Basin-wide management: A remote sensing/GIS approach. Coastal Zone 1989. 1822-1836.

Hession, C. 1989. Geographic information system technology and water quality modeling: an interface. Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. Richmond, Virginia.

Hession, C., K.L. Huber, S. Mostaghimi, V.O. Shanholtz, and P.W. McClellan. 1989. BMP effectiveness evaluation using AGNPS and a GIS. American Society of Agricultural Engineers. Paper Number 89-2566. St. Joseph, Mi.

Johnson, L.E. 1989. MAPHYD - a digital map-based hydrologic modeling system. Photogrammetric Engineering and Remote Sensing. 55(6):911-917.

Loftis, J.C., R.D. Phillips, R.C. Ward, and C.H. Taylor. 1989. WQSTAT II: a water quality statistics package. Groundwater. 27(6):866-873.

Reardon, J.C., L.D.Hanson, and J. Randolph. 1982. Using EPA's computerized data base (STORET) to analyze for agricultural water pollution. Journal of Environmental Quality. 11(3):427-432.

Shanholtz, V.O. and N. Zhang. 1989. GIS/hydrologic model interface for local planning jurisdictions. American Society of Agricultural Engineers. Paper Number 89-2562. St. Joseph, Mi.

Shanholtz, V.O. and N. Zhang. 1989. Hydrologic modeling system for Northern Neck Planning District. ISSL Report No. 100. Virginia Tech, Department of Agriculture Engineering. Blacksburg, Virginia.

Shanholtz, V.O. N. Zhang, E.R. Yagow, C.J. Desai, and J.M. Flagg. 1988. The use of a GIS to track the impact of Virginia Chesapeake Bay Agricultural Nonpoint Source Program. American Society of Agricultural Engineers. Paper Number 88-2535. St. Joseph, Mi.

Shanholtz, V.O., C.J. Desai, N. Zhang, J.W. Kleene, C.D. Metz, and J.M. Flagg. 1990. Hydrologic/water quality modeling in a GIS environment. American Society of Agricultural Engineers. Paper Number 90-3033. St. Joseph, Mi.

USDA-SCS. 1986. *Urban Hydrology for Small Watersheds, Technical Release 55, User's Guide*. United States Department of Agriculture, Soil Conservation Service, Engineering Division. Washington, D.C. 210-VI-TR-55, 2nd Edition.

USDA-SEA. 1978. Predicting rainfall erosion losses: a guide to conservation planning. United States Department of Agriculture, Science and Education Administration. Washington, D.C.

US EPA. 1991. *Nonpoint Source Management System, NPSMS Version 3, User's Guide*. United States Environmental Protection Agency, Assessment and Watershed Protection Division, Office of Wetlands, Oceans, and Watersheds, Nonpoint Source Management Branch. Washington, D.C. Prepared under EPA Contract 68-C9-0013.

US EPA. *STORET - Basic Seminar Documentation*. United States Environmental Protection Agency. Washington, D.C.

US EPA. *STORET - Advanced Seminar Documentation*. United States Environmental Protection Agency. Washington, D.C.

LITERATURE CITED
BEST MANAGEMENT PRACTICE'S

Barton, D.R., W.D. Taylor, and R.M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. North American Journal of Fisheries Management. 5:364-378.

CBLAD. 1989. *Local Assistance Manual: A Guide for the Development of Local Programs in Order to Comply with the Chesapeake Bay Preservation Act.* Chesapeake Bay Local Assistance Department. Richmond, Virginia.

VADCR. 1990. *Virginia Stormwater Management Regulations.* Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. Richmond, Virginia.

VADCR. 1991. *Virginia Erosion and Sediment Control Regulations.* Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. Richmond, Virginia.

VADCR. 1992. *Virginia Erosion and Sediment Control Law.* Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. Richmond, Virginia.

VDOF. 1988. *Loggers Guide: Save Money, Time, and Improve Water Quality.* Virginia Department of Forestry. Charlottesville, Virginia.

VDOF. 1989. *Forestry Best Management Practices for Water Quality in Virginia.* Virginia Department of Forestry. Charlottesville, Virginia. 76 pp.

LITERATURE CITED
CARTOGRAPHY

Monmonier, M.S. 1977. *Maps, Distortion, and Meaning*. Association of American Geographers. Resource Paper No. 75-4. Washington, D.C. 51 pp.

Muehrcke, P.C. 1978. *Map Use: Reading, Analysis, and Interpretation*. JP Publications, Madison, Wisconsin. 474 pp.