Virginia Volunteer Water Quality Monitoring Program Methods Manual

June 2024

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Prepared by:

Virginia Volunteer Water Quality Monitoring Program,
A cooperative effort of Alliance for the Chesapeake Bay, Virginia Department of Conservation and Recreation, Virginia Department of Environmental Quality and Virginia Save Our Streams Program of the Virginia Division of the Izaak Walton League of America

June 2024

Virginia Department of Environmental Quality

https://www.deq.virginia.gov/our-programs/water/water-quality/monitoring/citizen-monitoring

Acknowledgements

An earlier version of this document was published in 2007 by the Alliance for the Chesapeake Bay, Virginia Department of Conservation and Recreation, Virginia Department of Environmental Quality and Virginia Save Our Streams Program of the Virginia Division of the Izaak Walton League of America. Material in this publication may be reprinted or duplicated.

Much of the information in this manual has been adapted from the Alliance for the Chesapeake Bay's *Citizen Monitoring Program Manual* and U. S. Environmental Protection Agency (EPA) volunteer monitoring manuals. These include:

Center for Marine Conservation & U. S. EPA. *Volunteer Estuary Monitoring: A Methods Manual, Second Edition*

U. S. Environmental Protection Agency (USEPA), *Volunteer Lake Monitoring: A Methods Manual.* EPA 440/4-91-002.

U.S. EPA. 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003.

Electronic copies of these manuals can be found here: https://www.epa.gov/nps/nonpoint-source-volunteer-monitoring

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Why is Volunteer Monitoring Important?

Hundreds of Virginians volunteer their time to monitor the quality of Virginia's waterways. These backyard scientists conduct many types of monitoring that vary in sophistication. Examples include: evaluating macroinvertebrate (mainly insect larvae) populations in streams, measuring water samples for dissolved oxygen, temperature, and pH, collecting water samples to be analyzed in the lab for bacteria and nutrients, and conducting habitat evaluations and stream walks. These volunteer monitors may not have degrees in science but they do have an interest in the quality of their environment. Spending time in the water gives them an opportunity to learn about water quality while collecting valuable data.

Volunteer monitors play an important role in protecting Virginia's natural resources. Although the Virginia Department of Environmental Quality (DEQ) has a large network of professional monitoring stations, DEQ cannot possibly monitor all the waterways in Virginia. Virginia has approximately 50,000 miles of streams and rivers, 2,500 square miles of estuaries, and 100 significant lakes (public water supply and/or > 100 acres) located in Virginia. Local governments may have their own monitoring programs, but those programs gain tremendously when supplemented with volunteer data. Volunteer data are used in a number of ways: to educate students and the community, to collect baseline information to prioritize monitoring needs and establish background conditions, to contribute to local land use decisions, to indicate unusual conditions, for special studies, and for statewide water quality assessment reports. In compliance with state law (see § 62.1-44.19:11), volunteer monitoring data are not used as evidence in enforcement actions.

How Can You Become a Volunteer Monitor?

Becoming a volunteer monitor is easy. No special background is needed and any age group can participate. An existing organization working in your local watershed is a good place to start. Local organizations can usually provide the training and equipment needed. To find out if there is an existing program in your local watershed, contact the Virginia Volunteer Water Quality Monitoring Program (Appendix 1). If there is not an existing program in your area, you may want to consider starting your own program. Any of the Virginia Volunteer Water Quality Monitoring Program partners, Alliance for the Chesapeake Bay (ACB), Virginia Department of Conservation and Recreation (DCR), DEQ, and Virginia Save Our Streams Program of the VA Division of the Izaak Walton League of America (VA SOS) can provide assistance.

Virginia Citizen Water Quality Monitoring Program Contacts

- Alliance for the Chesapeake Bay
  https://www.allianceforthebay.org
- VA Department of Conservation & Recreation
  https://www.dcr.virginia.gov
- VA Department of Environmental Quality
  https://www.deq.virginia.gov/our-programs/water/water-quality/monitoring/citizen-monitoring
- VA Save Our Streams Program of the VA Division of the Izaak Walton League of America
  https://vasos.org/

Introduction to Volunteer Water Quality Monitoring in Virginia

In 2004, The Virginia Department of Environmental Quality created the position of Water Quality Data Liaison. The role of the liaison was due to the increasing amounts of water quality data provided to DEQ from Volunteer volunteers and other monitoring organizations. Since 1998, DEQ has provided support to volunteer groups to elevate the importance of volunteer monitoring and quality assurance of volunteer data.

In recognition to the importance of volunteer monitoring, in 1999 the Virginia General Assembly authorized the Citizen Water Quality Monitoring Grant Program. This grant program has provided various levels of financial support to promote and sustain volunteer monitoring efforts in Virginia. Due to the success of the grant program and volunteer monitoring in general, the 2007 General Assembly unanimously passed House Bill 1859 which sets a goal of volunteer groups monitoring 3,000 stream miles in Virginia. Copies of both pieces of legislation are in Appendix 3 of the manual.

ACB, DCR, DEQ, and VA SOS implement this program as a cooperative effort through a formal Letter of Agreement (LOA) signed on April 9, 2002 (Appendix 2). This agreement was renewed in 2006 and again in 2015 with the inclusion of the Virginia Water Monitoring Council (VWMC), and the Virginia Citizens for Water Quality (VCWQ). The LOA outlines the commitment of the partners to develop a comprehensive volunteer monitoring program and the indented uses of water quality data collected by volunteers. A copy of this LOA is provided in Appendix 2.

Letter of Agreement Signing Ceremony on October 20, 2006. Pictured are (left to right): Katie Register, Clean Virginia Waterways; Robbie Savage, Founder, World Water Monitoring Day; Leslie Middleton, Director, Alliance for the Chesapeake Bay; Chuck Frederickson, James River Association; Wayne Kirkpatrick, Chairman, Virginia Citizens for Water Quality; David Paylor, Director, DEQ; David Brancroft, President, Alliance for the Chesapeake Bay; Stacey Brown, Coordinator, VA SO; Nicole Sandburg, DCR

The overall goals of the Virginia Volunteer Water Quality Monitoring Program include:

- Supporting volunteer monitoring efforts statewide: ACB, DCR, DEQ, and VA SOS provide a number of services to volunteer monitoring groups, including coordination with DEQ monitoring efforts, technical assistance, assistance in locating funding, and training workshops.
- Promoting appropriate quality assurance and quality control: ACB, DCR, DEQ and VA SOS encourage use of appropriate protocols.
- Promoting the use of volunteer water quality data in Virginia: volunteer monitoring data is promoted as described in the LOA and is actively sought for inclusion in the Water Quality Assessment Report prepared by DEQ under section 305(b) of the federal Clean Water Act for the U.S. Environmental Protection Agency (EPA) and the Virginia Water

Quality Monitoring, Information and Restoration Act. This report assesses water quality data based on the ability of the public to safely enjoy the designated uses of the Commonwealth's waters as described in Virginia's water quality standards. Water quality data from a variety of sources are used for the assessments, including data collected by DEQ, other federal, state and local agencies, and volunteer monitoring organizations using DEQ-approved methods. For more information see https://www.deq.virginia.gov/our-programs/water/water-quality/monitoring/citizen-monitoring

- Promoting partnership and collaboration among volunteer water quality monitoring efforts.

In 2002, the Virginia General Assembly passed legislation establishing the Virginia Citizen Water Quality Monitoring Program in the *Code of Virginia* (Appendix 3). To implement this legislation, the program was modified. Given the substantial costs of laboratory analysis, volunteer monitoring organizations that receive state funds to support these analytical costs must meet additional requirements to ensure that the data collected will be useful to DEQ. These programs are required to: (1) conduct the sample analysis at a laboratory with DEQ-approved standard operating procedures and quality assurance/quality control procedures; (2) not collect water samples during spill events or in areas where the data are not useful for water quality assessments, such as in mixing zones near discharge pipes and locations intensively monitored by DEQ; (3) collect water samples that are representative of the stream (usually collected mid-channel just below the water surface) in safe locations on public property or where landowner permission was obtained; (4) submit data electronically to DEQ in the format provided in Appendix 4, and (5) must be collected following protocols and sample locations indicated in a DEQ-approved QAPP following the processes outlined in Chapter 2. A QAPP template is provided in Appendix 12.

The Virginia Volunteer Water Quality Monitoring Program supports Virginia Citizens for Water Quality (CWQ). VCWQ is a statewide consortium of volunteer groups, agency representatives, businesses, and individuals interested in preserving and enhancing water resources in Virginia. CWQ conducts an annual volunteer monitoring summit and serves as an information exchange for individuals and organizations involved with volunteer water quality monitoring. The DEQ Water Quality Data Liaison distributes meeting announcements and other information of interest to individuals and organizations on the VCWQ and other mailing lists.

Cooperative partnerships have enhanced relationships between state agencies and volunteer monitoring organizations, which have improved the quality and quantity of volunteer water quality data collected in Virginia. This foundation is expected to grow in the future.

Purpose of the Manual

Volunteer monitors are faced with a wide range of options. If you join an established program in your area, many decisions have already been made for you. If you are starting your own program, you will have many decisions to make. Since no program can measure everything all the time, you must make choices based upon what you are trying to learn about your watershed and your resources. This manual will help you make those choices when designing your program.

This manual provides guidance on the advantages and limitations of the more commonly used methods (protocols) for measuring water quality by volunteer monitoring programs. It does not attempt to include every protocol for each parameter. Most of the methods listed are currently in use by volunteer monitoring organizations throughout Virginia. The intent of this manual is not to limit the protocols used by organizations in Virginia, but to make the selection of protocols easier for newcomers to volunteer monitoring or for those expanding their volunteer monitoring programs.

In addition to this manual, there are many other resources on water quality monitoring (Appendix 5). This manual is specific to Virginia and is intended for use with other resources. Assistance in planning your program is available through the Virginia Volunteer Water Quality Monitoring Program. If you are interested in DEQ using your data, you are encouraged to seek assistance from the DEQ Water Quality Data Liaison. DEQ is most interested in data providing information regarding conditions for which Virginia has water quality standards. Water quality standards describe water quality requirements necessary to meet and maintain uses such as swimming and other water-based recreation, public water supply, fish consumption, and the growth of aquatic life. To learn more about how water quality data is assessed for the Water Quality Assessment Report, please see the most current version of the Water Quality Assessment Guidance Manual.

Organization of the Manual

This manual contains sections with chapters grouped by subject area. Section 1 contains Chapters 1-3 that describes planning your program before you begin monitoring and provides basic guidelines for every volunteer monitoring program. Section 2 contains chapters related to individual chemical monitoring parameters. Section 3 addresses specific biological measurements that volunteer monitoring programs may want to measure. Section 4 contains chapters related to physical measurements. The appendices contain additional useful background information and forms.

Each chapter devoted to a specific parameter (Chapters 4-15) contains a table describing methods for sampling that parameter (equipment suppliers for equipment can be found in Appendix 6). These tables do not include all available methods, but are meant to serve as references to methods used in Virginia. The tables list organizations using these methods (the contact information for these organizations can be found in Appendix 1) along with the monitoring level for each method. The level is based upon the appropriate uses for data collected using a particular method and the required quality assurance/quality control measures that are undertaken by the monitoring organization (Appendix 7 describes these monitoring levels). As more information becomes available on the methods, these levels are subject to change.

Section 1: Planning Before You Begin

Chapter 1

Planning Your Monitoring Program

Planning Your Monitoring Program

> You can purchase a test kit and monitor water quality in your backyard for your own information. If you want your data to be useful to others, however, careful planning is important.

Careful planning of your water quality monitoring program prior to recruiting volunteers and purchasing equipment is important because it can save considerable time and money. The Virginia Volunteer Water Quality Monitoring Program provides technical assistance and training services to volunteer monitoring organizations. When planning your program, you may want to consider creating a committee of others interested in your program, such as data users, local college faculty, potential volunteers, local government staff, etc.

> Joining an existing water quality monitoring program or working cooperatively with an established program is the easiest route for collecting water quality information as many of the decisions discussed in this chapter have already been made.

Appendix 8 contains worksheets that will be helpful in developing your monitoring program. Completion of the worksheets will help you focus your efforts and assist you in developing a program that collects useful data to meet the goals of your program. Appendix 9 provides additional technical information about planning a water quality monitoring program.

Your monitoring plan may change as your program evolves. For that reason, it is important to periodically update your monitoring plan. For example, program coordinators might find that a method is not producing high enough data quality, data collection is too labor-intensive or expensive, or additional parameters need to be monitored.

Step 1: What waterbody (ies) do you want to monitor and what is known about your watershed?

> **Who is Monitoring in Your Watershed?**
>
> - Virginia Department of Environmental Quality Environmental Data Mapper https://apps.deq.virginia.gov/EDM/
> - Virginia Water Monitoring Council https://vwmc.vwrrc.vt.edu/

The first step is to determine what waterbody (ies) you want to monitor and if any monitoring data has been collected there previously. The Virginia Water Monitoring Council (VWMC) is comprised of organizations and agencies involved with water quality monitoring. Since the mission of the VWMC is to promote and facilitate coordination of water monitoring programs throughout Virginia, the VWMC has developed an online database that allows users to determine whether water quality data is or has been collected in a specific watershed. While this database is the most comprehensive source of water quality monitoring information, it may not include every source of data about your watershed. The Virginia Department of Environmental Quality's (DEQ) online water quality monitoring database allows you to view water quality monitoring data (both current and historical) collected by the agency. Local governments may also have data or other documents that describe local water quality issues.

Collecting information on the issues affecting your watershed is important in planning an effective monitoring program. Knowing the issues and what is already being monitored may help you to decide what to monitor and keep you from duplicating efforts. For example, a local college may be monitoring the same sites that you were planning to monitor. It is not practical for both entities to spend money and time collecting the same information at the same sites.

Step 2: Why are you monitoring?

Once you have determined what is known about your watershed, you should determine the overall goals for your monitoring program. This is the most important step in planning your program because other questions about the monitoring program (Steps 3-7) depend upon this initial step.

After you have researched the issues of the watershed, you should identify specific questions you want to answer and the information needed to address the issues. Can you collect volunteer data that can help fill in any data gaps?

Establishing Goals for Monitoring is Critical to Determine:

- How your data can be used and how good it needs to be
- Where you will monitor
- What parameters or conditions you will measure
- What methods you will use to monitor
- When you will monitor

Determining why you want to collect data is important in collecting useful information without wasting time and money. Common goals of volunteer water quality monitoring programs include:

- Educating the local community about water quality issues to encourage protection of water quality
- Establishing baseline data where no other data exists
- Supplementing water quality data collected by agencies
- Documenting water quality changes over time (trends in water quality)
- Identifying potential water quality problems
- Providing a scientific basis for making decisions on watershed management
- Providing information to evaluate the effectiveness of best management practices
- Determining the impact of land use activity (urban, industrial, agricultural, etc.)

Step 3: How will your monitoring data be used and what level of data quality do your data users need?

Understanding how your data potentially will be used is essential to the program development. Partnering with potential data users during the planning process can improve the likelihood they will use your data. Some users, such as state agencies, will have more stringent requirements on the level of data quality needed and will require higher levels of quality assurance and quality control activities (activities used to assure data quality) than other data users. The range of uses of volunteer data is limited only by the imagination (Appendix 7).

Potential Data Users of Volunteer Data

- Environmental organizations
- State environmental agencies
- Local health departments
- Environmental consultants
- Universities/schools
- Local park staff
- Local planning and zoning agencies
- Soil and Water Conservation Districts
- U.S. Geological Survey
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Step 4: Where will you monitor?

Selecting representative sites is an important element in designing your monitoring program. Site locations will depend on the goal of the program. When selecting sites, you should consider the following questions:

- Is there a real need for data at the proposed sites?
- Do the proposed sites duplicate existing monitoring efforts by other organizations or agencies?
- Are the proposed sites in the main flow of the stream and representative of the stream (for smaller streams this is typically mid-channel and just below the water surface)? Representative also means that samples are not collected near a discharge pipe where the discharge mixes with the water in the stream.
- Are the proposed sites safe and easily accessible?
- Are the proposed sites on public property or can you obtain landowner permission?
- Is a proposed site above or below the confluence of two streams? If the site is below the confluence, the watersheds of both streams affect the water quality at the site.
- Can a representative water sample be collected during all tidal stages?

Selecting Sites

To make your program most effective, you may wish to discuss your potential site locations with the DEQ Water Quality Data Liaison, who can provide assistance on site selection. It may be beneficial to discuss potential sites with intended local data users, including your local soil and water conservation district and your local government environmental staff.

Identifying Sites

Once you select the monitoring sites, you must be able to identify each site location. Your data is not useful without the exact monitoring location. Determine latitude and longitude using a GPS unit in the field or pinpointing the site on a U.S. Geological Survey (USGS) 7.5 minute series topographic map (1:24,000 scale).

In addition to latitude and longitude, a brief description of the site location (i.e. north side of Rt. 0 bridge crossing Deer Creek) is useful. A narrative description provides a way for someone to quickly identify the site location without plotting the latitude and longitude.

Assigning Site Numbers

You should develop a systematic approach to assigning site identification numbers. Identifying each site by an assigned unique number provides greater consistency than using a site name, which may be modified easily by newcomers to your program.

Sampling Depth

In addition to geographic location, you need to determine the depth you plan to sample in the water column. For most volunteer programs, just below the surface will be sufficient for most parameters. DEQ surface water samples are typically 0.3 meters (1 foot). If you are planning to monitor a lake or deep estuarine waters, this is a critical question, particularly for dissolved oxygen monitoring. Dissolved oxygen in lakes and the Chesapeake Bay can vary greatly with depth (this vertical stratification is discussed further in Chapter 4). Sampling at greater depths (greater than 1 foot or 0.3 meters) may require special water sampling devices (see Chapter 4).

Step 5: What parameters or conditions will you measure?

Our waterways are complicated systems. Determining what to monitor will depend on the goals of your program, the intended use of the data, the needs of the data users, and the resources of your volunteer monitoring program. If, for example, your goal is to provide baseline data that will be useful to state water quality agencies, you should consult those agencies to determine which parameters have state water quality standards and which they consider of greatest value. DEQ is most concerned with parameters for which Virginia has water quality standards (please refer to the Introduction of this manual). Costs of test kits or meters, available laboratory facilities, assistance from state or university advisors and/or laboratories, and the abilities and desires of volunteers will also have an impact on the choice of parameters to be monitored. Table 1-1 lists some water quality parameters that are commonly monitored by volunteer monitoring programs in Virginia. More detailed information can be found in Chapters 4-17.

Table 1-1. Common Water Quality Parameters

Parameter	**Virginia Water Quality Standard**	**Importance**
Dissolved Oxygen	Yes	Essential for aquatic organisms.
pH	Yes	Affects chemical and biological processes; organisms can only survive in specific range.
Nitrogen	Standard for nitrate in public drinking water supplies; others to be developed.	Essential for plant growth; necessary for metabolism and growth of aquatic organisms. Excess nitrogen can be harmful to aquatic life by increasing growth of algae and aquatic vegetation and decreasing oxygen availability.
Phosphorus	Screening value for total phosphorus; standard to be developed.	Essential for plant growth; necessary for metabolism and growth of aquatic organisms. Excess phosphorus can be harmful to aquatic life by increasing growth of algae and aquatic vegetation and decreasing oxygen availability.
Benthic Macroinvertebrates	Narrative standard based on type and abundance of observed organisms	Good indicators of water quality.
Bacteria	Yes	Indicator of fecal contamination; can cause illness.
Chlorophyll *a*	Screening value for Chlorophyll *a*	Estimates the abundance of algae.
Submerged Aquatic Vegetation (SAV)	No	Food and habitat for aquatic organisms.
Temperature	Yes	Affects chemical and biological processes.
Turbidity/Transparency or Total Solids	No	Indicators of runoff effects; affect sunlight reaching SAV.
Salinity	No	Affect the distribution of plants and animals in estuarine environments.
Conductivity	No	Useful measure of general water quality. Significant changes may indicate a discharge or another source of pollution.

Step 6: What methods will you use to monitor?

For most parameters, there are a variety of monitoring methods available with varying complexity and levels of data quality. You should select methods based upon cost and the quality of data necessary to meet the goals of the program and the intended data use. For example, data intended for water quality assessment use by DEQ must be collected using DEQ-approved methods and requires a higher level of data quality than data used to screen for potential problems (Appendix 7). You can, for many parameters, begin monitoring using less sophisticated equipment and upgrade your methods as resources allow. Partnering with colleges and universities is beneficial since they generally have technical knowledge and often have equipment available.

Meters may be used to measure many water quality parameters such as temperature, dissolved oxygen, pH, and conductivity/salinity. Although meters are quick to use in the field, they are more expensive than test kits and require calibration and maintenance to ensure accuracy. Sophisticated equipment will not provide better data if it is not properly used. Field test kits for the same parameters may be less expensive but may be unacceptable to some data users. Please refer to Chapters 4-17 for discussions of appropriate methods for commonly measured parameters.

When choosing a method, you should consider the method detection limit (the minimum concentration of a parameter that can be determined with 99% confidence that the true concentration is greater than zero) and the range. When selecting a test kit or other method, it is helpful to first determine the average value for the parameter in your stream so that you can select an appropriate method. For example, a test kit whose detection limit is 0.2 mg/L for total phosphorus will not be very useful if the typical total phosphorus concentrations are 0.04 mg/L. The importance of the method detection limit depends heavily on the intended use of the data. While results from the total phosphorus kit mentioned above might not have much use from an agency perspective, it can detect when total phosphorus levels are elevated.

Step 7: When will you monitor?

In deciding when to monitor, you should consider several time scales: time of year, monitoring frequency, time of day, and sample holding time.

Time of Year

Aquatic ecosystems change seasonally and the data usually reflects these changes. During wet weather, more runoff carrying bacteria, nutrients, and pollutants enter waterways. Therefore, higher levels of these parameters generally are found during rainy seasons. Seasonal temperature changes greatly influence dissolved oxygen levels as colder water can hold more dissolved oxygen than warmer water. Due to seasonal variability, water quality monitoring events should be distributed throughout the year.

Monitoring Frequency

Ultimately, sampling frequency depends on the goals of the program, financial resources, and volunteer resources. For the purpose of DEQ's water quality assessment, sampling events should be conducted in such a manner that each sampling event represents an "independent" measure of water quality. Monitoring events are not considered independent if they are not sufficiently separated in time. Although the interval between sampling events that is necessary to insure independence of measurements is parameter-specific, a longer interval ensures the independence of the observations. Water quality monitoring events should be distributed evenly throughout the year on a certain interval (such as weekly, biweekly, monthly, bimonthly, or quarterly). When determining the sampling interval, you should keep in mind that one or two sampling events are generally not very useful in determining the water quality at a station. Larger data sets can be used to discriminate among rare, sporadic, frequently recurring, or continuous water quality issues.

Sampling few times during the year is sufficient for benthic macroinvertebrates since they indicate conditions over a long period of time. Usually sampling once or twice a year is sufficient to determine the health of the benthic community. In addition, by sampling just before and/or after a major disturbance in a stream can help gauge the impact to the benthic community. Sampling of bacteria in a popular swimming area may be performed more frequently during the summer if the goal of the program is to determine if the water quality is safe for swimming.

Time of Day

Since some parameters (dissolved oxygen, pH, temperature) fluctuate depending upon the time of day they are measured, it may be helpful to select a consistent sampling time for a site. Volunteers cannot be expected to always sample at the same time of day, but some consistency can help reduce the daily variability in the data. More data collected at a site over time will better identify some of this daily variability.

Temperature, dissolved oxygen, and pH can fluctuate naturally as the sun rises and aquatic plants undergo photosynthesis. Dissolved oxygen levels, for example, are generally lowest at sunrise and highest in the afternoon as aquatic plants consume oxygen during the night and release oxygen as a byproduct of photosynthesis during the day.

If you are monitoring tidal waters, tidal action affects the representative natural conditions of the water body. Most volunteer programs do not monitor based upon tidal stage because it is not reasonable for volunteers to adapt to the continuous time changes of tidal stages. If possible, it is preferable to collect samples on the ebb or slack tide.

Holding Time of Samples

The maximum time that samples can be held before testing (holding time) should also be considered. Delivering samples to a lab on a Friday afternoon is not reasonable if the lab is closed on weekends and the samples have a short holding time. When applicable, holding times for various water quality parameters are provided in each method chapter.

Step 8: How will you manage your data and present your monitoring results?

You should have a clear plan for handling the data collected. Someone must check field and lab data sheets while screening for outliers (results that differ significantly from past or expected results), enter the data into an electronic format, and check for data entry errors. Where will the data sheets be stored? You may need to develop or adapt an electronic database or spreadsheet to store and manipulate the data so that it will be more readily available for data users. You may submit your data to DEQ for agency use, either by sending directly to the agency, or by submitting them through the Chesapeake Monitoring Cooperative. The instructions how to submit data to DEQ are listed in Appendix 4.

In creating a database, having a plan for analyzing and communicating the data to the public, to data users, and to the volunteers is useful. Raw data may have limited meaning to the public without some summarization and interpretation of the results. The volunteers will more than likely want to know "what the data means."

Step 9: How will the program ensure that data are credible?

Making decisions and answering the questions addressed in Steps 1-8 are the first steps to ensuring that the data collected by your program is credible. The level of data quality needed is dependent upon the goals of your program and the intended uses of the data. If the goal of your program is education, then data credibility may not be a high priority. If your program is designed to collect data that can be used in making management decisions or to assess water quality, data credibility is very important.

Potential data users may be skeptical of volunteer data and have doubts about the ability of the program to collect accurate data. A written plan, known as a Quality Assurance Project Plan (QAPP), is the key to overcoming this skepticism. The QAPP must prove to skeptics that the data collected is:

1) Consistent over time, within projects and group members.
2) Collected and analyzed using standardized and acceptable techniques.
3) Comparable to other data collected for assessment by using the same methods.

Without such documentation, the data may not be used with confidence. The QAPP is also important for educating future volunteers and data users about every aspect of the program. Please see Chapter 2 for a detailed description of developing a QAPP.

Step 10: How will the program be supported?

It is important to determine how your monitoring program will be supported financially and logistically. Monitoring equipment and data management, among other facets of a monitoring program, usually cost money. Thus, it is useful to explore your options for covering the costs of equipment, data management, and coordination – whether it is from donated money and volunteer time, grants, or fees.

Chapter 2

Developing a Quality Assurance Project Plan

What is a Quality Assurance Project Plan (QAPP)?

The quality assurance project plan is a written document that describes all aspects of your monitoring project and includes the detailed quality assurance and quality control activities that will be used to ensure the data collected and analyzed meets the project requirements. The QAPP describes the organization of the program and should include the standard operating procedures (SOPs) for sample collection in the field and lab analysis. The monitoring plan you developed in Chapter 1 is the foundation for the QAPP. If you have carefully completed the worksheets in Appendix 8, you already have most of the information needed for your QAPP.

Quality assurance (QA) and quality control (QC) are those activities you undertake to demonstrate the accuracy (how close to the true result you are) and precision (how reproducible the results are) of your monitoring. QA generally refers to a broad plan for maintaining quality in all aspects of a program, including quality control measures, sample collection, sample analysis, data management, documentation, etc. QC consists of the steps, including measurements, calibrations, etc., you will take to assure the quality of specific sampling and analytical procedures. The Virginia Water Monitoring Council has developed a handout explaining basic QA/QC concepts (Appendix 11).

Why is a Quality Assurance Project Plan Important?

If the goal of your volunteer monitoring program is to collect data that can be used for management decisions, your data users may require a QAPP. The QAPP provides the documentation that assures the quality of the data to your data users. The burden of proving the data quality is on your organization.

Although the development of a QAPP may appear to be a difficult process, it will be well worth the effort to see your data used in a meaningful way. Seeing the program's data used may provide additional motivation for retaining and recruiting volunteers who want their efforts to be worthwhile. A written QAPP is also important for educating future volunteers, project managers, and data users about the program and how the program is organized.

For the Department of Environmental Quality (DEQ) to use volunteer data for 305 (b) water quality assessments, the data must be collected under a DEQ-approved QAPP using approved analytical procedures. The U. S. Environmental Protection Agency (EPA) requires that any monitoring program sponsored by EPA through grants, contracts, or other formal agreements carry out a quality assurance/quality control program and develop a quality assurance project plan.

How Do You Develop a Quality Assurance Project Plan?

Developing a QAPP is a dynamic process that should involve consulting the data users for their requirements. Seeking advice from other organizations using similar methods also can be helpful. The DEQ Water Quality Data Liaison is available to provide assistance with QAPP development. Any monitoring project seeking DEQ approval of a QAPP should submit the plan to the DEQ Water Quality Data Liaison.

DEQ recommends that all volunteer water quality monitoring QAPPs follow the format outlined in the "Handbook for citizen science quality assurance and documentation" developed by EPA. This guide is available at https://www.epa.gov/citizen-science/quality-assurance-handbook-and-guidance-documents-citizen-science-projects.

Chapter 3

Before You Begin

Preparation for Monitoring

Volunteers should check their equipment, test kits, and reagents (chemicals) to ensure that they are in proper condition prior to sampling. Data sheets and labels for lab samples can be prepared at home prior to monitoring to save time and minimize errors in the field.

Reused sample containers and glassware should be cleaned and rinsed after each sampling event. All reagents should be stored tightly capped away from heat, sunlight, and extreme cold. All reagents should be stored out of the reach of children and pets.

Signs of Degraded Reagents

- Color has changed
- Reagent has floating particles or solids forming
- Crust has formed around lid
- Past expiration date (Appendix 13 gives instructions on determining the expiration date of some commonly used test kit reagents)

Safety

Safety is the most important element of any volunteer monitoring program**. No data is more important than safety! Safety always comes first in data collection.** If a site appears severely polluted or there is an urgent problem (such as fish kill, leaking drum, or oil spill), volunteers should **not** sample and immediately report the pollution event to the Virginia Department of Environmental Quality (DEQ) for investigation.

Training for all volunteers should include a safety component. All volunteer monitors are encouraged to sample in teams or with partners and to inform someone where they are going and when they plan to return. All monitoring stations should be safe for volunteers to access and perform their sampling. All volunteers should be instructed to take additional safety precautions in high water conditions. Additional safety rules for volunteer monitors can be found in the box on the next page.

Reporting an Urgent Pollution Event

- During normal work hours, call the appropriate DEQ Regional Office. A map of DEQ Regional Offices and phone numbers to report pollution incidents can be found at https://www.deq.virginia.gov/get-involved/about-us/contact-us
- On nights, holidays, and weekends call the Department of Emergency Management's (DEM) 24-hour reporting number.
  In-state calls: 800-468-8892.
  Out-of-state calls: 804-674-2400
- Assemble the following information about the pollution event (if known): location of the pollution event (so that staff can investigate), when the pollution event was observed (report as soon as possible), what is the observed problem, and who is causing the problem.
- To report a pollution incident online, visit https://portal.deq.virginia.gov/prep/createReport

Safety Rules for Volunteer Monitors

- Watch weather reports prior to going into the field.
- Carry first aid kit and water.
- Dress properly for the weather. Don't forget to wear blaze orange during hunting season!
- Sample in teams or with partners.
- Inform someone where you are going and when you plan to return.
- All monitoring stations should be safe for volunteers to access and perform their sampling.
- Inform sampling team members of relevant health information in case of emergency.
- If you do not feel comfortable with the monitoring site or your surroundings, leave the site.
- If the site appears severely polluted, report immediately.
- If you drive to site, park in a safe location.
- Do not cross private property without permission.
- Watch out for poisonous plants and wildlife. Dress appropriately for protection against ticks.
- Be careful on bridges, stream banks, boats, docks, and when wading. If you monitor from a boat, abide by all boating regulations (see the Virginia Department of Wildlife Resources website at https://dwr.virginia.gov/boating/).
- Do not wade in fast moving or high water.
- Use antibacterial soap after monitoring and do not eat until you have washed your hands.
- Avoid contact between chemicals and skin, eyes, or mouth. Wearing gloves is recommended.
- Properly store all chemicals away from children and pets, while avoiding extreme temperature fluctuations and direct sunlight.
- Properly clean up and dispose of any spills of chemicals.
- Properly dispose of all wastes from test kits.

Collecting Water Samples

Sections 2-4 of this manual discuss different types of sampling methods for various parameters in more detail. Below are general rules that you can apply for collecting water samples.

When collecting water samples, it is important to adhere to the following general guidelines:

- **Samples should be collected in the main flow representative of the stream you are monitoring** (for small streams, this is usually mid-channel) just below the water surface, about 0.3 meters (1 foot) deep.

- **Samples should <u>NOT</u> be collected in stagnant water or next to the stream bank.** Level III data collected next to a bank or in stagnant water will be downgraded to level II.

- **Sample collection is not recommended in the immediate mixing zone of a discharge.** Only samples representative of the stream (once effluent is well mixed with the stream flow) can be used by DEQ for water quality assessments.

- **If you collect samples by wading, always approach the sampling location from downstream,** disturbing bottom sediment as little as possible. **Always face upstream to collect samples or take measurements.**

- If samples are collected from a bridge, you should **collect from the upstream side of the bridge** if there are no electrical cables or other obstructions present. If cables are present, use the downstream side of the bridge.

- **Samples being transported to a lab should be properly labeled.** It is recommended that lab sample labels include the name of the collector, site ID, date, and time in case the lab has any questions about the sample.

- **Samples being transported should be properly preserved** (usually in a cooler with wet ice – blue ice packs are not recommended).

Using a Meter

- When using a meter to measure stream conditions, it is recommended that you place the meter directly in the stream or lower it from a bridge while facing upstream (please see the box on page 3-4 for more information). An alternate method is to collect the water sample in a bucket and use the meter to immediately take measurements in the bucket.
- Always be careful that the probes are protected from impact and are placed in an area representative of the stream.
- Meter probes should be lowered to about 0.3 meters (1 foot) below the water surface.
- While the probe is submerged, it is recommended to slowly move the probe from side to side if the water is slow flowing and does not have an automatic stirrer to help move the water.

Samples Collected Directly from Stream with Sample Containers

- If possible, collecting water samples directly from the stream is preferable to using a bucket as it reduces the possibility of contamination and carryover from previous sampling, especially for bacterial sampling. If wading is not possible for collecting bacterial samples, consider using an extension pole for the sample bottle.
- When wading, approach sampling location from downstream.
- While facing upstream, thoroughly rinse sample bottles with stream water (do **not** rinse sample containers used for bacterial samples). If rinsing containers with sample water, discard rinse water downstream of sample site or on the stream bank.
- Collect samples while facing upstream and avoid disturbing sediment.

Figure 3-1. Collecting a water sample *(from Volunteer Estuary Monitoring: A Methods Manual, Second Edition).*

Samples Collected Directly from Stream with a Bucket

- From the upstream side of the bridge, gently toss or lower bucket into an area representative of the stream (please see box on page 3-4 for more information on collecting samples from a bridge or by wading). If you are collecting sample water for dissolved oxygen analysis, be especially gentle. Splashing the water in your bucket can aerate your sample and alter your results.
- Rinse the bucket and reusable containers thoroughly with sample water before collecting sample water. Do **not** rinse sterile bacteria sampling containers if you are collecting water for bacterial sampling. Discard rinse water downstream of sample site or on the stream bank.

Section 2: Chemical Monitoring

Chapter 4: Dissolved Oxygen
Chapter 5: pH
Chapter 6: Nutrients

Chapter 4

Dissolved Oxygen

What is Dissolved Oxygen?

Oxygen found in aquatic systems is dissolved in water. This dissolved oxygen (DO) enters the systems from the atmosphere and from photosynthesis of aquatic plants (Figure 4-1). Currents and waves help introduce oxygen into the aquatic system due to more water being in contact with the atmosphere and better mixing of surface and deeper waters.

Why Monitor Oxygen?

Dissolved oxygen is one of the most important measures of water quality. An aquatic system with low levels of oxygen cannot support healthy populations of animal or plant life. If more oxygen is being used than is being introduced, organisms may weaken, move away, or die. Aquatic animals and plants use oxygen for respiration. Oxygen is also removed from the aquatic system through decomposition of organic material. Excessive nutrient levels from runoff, failing septic systems, or wastewater treatment plants can contribute to low dissolved oxygen levels by causing abundant growths of phytoplankton (microscopic plants and algae) called blooms. Living phytoplankton may deplete oxygen levels during the night and as the phytoplankton die, decomposition of the organic material by bacteria consumes oxygen.

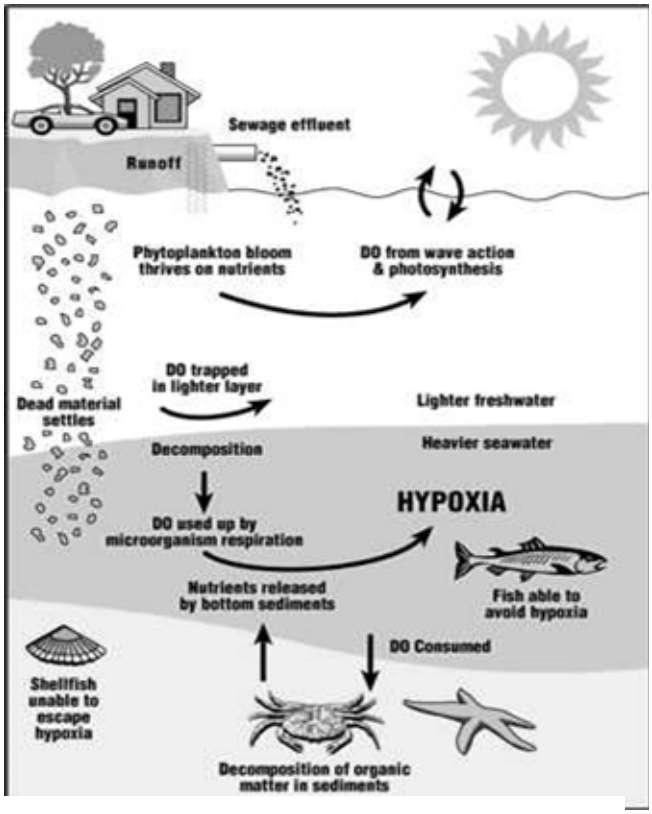


Figure 4-1. Processes affecting dissolved oxygen levels *(from Volunteer Estuary Monitoring: A Methods Manual, Second Edition).*

What Do Your Dissolved Oxygen Results Mean?

Dissolved oxygen (DO) is measured in mg/L (which is equivalent to parts per million or ppm). Aquatic organisms need a certain amount of dissolved oxygen in order to survive. The effects of low dissolved oxygen concentrations on aquatic organisms can be found in Table 4-1. Table 4-2 summarizes the water quality standards for dissolved oxygen in Virginia.

Table 4-1. Effects of Dissolved Oxygen on Aquatic Life

Levels of Dissolved Oxygen			
> 5 mg/L	**Between 3 – 5 mg/L**	**<3 mg/L – Hypoxia Occurs (low dissolved oxygen levels)**	**<0.5 mg/L - Anoxia Occurs (lack of dissolved oxygen)**
Level needed to support most aquatic life.	Aquatic organisms may become stressed.	Mobile organisms will move to areas of higher dissolved oxygen and immobile species may die.	Waters cannot support most aquatic life.

Table 4-2. Virginia Water Quality Standards for Dissolved Oxygen

	Most Waters	**Stockable Trout Waters**	**Natural Trout Waters**
Concentration of Dissolved Oxygen	Minimum 4 mg/L	Minimum 5 mg/L	Minimum 6 mg/L

Dissolved oxygen concentrations are affected by a number of variables such as time of day, depth, temperature, and salinity. Typically, DO concentrations of surface samples are highest around mid-day due to photosynthetic activity of aquatic plants. During the night, DO concentrations decline as DO is consumed through respiration while photosynthesis is halted due to the lack of sunlight. Therefore, DO levels are typically lowest in the early morning. Salt water cannot hold as much DO as fresh water (Figure 4-1). Lower DO concentrations are expected during the summer, since warm water cannot hold as much DO as cold water.

DO levels in lakes and estuaries can vary greatly with depth. During the summer months, vertical stratification (where warmer water is above colder water), can keep dissolved oxygen from reaching deeper waters. The deeper waters may maintain a low DO level until mixing occurs during storms or change of seasons.

The potential DO level, or DO saturation, is the maximum dissolved oxygen level possible under factors, such as temperature and salinity, which affect DO. Appendix 14 summarizes DO saturation levels at varying altitudes and water temperatures. Percent saturation is the amount of oxygen in the water relative to the potential DO level. Percent saturation can be determined as follows:

$$\% \text{ DO Saturation} = \frac{\text{Measured DO (mg/L)}}{\text{Saturated DO (mg/L) (from table 1 in Appendix 14)}} \times 100$$

Sample collection and test methods

Chapter 1 outlined a number of factors that every volunteer water quality monitoring program should consider. In addition to those summarized in Chapter 1, further considerations specific to monitoring for dissolved oxygen are discussed below.

When to Sample

Since DO fluctuates seasonally, it is best to sample DO throughout the year to obtain a more complete picture of water quality. If this is not possible, then sampling early spring through late fall may be preferred since critical DO levels are most common during warmer periods of the year. Since dissolved oxygen may fluctuate throughout the day, you may wish to sample about the same time of day so that your data does not show these fluctuations. This may be of particular interest if you are monitoring estuarine or lake waters and plan to track trends in DO levels.

Where to Sample

As described earlier, vertical stratification can affect DO levels at different depths. Since dissolved oxygen levels vary depending upon the depth, especially in the warmer months, volunteer monitoring programs may decide to measure DO at varying depths. This may be of particular interest if you are planning to monitor lakes or estuarine waters. Several water samplers designed to collect samples at different depths are shown in Figure 4-2. Meters attached to long cables can be used to collect profile data directly.

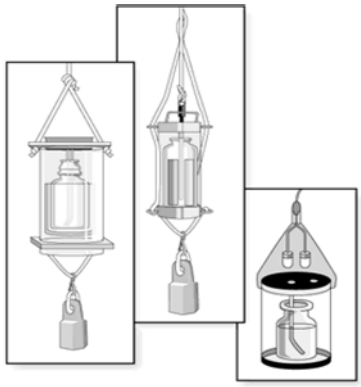


Figure 4-2. Dissolved oxygen samplers *(from Volunteer Estuary Monitoring: A Methods Manual, Second Edition).*

Choosing a Method

Dissolved oxygen can be easily and accurately measured using field test kits or meters. If using a meter, DO must be measured in the field. Some field test kits also require DO to be measured in the field, while others that are based on the Winkler titration method allow you to fix the water sample immediately upon collection and complete the analysis in a more desirable location within a few hours. The fixed samples must be stored in the dark without extreme temperature fluctuations.

Test Kits

Test kits may be more cost-effective than meters, but they do require replacement reagents once reagents expire or are used. Reagents also require proper storage, safety precautions, and proper disposal of waste. Monitors must follow protocols closely to ensure accurate results.

Titrators with detection limits greater than 0.2 mg/L or those not based upon a Winkler method have limited uses, such as for educational purposes or to screen for potential problems. Winkler method titrators that measure DO in increments of 0.2 mg/L or less are acceptable for Department of Environmental Quality (DEQ) water quality assessments if the Quality Assurance Project Plan (QAPP) is approved by DEQ.

Volunteer measuring dissolved oxygen using a test kit *(photo courtesy of Alliance for the Chesapeake Bay).*

Recommended quality assurance/quality control (QA/QC) measures include collecting and testing two water samples simultaneously to verify that the sampling is being done correctly. The difference between the two samples should be no more than $\pm$ 0.6 mg/L. Because titrants are low concentration solutions that can lose strength over time and need to be replaced before their expiration dates (see Appendix 13 for list of commonly used test kit reagents). To ensure accuracy, it is recommended to verify titrants by checking against a standard before going out to the field to sample.

Located at the end of this chapter are instructions developed by the Alliance for the Chesapeake Bay when using the modified Winkler titration method.

Electronic Meters

While meters are more expensive than test kits, they offer the benefits of providing accurate results, and may allow the measurement of several parameters with one instrument. Data collected with meters are acceptable for DEQ water quality assessments if the protocols and QAPP are approved by DEQ.

A meter must be calibrated at the beginning of each sampling day. The calibration results should be acceptable when compared to the chart provided in Appendix 14. If the calibrated value is not within $\pm$ 0.2 mg/L of the chart, the meter should not be used and maintenance is required.

Additionally, the calibration should be confirmed at the end of the sampling day (this is referred to as a "post check") to determine if the meter has drifted during the sampling day. The post check follows the methods of calibration without pressing the calibration button. The obtained meter value should be compared to the chart provided in Appendix 14. The meter reading should be within $\pm$ 0.5 mg/L of the table value. If the difference is not within this range, the data collected with the meter should be flagged. All calibration, post check, and QA/QC data should be recorded and kept on file.

Located at the end of this chapter are instructions and a sample calibration log sheet developed by DEQ for using dissolved oxygen probes.

Summary of Dissolved Oxygen Monitoring Methods

Method (Vendor and Catalogue #)	**Monitoring Level (see Appendix 7)**
Titration Test Kit	I, II, or III
Meters (a multi-probe meter is more cost-effective than a single probe meter)	I, II, or III

Dissolved Oxygen: Modified Winkler Titration Test Kit- *Protocols provided by the Alliance for the Chesapeake Bay*

Equipment: LaMotte Dissolved Oxygen Test Kit 5860

Sodium Thiosulfate Check: (For Level III Quality Assurance)

Prior to each sampling event (either the night before or the day of), you must run a test to make sure your Sodium Thiosulfate is still fresh and functional. Sodium Thiosulfate is fairly unstable and can degrade very suddenly, making it necessary to check it before each DO sampling.

1. Rinse the titrating tube (small glass vial with plastic lid with hole in it) with a small amount of 10 mg/L Dissolved Oxygen Standard Solution. (Solution is available from HACH at www.HACH.com: Part number 40149)

2. Pour rinse into waste container.

3. Pour 20 ml of the Dissolved Oxygen Standard Solution into the rinsed titrating tube.

4. Add 8 drops of Sulfuric Acid (hold the bottle vertical to ensure equal drop size) to the 20 ml of solution and mix by swirling. Then place plastic cap (with hole in it) onto titrating tube.

5. Fill titrating syringe to the "0" mark with Sodium Thiosulfate.

6. Titrate using the Sodium Thiosulfate.

7. When solution turns a pale yellow color, but not clear:
    - Remove cap, leaving syringe in cap.
    - Add 8 drops Starch Solution (white bottle). Swirl titration sample gently to mix to a uniform blue color. Recap glass tube and continue titration process.

8. Continue adding Sodium Thiosulfate until solution turns from blue to clear.

9. Read results on syringe - Record your results under the Dissolved Oxygen QA check on your field datasheet.

10. If results are less than 9.4 mg/L or greater than 10.0 mg/L, perform a 2nd test and record in the space on datasheet marked "2nd check".

11. Dispose of solution in titrating tube and syringe by pouring down sink and flushing with additional tap water.

Dissolved Oxygen- Modified Winkler Titration Field Collection

NOTE: Duplicate tests are run simultaneously on each sample to guard against error. If the amount of DO in the second test is more than 0.6 mg/L different than the first test, perform a third test. Record the average of the two closest results.

Since you will be doing two tests at the same time, thoroughly rinse both water sampling bottles with sample water. If using a bucket do not return the rinse water to the bucket.

1. Using the first sample bottle, submerge about 1/2 of the bottle opening allowing the water to gently flow into the bottle. Try to fill the bottle without causing a lot of bubbles. Submerge the filled bottle.

2. Turn the submerged bottle upright and tap the sides of the bottle to dislodge any air bubbles clinging to the inside of the bottle. Cap the bottle while it is still submerged.

3. Retrieve the bottle and turn it upside down to make sure that no air bubbles are trapped inside. If any air bubbles are present, empty the sample bottle on the ground and refill. Fill the second sample bottle. Once two satisfactory samples have been collected, proceed immediately with Steps 4 & 5.

4. Place both sample bottles on a flat surface and uncap. While holding the bottle vertical, add 8 drops of Manganese Sulfate Solution followed by 8 drops of Alkaline Potassium Iodide Solution to each sample bottle. Always add the Manganese Sulfate first. Cap each sample bottle and mix by inverting gently several times. A precipitate will form. Allow the precipitate to settle to the shoulder of the bottle. Mix both bottles again and allow the precipitate to settle to the shoulder again.

5. Add 8 drops of the Sulfuric Acid both sample bottles. Cap the bottles and gently shake to mix, until both the reagent and the precipitate have dissolved. A clear-yellow to brown-orange color will develop. If brown flecks are present, keep mixing the samples until the flecks will not dissolve any further.

NOTE: Following the completion of Step 5, the samples have been "fixed," which means that dissolved oxygen cannot be added to the sample bottles. The titration procedure described in Steps 6-13 may be performed at a later time (but must be performed within 8 hours of sample collection). This means that several samples can be collected and "fixed" in the field and then carried back to a testing station for the remaining steps.

Titration

6. Pour 20 ml of the solution from one of the sample bottles into one of the glass tubes with a hole in its cap. Fill to white line so that the bottom of the meniscus (the curved surface of the liquid in the tube) rests on the top of the white line. The amount is critical so be sure to use the glass dropper to add or remove the sample solution from the tube. Place cap on the tube.

7. Fill syringe (titrator) to the 0 mark with Sodium Thiosulfate solution. Be sure that there are no air bubbles in the syringe. Refer to kit manual for instructions on how to properly fill syringe.

8. To titrate the solution in the tube, insert the syringe into the cap of tube. Slowly add the Sodium Thiosulfate to test tube and gently swirl the glass tube to mix. Continue this process until the yellow-brown solution in the glass tube turns a pale yellow or straw color. Once you reach this point, take the cap off while leaving the syringe in the cap.

9. Add 8 drops of Starch Solution to the glass tube. Swirl the tube gently to mix. The solution should turn from light yellow to dark blue.

10. Recap the glass tube and continue the titration process with the Sodium Thiosulfate remaining in the syringe (adding one drop at a time and swirling as described in Step 8), until the test tube solution turns from blue to clear. This is the endpoint. If the solution turns blue again, ignore it. Do not add any more Sodium Thiosulfate than is necessary to produce this first color change. Be sure to gently swirl the test tube after each drop.

NOTE: When the dissolved oxygen level is above 10 mg/L, the solution in the tube will still be blue when the plunger tip of the titrator reaches 10 units. If it reaches this 10 unit line, do not go beyond that line. Usually, this will only happen when the water temperature is cold. In this case, refill the syringe to the 0 line from the Sodium Thiosulfate bottle and continue adding a drop at a time and swirling until reaching the endpoint.

11. Using the scale on the side of the syringe, read the total number of units of Sodium Thiosulfate used. Each line is 0.2 units. This number equals the number of milligrams per liter (mg/L) of dissolved oxygen in the water sample.

12. Carry out Steps 6-11 on second sample bottle and second glass tube.

13. Record the results of the two tests on the data sheet. If the difference between Test 1 and Test 2 is more than 0.6 mg/L, perform a third test and record the two results which are within 0.6 mg/L.

Calibrating Dissolved Oxygen Probes and Meters- *Provided by the Virginia Department of Environmental Quality*

Equipment: Various models of dissolved oxygen probes and meters

The instructions below are to be used with the DEQ supplied calibration log sheet to calibrate dissolved oxygen (DO) meters. With practice and proper care for the DO probe, users can complete the entire DO probe calibration process within 5-10 minutes.

Please Note- some probes may differ in displaying values. For DO probes, parts per million (ppm), and milligrams per liter (mg/L) are the same value. In addition, barometric pressure may be displayed in millibars (mBar) or in millimeters of mercury (mmHg).

Date- Record the date of calibration. Calibration must be done each day you collect DO samples

Temp C Pre Cal- Temperature of the probe just before you calibrate the probe

Barometric Pressure (BP) mmHg or mBar- Most probes allow the user to adjust the barometric pressure readout of the probe for calibrating DO. The standard unit for barometric pressure is millimeters of mercury (mmHg) or millibars (mBar). You can get local barometric pressure readings from www.wunderground.com or www.noaa.gov. If using weather station data, it is important to adjust the reading by the altitude of the weather station. Appendix 14 explains how to calculate the correct reading.

DO Theoretical Value mg/L- Prior to calibrating your probe, you should determine the theoretical DO value to confirm your probes readout. To determine the theoretical value, please follow the instructions found in Appendix 14.

Probe DO Level After Cal- Record the mg/L reading of the calibrated DO level. If everything is working properly, the probe should display the correct DO level based on the altitude and temperature that you are calibrating at. The theoretical DO value and the probes calibrated readout should be within 0.2 mg/L. If not, try to recalibrate the probe or perform maintenance on the probe based on manufacturer instructions.

After calibration, you may turn off the probe if the manufacturer says so. If not, please keep the probe on at all times while you are taking it out to the field and performing your field samples.

After the sample run is complete, return the probe to the calibration station to perform a quick post check. The post check consists of placing the probe in the DO calibration chamber and letting it equalize. This may take between 2 to 10 minutes depending on the condition of the probe.

Temp C Post Check- After you have placed the probe in the calibration chamber to equalize. If you did the morning calibration indoors, the probe temperature should be roughly close to the

same as the morning calibration. If you are calibrating the probe outside, the temperature may be different from the earlier reading. This should not affect the post check.

Barometric Pressure Post Check- Record the barometric pressure reading of the probe. This may have changed from the morning reading due to weather changes. You can get current local barometric pressure readings from the Internet. Remember to adjust any weather station data based on the instructions found in Appendix 14.

Theoretical DO Level Post Check- As in the morning calibration, use Appendix 14 to determine your theoretical DO level.

DO Level Post Check- Record the reading of the probe (ppm or mg/L). **DO NOT** recalibrate the probe. The purpose of this check is to see if the probe has drifted out of acceptable limits during the day.

Post Check Difference- Difference between the probe reported value and the theoretical DO value. If the probe is functioning properly there should be a difference of less than 0.50 mg/L from the afternoon theoretical DO level and the probe readout. The color scale signifies the following:

> **Red**- Displayed to show if the calibration difference is greater than 0.50 mg/L. The probe needs service and you must flag the data because the probe did not hold onto the calibration.
>
> **Yellow**- Displayed to show a calibration difference of 0.16 to 0.50 mg/L. The calibration of the probe is approaching the limits of accuracy and preventative maintenance may be required. It may be wise to clean the probe or replace the probe membrane when this occurs.
>
> **Green-** Displayed to show if the calibration difference of 0.00 to 0.15 mg/L. The probe is functioning properly and no action is necessary except for general housekeeping according to manufacturer directions.

Initial- Please initial the person calibrating and using the probe for your records. This is good to know in case something happens to the probe while someone else was using it.

Notes- Space provided for any notes or comments regarding the probe.

Dissolved Oxygen Probe Calibration Form

Group Name: **Probe Model:**

0.00 - 0.15: Probe OK	0.16-0.20 at calibration or 0.16-0.50 End of Day: Probe service needed soon	>0.20 at calibration or >0.5 Post Check: Flag data and service probe

Date	Temp C Pre Cal	BP at Calibration	DO Theoretical Value (mg/L)	Probe DO Calibrated Value (mg/L)	Calibrating Difference mg/L	Temp C at End of Day	BP Post Check	Theoretical DO Level Post Check (mg/L)	Probe DO Level Post Check (mg/L)	Post Check Difference mg/L	Initial	Notes
1/1/2004	20.2	761.1	8.65	8.89	**0.15**	21.4	751.4	8.9	8.76	**0.14**	JEB	This is an example
1/2/2004	20.4	720	8.76	8.6	**0.16**	22.1	721.1	7.84	8.3	**0.46**	JEB	This is an example
1/3/2004	20.1	741	8.64	8.94	**0.30**	20.5	742.1	8.15	8.77	**0.62**	JEB	This is an example

Chapter 5

pH

What is pH?

pH is a term used to indicate the acidity or alkalinity of a solution as ranked on a scale from 0 to 14. Acidity increases as the pH decreases. The pH scale measures the concentration of hydrogen (H^+) and hydroxide (OH^-) ions, which make up water ($H^+ + OH^- = H_2O$). When both types of ions are in equal concentration, the pH is 7.0 or neutral. Below 7.0, the water is acidic (there are more hydrogen ions than hydroxide ions). When the pH is above 7.0, the water is alkaline, or basic (there are more hydroxide ions than hydrogen ions).

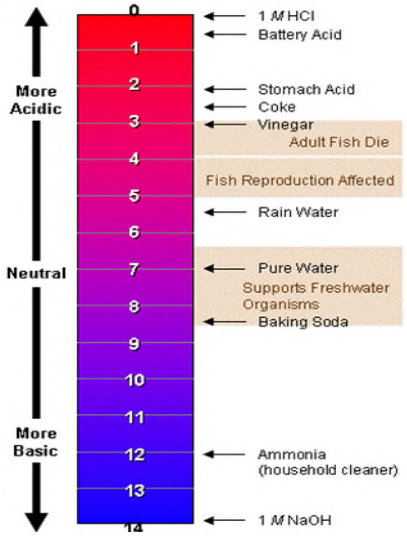


Figure 5-1. pH scale- (image from Virginia Cooperative Extension)

Why monitor pH?

pH affects many chemical and biological processes in the water. For example, different organisms flourish within different ranges of pH. Most aquatic organisms prefer a pH range between 6.5 and 8. A pH value outside this range reduces the diversity in the waterway because it stresses the physiological systems of most organisms and can reduce reproduction. Low pH can also allow toxic elements and compounds to dissolve and become more "available" for uptake by aquatic plants and animals. This can produce conditions that are toxic to aquatic life, particularly to sensitive species like rainbow trout. Changes in acidity can be caused by atmospheric deposition (including acid rain), weathering of surrounding rock, certain wastewater discharges, and the decomposition of plants and animals.

What Do Your pH Results Mean?

The water quality standard in Virginia defines acceptable pH as being between 6 and 9. pH values above or below this range indicate a violation of our state's water quality standards.

Since the pH scale is logarithmic, a drop in the pH by 1.0 unit is equivalent to a 10-fold increase in acidity. For example, a water sample with a pH of 5.0 is 10 times more acidic than one with a pH of 6.0, and a pH of 4.0 is 100 times more acidic than a pH of 6.0. Changes in pH of just one or two units can be very stressful to aquatic organisms.

Sample collection and test methods

Chapter 1 outlined a number of factors that every volunteer water quality monitoring program should consider. In addition to those summarized in Chapter 1, further considerations specific to monitoring for pH are discussed below.

When to Sample

Since pH fluctuates daily and seasonally, it is best to sample pH throughout the year to obtain a more complete picture of water quality. Because pH, like dissolved oxygen, may fluctuate throughout the day due to photosynthesis, you may wish to sample about the same time of day so as not to confuse daily fluctuations with pollution events. pH is increased by photosynthetic activity, which results in daily fluctuations, especially on sunny, warm days. This is of particular interest if you plan to track trends in pH levels.

Choosing a Method

pH is easily measured and must be measured in the field within 30 minutes (immediately is preferable) of collection of the water sample.

Test Kits

Test kits may be more cost-effective than meters, but they require replacement reagents once they expire or are used. Test kits also require proper storage, safety precautions, and proper disposal of waste. Monitors must follow protocols closely to ensure accurate results. pH test kits are cheap, safe and easy to use.

Volunteer measuring pH using a LaMotte test kit *(photo courtesy of Alliance for the Chesapeake Bay)*.

If you plan on using a field test kit with a limited pH range (known as "narrow range" kits), you should first determine the average pH for your stream in order to select the correct range for your test kit. You can determine the average pH of your stream by either testing the stream with a wide range test kit (typically measures pH values from about 3-10) or locating existing pH data.

Since many volunteer monitoring programs in Virginia use the LaMotte pH (liquid) test kits, the Department of Environmental Quality (DEQ) conducted a comparison study between these test kits and a reliable meter. These test kits were found to be useful in making general observations on water quality by DEQ if the Quality Assurance Project Plan (QAPP) is approved by DEQ. However, data from pH test kits are insufficient for DEQ to make water quality assessments because the color determinations may have a degree of subjectivity.

Located at the end of this chapter are procedures developed by the Alliance for the Chesapeake Bay for using LaMotte pH test kits.

Electrometric Meters

While meters are more expensive than test kits, they can provide accurate and reliable results and may allow the measurement of several parameters with one instrument. Data collected with meters are acceptable for use by DEQ for water quality assessments if the protocols and QAPP are approved by DEQ.

A meter must have the ability to calibrate at least 2 well-separated pH values to meet DEQ's QA/QC requirements. A pH meter should be calibrated with at least 2 standard pH buffers (solutions of known pH values) for the range that are close to the expected sample pH values. If the pH value is usually below 7, then calibration should use the standard pH buffers 4.00 and 7.00. If pH value is usually above 7, then calibration should use buffers 7.00 and 10.00. Meters must be calibrated at the beginning of the day before samples are collected.

A post check must be conducted at the end of the day to determine if the meter has drifted during the sampling day. A post check means that you take pH readings for the same buffers you used at the beginning of the sampling day (this is not a calibration). The results for each buffer must be within $\pm$ 0.2 units of the buffer value. If the results are not within this range, the data collected with that meter should be flagged and maintenance or replacement of the probe is required. All calibration, post check and QA/QC data should be recorded and kept on file.

> Located at the end of this chapter are instructions and a sample calibration log sheet developed by DEQ for using pH probes.

Summary of pH Monitoring Methods

Method (Vendor and Catalogue #)	**Monitoring Level (see Appendix 7)**
Wide Range (3.0 – 10.0) Field Test Kit	I or II
Various narrow range field test kits	I or II
pH Tester (Oakton Testr 2) *Must use standard buffers for calibration	I , II, or III
Meters (a multiprobe meter is more cost-effective than a single probe meter) *Must use standard buffers for calibration	I, II, or III

pH Test Kit- *Protocols provided by the Alliance for the Chesapeake Bay*

Equipment: LaMotte pH kits (2109, 2110, 2111, 2112, 2117)

Method:

Look on the front of black box to determine whether you have a wide range pH kit or a narrow range pH kit (i.e. cresol red, phenol red, bromthymol blue, thymol blue).

1. Rinse one sample test tube and cap twice with water from the bucket.

2. Fill the sample test tube to the black line with water from the bucket. The bottom of the meniscus should be even with the line. Use plastic dropper to add or remove water from test tube.

3. For wide range pH kit, add ten drops of the wide range indicator while holding the reagent bottle completely upside down. For narrow range kits, add 8 drops of the indicator while holding the reagent bottle completely upside down.

4. Cap the test tube and mix the sample thoroughly.

5. Slide the tube in the comparator slot, hold it up to the sunlight, and record the pH value from the color in the comparator that most closely matches the sample tube color. When the color observed is between 2 colors on the comparator, the value is reported to the nearest 0.5 unit (for wide range kit) or 0.1 unit for other pH kits.

Calibrating pH Probes and Meters- *Provided by the Virginia Department of Environmental Quality*

Equipment: Various models of pH probes and meters

The pH probe calibration procedure a similar protocol used in calibrating the DO probe. Most meters allow calibrating the pH probe using two different buffers. In most cases the use the 7.00 and 4.00 pH buffer solutions is suitable and reflects the pH found in the majority of Virginia waterways. If you are experiencing pH values above 7.00, calibrate using 7.00 and 10.00 buffer.

Use fresh buffer solution when you calibrate the probe and check the readings at the end of the day. If the probe is capable in doing so, please record the probe readings to the nearest hundredth unit place (Ex. 7.01) when performing the calibration.

Date- Record the date of calibration. Calibration must be done each day you perform samples.

Temp C Pre Cal- Temperature of the probe during calibration.

Pre Cal pH 7- Record the probe reading as you place the probe in the 7.00 buffer solution. Gently swirl the buffer or the probe to obtain an accurate reading.

Cal 7 Buffer- Calibrate the probe, the probe should now read a value close to 7.00 pH units. Most manufacturers of buffers provide a table showing the pH result that probes should display based on temperature. Check against this value displayed on the probe is close to this value.

Pre Cal pH 4 (or 10)- Clean the probe with distilled or deionized water and blot dry and then immerse the probe in the 4.00 (or 10.00) buffer solution, record the stabilized value.

Cal 4 (or 10) Buffer- Calibrate the probe and it should now read a value close to 4 (or 10) pH units. Again, consult the buffer solution table to ensure accuracy.

After calibration, you may turn off the probe if the manufacturer says so. If not, the probe should be kept on at all times while going out into the field and prior to the post check. Follow manufacturer instructions regarding transporting of the probe into the field to prevent damage and drying out of the pH probe.

Temp C Post Check- Record the temperature of the probe at the end of the day when you are performing the calibration check.

pH 7 Post Check- Place the probe into the pH 7 buffer and ensure adequate mixing. Record the value the probe displays when it equalizes. **DO NOT** recalibrate the probe. The purpose of this end of day check is to detect unacceptable probe drift.

pH 4 (or 10) Post Check- Place the probe in the pH 4 (or 10) buffer and ensure adequate mixing. Again, record the value when it equalizes. **DO NOT** recalibrate the probe.

Difference for (7, 4 or 10) Buffer - These two columns calculate the differences based on the following color system:

Red- The pH difference is greater than 0.2 SU. Flag the data and repair/replace the probe.

Yellow- The pH is between 0.15 and 0.2 SU. The probe may need servicing soon.

Green- The pH difference is between 0.00 and 0.15 SU. The probe is functioning properly and no further action is necessary. Follow general housekeeping as outlined by the manufacturer.

Initial- Please initial the person calibrating and using the probe for your records.

Notes- Space provided for any notes or comments regarding the probe.

pH Probe Calibration Form

Group Name:								Probe Model:				
0.15 S.U. Probe OK			0.16-0.20 probe service needed soon					>0.20 S.U. Flag data and service probe				
Date	**Temp C Pre Cal**	**Pre Cal pH 7**	**Cal 7 Buffer**	**Pre Cal pH 4 (or 10)**	**Cal 4 (or 10) Buffer**	**Temp C Post Check**	**pH 7 Post Check**	**pH 4 (or 10) Post Check**	**Difference for 7 Buffer**	**Difference for 4 (or 10) Buffer**	**Initial**	**Notes**
01/01/04	20.20	6.87	7.04	4.05	4.01	21.40	7.20	4.11	**0.16**	**0.1**	JEB	This is an example
01/02/04	19.50	7.00	7.01	4.55	4.00	20.40	7.60	4.21	**0.59**	**0.21**	JEB	This is an example
01/05/04	20.00	7.50	7.04	3.99	4.05	21.10	7.05	4.21	**0.01**	**0.16**	JEB	This is an example

Chapter 6

Nutrients

What Are Nutrients?

Nutrients are necessary for the survival and growth of aquatic plants, which are the base of the food chain for all other aquatic organisms. Plants and algae need a number of nutrients (such as nitrogen, phosphorus, silica, carbon, potassium, calcium, and magnesium) for growth and reproduction. Of these nutrients, the lack of nitrogen and phosphorus limit plant growth in most aquatic system. For the purposes of this manual, we will refer to nitrogen and phosphorus when we speak about *nutrients.* The different forms of nitrogen and phosphorus will be discussed in further detail later in this chapter in the section entitled sample collection and test methods

Why Monitor Nutrients?

Nutrient levels in an aquatic system vary depending upon temperature, rainfall, runoff, biological activity, and the flushing of the aquatic system. Nutrient levels are generally higher in the spring and early summer and impact the aquatic system in several ways. High nutrient levels can accelerate eutrophication of a waterway. Eutrophication is characterized by abundant growths of phytoplankton (microscopic plants and algae) called algal blooms that may block sunlight from submerged aquatic vegetation (see Chapter 10). These algal blooms result in lower dissolved oxygen levels as decomposition of their organic matter consumes the dissolved oxygen.

Nutrient concentrations in aquatic systems are influenced by both natural and human sources. Natural sources of nitrogen and phosphorus include decomposition of organic matter, nitrogen fixation of atmospheric nitrogen by certain bacteria and algae, and geologic formations rich in nitrogen or phosphorus. Human sources include discharges from wastewater treatment plants, stormwater runoff, livestock wastes, fertilizer runoff from lawns and agricultural fields, groundwater seepage from failing septic systems, planting of nitrogen fixing plants (such as clover or beans) in agricultural fields, and atmospheric deposition (including acid rain) from the burning of fossil fuels.

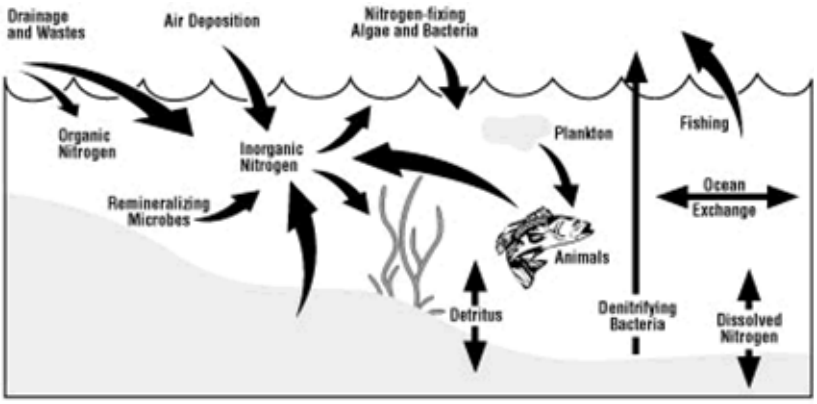


Figure 6-1. The nitrogen cycle *(from Volunteer Estuary Monitoring: A Methods Manual, Second Edition).*

What Do Your Nutrient Results Mean?

Developing nutrient criteria for the nation's waters is currently a hot issue. The debate centers on determining the limiting nutrient for a particular type of water in a particular ecoregion. Currently, Virginia has adopted water quality standards for some nutrients (such as total ammonia) as they relate to the toxicity to aquatic animals and nitrate for public drinking water supplies).
However other standards are still under development to establish criteria to various waterbody types and uses (e.g. lakes, streams and the Chesapeake Bay and its tributaries). Information on the criteria and development of these standards can be found on the following websites: http://www.chesapeakebay.net and https://www.deq.virginia.gov/our-programs/water/water-quality/standards.

Sample collection and test methods

Chapter 1 outlined a number of factors that every volunteer water quality monitoring program should consider. In addition to those summarized in Chapter 1, several considerations specific to monitoring for nutrients are discussed below.

Different Forms of Nutrients

Nitrogen and phosphorus can be found in aquatic systems in many different forms, or species. While monitoring each individual species may help determine the source, it is important to remember that, when developed, Virginia's water quality standards may be for total nitrogen and total phosphorus.

Nitrogen Species

In aquatic systems, nitrogen exists in various inorganic chemical species (ammonia, nitrate and nitrite are all common components of synthetic fertilizers) and in particulate and dissolved organic and inorganic forms. Total nitrogen is a combination of nitrate, nitrite and Total Kjhedal Nitrogen (TKN). TKN is organic nitrogen, which is a complex mixture of compounds primarily derived from living and dead organisms.

Nitrification is the process whereby some bacteria convert ammonium to nitrite and then nitrite to nitrate. Since this process consumes oxygen, a system with low dissolved oxygen levels may experience decreased concentrations of ammonia and subsequently increased levels of nitrites. Nitrate is highly water-soluble and is easily carried by runoff. At high levels, nitrates and ammonia can be toxic. The natural level of ammonia and nitrate in discharge from wastewater treatment plants can be as high as 30 mg/L. However many of these facilities are now being required to lower the level of nutrients released into the environment.

Phosphorus Species

In aquatic systems, phosphorus exists as orthophosphate (dissolved and inorganic), total phosphorus (dissolved and particulate), organic phosphate, and polyphosphate (from detergents). Orthophosphate is commonly measured and is found in fertilizers. Phosphate that is not associated with organic material is inorganic and this inorganic phosphorus is the form required by plants. Animals can use either organic or inorganic phosphate. Many phosphorus species attach to soil particles and can be transported with sediment through runoff. Phosphate in the aquatic system may bind to minerals in the sediment resulting in low phosphorus levels in the water. During conditions of no dissolved oxygen, bound phosphorus can be released into the water column triggering algal blooms. .

Monitoring phosphorus is challenging because it involves measuring very low concentrations (0.01 mg/L or even lower). Even such very low concentrations of phosphorus can have a dramatic impact on streams. Methods that do not have detection limits this low can be used to identify potential problem areas.

When to Sample

Since nutrient concentrations are highly variable, it is best to sample for nutrients throughout the year and over a long period of time to obtain a more complete picture of water quality. Frequent sampling can also facilitate explaining variability in the data.

Test Methods

Choosing a method for nutrient analysis can pose a dilemma. Your decisions on the goals of your program and the intended data use will determine the method that you should use. At this time, laboratory analyses of nutrients are the only methods that yield results accurate enough for DEQ's water quality assessments. Other methods may be used for educational or screening purposes.

Field Test Kits

Field test kits cannot measure total nutrient concentrations. Since water quality nutrient standards are written in terms of total nutrient concentrations (e.g. total nitrogen), information collected with test kits may only be used for screening purposes. Data collected from nutrient test kits are not acceptable for use by DEQ for water quality assessments. Different forms of nutrients can be measured using test kits to screen for potential problem areas or "hot spots". In general, nutrients are found in low concentrations that may be lower than the detection limits of the test kits. However, test kits that detect low levels can collect information about periodic increases in nutrient concentrations and help target areas where more advanced monitoring may be of interest.

Laboratory Methods

There are various types of methods used by laboratories to measure nutrients. These methods depend on what type of nutrient species is being tested and equipment available to the laboratory. If a volunteer group uses a laboratory for nutrient analysis, several recommended protocols need to be followed in order to DEQ to use the data in water quality assessment.

- Laboratory uses EPA approved or EPA recognized methods.
- The SOP used by the lab is approved by DEQ.
- Proper preservation of samples: Table 6-1 describes acceptable preservation methods of water samples for lab analysis of various nutrient species.
- Field splits: A field split is simply a second water sample taken at the same time as the first to measure the homogeneity of the samples. It is recommended that field splits are collected randomly for 10% of your samples (for a large sample size, 5% is acceptable). For example, if you collect 50 samples, you should collect 5 field split samples from random sites.
- Field equipment blanks are only necessary if water samples are collected in a bucket or other sampling device and transferred into the sample container. A field equipment blank uses pure and clean water (e.g. distilled or deionized water) rinsed through the sample collection devices to detect cross-contamination between sites. A field equipment blank is collected and transferred in the same manner as the stream water sample. It is recommended that you collect field equipment blanks randomly for 10% of your total samples (for a large sample size, 5% is acceptable).

Table 6-1. Preservation Methods for Laboratory Analysis of Various Nutrients

Parameter	**Chill on Ice to <4ºC** (immediately)	**Lower pH to < 2** (add 2 ml of sulfuric acid to 1 liter of sample)	**Freeze (in the lab)**	**Holding Time**
Total nitrogen	YES		YES	28 days
Ammonia/TKN	YES	YES		28 days
Nitrate/Nitrite	YES	YES		28 days
Total phosphorus	YES	YES		28 days
Orthophosphate	YES			48 hours

Summary of Nutrient Monitoring Methods

Method (Vendor and Catalogue #)	**Monitoring Level (see Appendix 7)**
Nitrate Test Kits	I
Ammonia Test Kits	I
Nitrite Test Kits	I
Phosphate Test Kits	I
Laboratory method	I, II or III

Section 3: Biological Monitoring

Chapter 7: Benthic Macroinvertebrates
Chapter 8: Bacteria
Chapter 9: Chlorophyll a
Chapter 10: Submerged Aquatic Vegetation (SAV)

Photos Courtesy of the Virginia Department of Conservation and Recreation and Alliance for the Chesapeake Bay

Chapter 7

Benthic Macroinvertebrates

What Are Benthic Macroinvertebrates?

Benthic macroinvertebrates are organisms that live on the bottom of a body of water (benthic), lack a backbone (invertebrate) and are visible to the eye (macro). Benthic macroinvertebrates include insects in their larval or nymph stages, crustaceans (such as Crayfish), and mollusks (such as clams).

Why Monitor Benthic Macroinvertebrates?

Volunteer monitoring programs in wadeable, nontidal freshwater streams commonly monitor benthic macroinvertebrates. They are good indicators of water quality because:

- They are affected by the physical, chemical, and biological conditions of the stream.
- They show the effects of short and long-term pollution events.
- They may show the cumulative impacts of pollution.
- They may show impacts from habitat loss not detected by traditional water quality assessments.
- They are important in the food web of the stream.
- Some are very intolerant of pollution; while others are tolerant of pollution.
- They are relatively easy to monitor.

Benthic macroinvertebrate monitoring is often a popular choice for volunteer monitoring programs in nontidal freshwater streams because it is generally less expensive than other kinds of monitoring and the monitoring events can be less frequent while showing cumulative effects. Many volunteers, especially children, enjoy collecting "bugs."

What Do Your Macroinvertebrate Results Mean?

The purpose of collecting benthic macroinvertebrate samples is to determine if a waterbody can meet conditions to support aquatic life. Unlike other water quality parameters, it is difficult to provide a universal score to determine if a waterbody can meet acceptable aquatic life uses. This is because benthic health is dependent on multiple parameters such as the type of stream bed and the rate of flow. Because of these variables, a score using one type of method does not necessarily relate to a score for another method.

The study of benthic macroinvertebrates generally includes collecting samples from the habitat(s) of the organisms and identifying and sorting the organisms in the collection. After all organisms have been identified (to order or family depending upon methodology), a water quality index may be calculated depending upon the methodology you choose to use. The calculation of the water quality index varies from one methodology to another but the end result may be a number that corresponds to a water quality rating.

Information about the sources of pollution cannot be obtained from a single macroinvertebrate survey alone. Sources of pollution can be inferred from a macroinvertebrate study by incorporating a habitat and watershed assessment and looking at conditions upstream and downstream of potential sources of pollution. While chemical monitoring can only describe

water quality at the moment the water is monitored, the macroinvertebrate community shows cumulative impacts.

Sampling Considerations

Stream with riffles *(photo courtesy of VA Save Our Streams)*.

There are two programs in Virginia that provide training and certification of volunteers for macroinvertebrate monitoring: the Virginia Save Our Streams Program (VA SOS) and the Audubon Naturalist Society (ANS). The method used by ANS is appropriate for nontidal, wadeable freshwater streams with riffles (areas where the water bubbles over the rocks) generally located west of the fall line (parallels I-95) in Virginia. VA SOS has a "Modified Method" that is appropriate for nontidal, wadeable freshwater streams with riffles generally located west of the fall line and an Eastern "Muddy Bottom" method for freshwater, wadeable streams without riffles (generally those areas located east of the fall line). Although benthic macroinvertebrates are found in tidal and estuarine (salt) waters of Virginia, there is currently no method appropriate for volunteers to use for monitoring these organisms.

VASOS Modified and Muddy Bottom Method

In 2001, VA SOS began using a modified method based upon a two-year scientific study of the traditional Save Our Streams method. This two-year study resulted in changes to the collection and identification procedures to yield results that more closely matched those obtained when using professional methods (see https://www.vasos.org/wp-content/uploads/EngelVoshellAmerEnto2002.pdf for a copy of the study by Engel and Voshell, 2002). VA SOS trains and certifies volunteers across Virginia in the modified method which is appropriate for non-coastal Virginia Streams (i.e. those west of the Coastal Plain). Additionally, VA SOS in conjunction with Randolph-Macon College has developed a protocol for macroinvertebrate monitoring in the nontidal, freshwater streams of Virginia's Coastal Plain. Monitoring results obtained by certified VA SOS monitors are used by the Virginia Department of Environmental Quality (DEQ) to determine where follow-up monitoring by DEQ, using official agency protocols, is warranted (Table 7-1).

Volunteers collecting macroinvertebrates in eastern Virginia *(photo courtesy of Alliance for the Chesapeake Bay)*.

ANS Method

The ANS uses a modified version of professional rapid bioassessment methods for macroinvertebrate collection and habitat assessment. ANS provides training and certification for volunteers in Northern Virginia, including macroinvertebrate identification to order and family levels, protocol implementation, and habitat assessment. Training is offered at their sanctuaries in Fairfax and Loudoun Counties. Monitors work in teams led by a certified leader. Monitoring

results obtained using the ANS method is used to determine where follow-up monitoring by DEQ, using official agency protocols, is warranted (Table 7-1). . Table 7.1 shows the VA SOS scores for Modified and Muddy Bottom methods along with ANS method

Table 7-1. How VASOS and ANS Scores Are Generally Interpreted by DEQ

Method	Score	DEQ General Interpretation
VA SOS Modified Method Score	1-7: Unacceptable Ecological Conditions	Prioritize sites for additional monitoring by DEQ. Evidence of potential degradation indicated.
	8: Gray Zone – Indeterminate Ecological Conditions	
	9-12: Acceptable Ecological Conditions	Do not prioritize site for additional monitoring. Score provides no evidence of potential degradation.
VASOS Muddy Bottom Method Score	0-7 Unacceptable Ecological Conditions	Prioritize sites for additional monitoring by DEQ. Evidence of potential degradation indicated. .
	8-14 Partially Acceptable Ecological Conditions	
	15 – 24 Acceptable Ecological Conditions	Do not prioritize site for additional monitoring. Score provides no evidence of potential degradation.
Audubon Naturalist Society Method Score	Poor	Prioritize sites for additional monitoring by DEQ. Evidence of potential degradation indicated.
	Fair	
	Good	Do not prioritize site for additional monitoring. Score provides no evidence of potential degradation.
	Excellent	

In addition to volunteer methods, some groups employ professional bioassessment protocols that are identical or equivalent to agency methods (see Appendices B through E of the DEQ Biomonitoring Quality Assurance Project Plan for agency methods: https://www.deq.virginia.gov/home/showpublisheddocument/6996/637520993335570000). After a quality assurance review by the agency, data produced using these methods may be used for official water quality assessment. For more information on this process please contact citizenwater@deq.virginia.gov.

Summary of Benthic Macroinvertebrate Monitoring Methods

Method	**Monitoring Level (see Appendix 7)**
Modified Virginia Save Our Streams Method	I or II
Audubon Naturalist Society	I or II
Eastern "Muddy Bottom" Virginia Save Our Streams Method	I

Chapter 8

Bacteria

What Are Bacteria?

Bacteria are single-celled organisms that occur in a variety of forms and have a wide range of characteristics. While most bacteria are harmless to humans and play important roles in the environment, some bacteria can cause disease.

Why Monitor Bacteria?

Pathogenic (disease-causing) bacteria, viruses, and protozoans are often found in fecal waste. These pathogens can cause a variety of illnesses and diseases when ingested during recreational contact or consumed in contaminated water and shellfish. Fecal waste from humans or other warm-blooded animals may enter a waterbody from various sources including faulty wastewater treatment plants, livestock, malfunctioning septic systems, untreated sewage discharge, pets, stormwater runoff, wildlife, or boat waste. Since it is not practical to monitor for every pathogen, "indicator" species are monitored. The presence of indicator species suggests the presence of fecal waste that may include pathogenic microorganisms. In addition to threatening public health, elevated levels of fecal material can also cause cloudy water, nutrient enrichment, unpleasant odors, and an increased oxygen demand (please see Chapters 4 and 6).

Which Bacterial Indicator Should You Use?

Bacterial indicators commonly measured by professional and volunteer monitoring programs include fecal coliform, *Escherichia coli* (*E. coli*) and enterococci. These indicators are normally prevalent in the fecal waste of warm-blooded animals and humans. This manual does not discuss monitoring total coliforms (*E. coli* and fecal coliforms belong to this larger group) since the presence of total coliforms does not necessarily indicate fecal contamination. However, total coliforms may be useful for testing drinking water because their presence can indicate contamination of a drinking water supply.

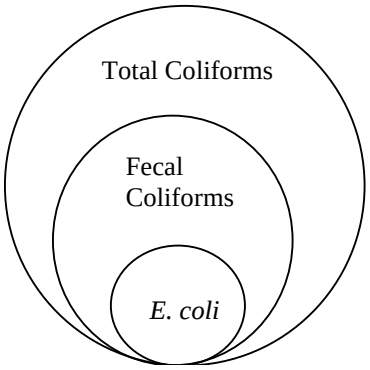


Figure 8-1. Relationship of *E. coli* and fecal coliform bacterial indicators.

Fecal Coliform

Fecal coliforms are a subset of total coliform bacteria that are found in the fecal waste of warm blooded animals. Before 2003, the Virginia Department of Environmental Quality (DEQ) used this type of bacteria to determine whether a waterbody is safe enough to support primary contact activities such as swimming. Since then, DEQ has targeted more specific bacteria (*E. coli* and enterococci). The Virginia Department of Health continues to monitor fecal coliform when recommending shellfish eating advisories. For the purposes of volunteer monitoring, DEQ recommends testing for *E. coli* (freshwater) or enterococci (saltwater) bacteria because the Commonwealth has adopted water quality standards for these indicator organisms for primary contact such as swimming.

Escherichia coli (*E. coli*)

E. coli is a species within the fecal coliform group that is specifically associated with the fecal waste of warm-blooded animals. In freshwater, *E. coli* corresponds more closely with swimming-related illnesses than fecal coliform.

Enterococci

Enterococci are another group of bacteria found mainly in the intestinal tract of warm-blooded animals. It is not a type of coliform bacteria but a subgroup of the fecal streptococci group. DEQ monitors enterococci at brackish and marine sites.

What Do Your Bacteria Results Mean?

Water quality standards for *E.coli* and Enterococci were recently amended by Virginia and the changes became effective in October 2019 (Table 8-1). These standards are used to determine if a waterbody supports primary contact recreational activities.

Table 8-1. Virginia Water Quality Standards for Bacteria

Indicator	**Statistical Threshold Value** (samples in a 90 day period)	**Geometric Mean** (samples in a 90 day period)
E. coli (freshwater)	410 counts /100 ml water	126 counts/100 ml water
Enterococci (salt/brackish waters)	130 counts/100 ml of water	35 counts/100 ml of water

How Will DEQ Use Your Data?

DEQ recently published, for public comment, recommended methods for assessing bacteria using revised criteria. These methods are found in the 2022 Water Quality Assessment Guidance Manual, available on the DEQ website at https://www.deq.virginia.gov/our-programs/water/water-quality/assessments/wqa-guidance-manual.

For listing or delisting waters impaired for bacteria (recreational), at least 10 samples collected weekly over a 90-day period using a Level III approved method is recommended. Less frequent (*i.e.*, monthly) testing using a Level III method may be sufficient to list waters as impaired if the Statistical Threshold Value is exceeded multiple times in a dataset. Level II and III bacteria data can also be used by DEQ to identify waters for follow up sampling, identify bacteria sources, and track the progress of restoration activities.

Suggested Monitoring Frequency

To maximize the utilization of data by DEQ and minimize volunteer workload, DEQ offers the following monitoring recommendations.

- Groups using Level III methods or to help inform the public on local recreational conditions are encouraged to sample weekly from Memorial Day to Labor Day.

- Groups using Level II methods or who monitor impaired waters for TMDL projects or identify waters for DEQ follow-up monitoring are encouraged to monitor monthly.

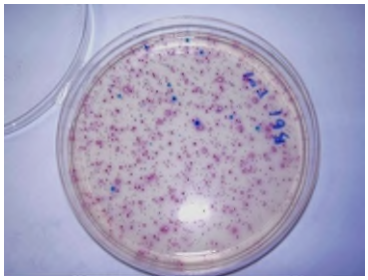
Sample collection and test methods

Chapter 1 outlined a number of factors that every volunteer water quality monitoring program should consider. In addition to those summarized in Chapter 1, several considerations specific to monitoring for bacteria are discussed below.

Presence-Absence Tests

These simple tests are designed to determine whether the target bacteria are present in a water sample. They are appropriate for educational purposes and for determining the presence of bacteria in drinking water. A variety of companies sell these test kits. Presence-absence tests are not used by any environmental water quality monitoring programs in Virginia because they do not provide useful information for surface waters since bacteria are commonly found in surface waters.

Coliscan Easygel



Coliscan Easygel (Micrology Labs, Appendix 6) is simple to use and relatively inexpensive. The Coliscan Easygel method measures total coliforms and *E. coli.* A water sample is added to a liquid medium and poured onto a treated Petri dish. Incubation is highly recommended. Inexpensive incubators can be purchased or easily constructed.

The Coliscan Easygel method was compared to laboratory analysis and found to be an acceptable tool for screening purposes although the data cannot be used directly by DEQ for water quality assessments (Level II). This method is useful because it can assist in locating "hot spots" for fecal contamination and target areas for more extensive monitoring.

> Located near the end of this chapter are instructions and data log sheet developed by DEQ.

R-Card

R-card is a new, simple method to estimate *E. coli* concentrations in aqueous samples. Sample water (currently 1 mL or 3 mL, depending on the product) is placed onto a card, covered with a plastic film, and incubated. After incubation, visible colonies are identified by color and counted, as with Coliscan Easygel enumeration.

R-Card has been found to produce results that are comparable to Coliscan Easygel and may be used to identify potential hotspots and waters for DEQ sampling (Level II) but may not be used directly by DEQ for water quality assessments.

> Located near the end of this chapter are instructions and data log sheet developed by DEQ.

Membrane Filtration (MF)

The MF procedure may not be useful if the sample has high concentrations of suspended materials since the filter can easily become clogged. In this method, the sample water is filtered to trap bacteria on the surface. The filter is placed in a Petri dish along with a growth media ("food" for the selected bacteria) and incubated. The MF method yields a direct count of bacteria colonies per 100 ml of water. This method is often used to analyze water samples collected in freshwater areas. For more information on this procedure, please see EPA Method 1603 for *E. coli* and the EPA Method 1600 for *Enterococci*.

Colilert and Enterolert

Colilert and Enterolert (IDEXX Laboratories, Appendix 6) are laboratory methods used by most volunteer monitoring groups and based upon the most probable number method (see lab analysis section below) to detect total coliforms and *E. coli.* The Enterolert is for use in saltwater (enterococcus) while Colilert is designed for freshwater (*E. coli*). The U. S. Environmental Protection Agency (EPA) has approved this method for surface water testing. Bacterial samples collected using this method can be used by DEQ for water quality assessments.

> At the end of this chapter are instructions and data log sheet developed by DEQ to test for *E. coli* or enterococcus bacteria using Colilert or Enterolert methods.

Quality Assurance/Quality Control Issues

Sample Collection

It is preferred that you collect water samples for bacterial analysis directly from the stream, either by wading or using a pole with a holder for the sample bottle. If this is not possible for safety reasons, the water sample may be collected in a bucket or other sterile container and transferred to the sterile sample container. If using a sampling device such as a bucket, rinse the container with sample water prior to collecting and pouring sample water into a sterile sample bottle. Do not rinse sterile sample bottles with sample water.

Some sample containers obtained from a lab contain a sodium thiosulfate tablet. This tablet is not necessary for surface water samples unless chlorine may be present. The purpose of the tablet is to neutralize chlorine in water samples.

> At the end of this chapter are instructions on how to collect samples using various pieces of equipment and can be used for any form of bacteria monitoring program.

Field Equipment Blanks

Field equipment blanks are only necessary if water samples are collected in a bucket or other sampling device and transferred into the sample container. Field equipment blanks use bacteria free water such as distilled or bottled spring water that is rinsed through the sampling devices to detect cross-contamination between sites. The field equipment blank is collected and transferred in the same manner as the stream water sample. It is recommended that field equipment blanks are collected randomly for 10% of your samples (for a large sample size, 5% is acceptable). For example, if a program collects samples using a sample bucket at 50 sites, five of the sites should include an equipment blank sample.

Holding Time

DEQ conducted bacteria holding time studies for *E. coli* and Enterococci in ambient water samples. The study results indicated *E. coli* can be held up to 48 hours and Enterococci 30 hours without changing bacterial counts when the samples are stored in temperatures less than 4ºC. DEQ recommends processing samples within 24 hours after collection to ensure samples are tested within acceptable holding times and provide prompt results to current conditions.

Summary of Bacteria Monitoring Methods

Method	**Monitoring Level (see Appendix 7)**
Various Presence-Absence Tests	I
Coliscan Easygel (*E.coli*)	I or II
R-card (*E. coli*)	I or II
Colilert (*E. coli*), Enterolert (enterococcus)	I, II, or III
Membrane Filtration – (various)	I, II, or III

General Safety

1. Field monitors work in teams of two or more or notify the designated team coordinator where they will be and expected return time.

2. Where possible, potential sample sites are surveyed prior to sampling to ensure safety of samplers such as pedestrian access on a bridge or a streambank site is safely accessible.

3. Monitors should never wade into waters iced over or during high flow conditions.

4. Monitors exercise extreme caution if sampling during hazardous weather conditions such as severe thunderstorms and ice or snow precipitation. Sampling is postponed if conditions are unsafe.

5. Monitors are not to sample a site if they feel uncomfortable with the site. They are to report back to the coordinator about their concerns so an alternative site can be selected.

6. Field and laboratory personnel wear appropriate Personal Protection Equipment (PPE) such as gloves or use hand sanitizer when handling samples.

Field Sampling Procedure

Trained and certified volunteer monitors will collect water samples from identified sampling locations and at a frequency specified in the project plan. Valid samples must meet the following criteria:

1. Sampling uses one or more procedures outlined below.

2. Samples are collected were water is flowing and is representative of water conditions.

3. Field sampling sheet is filled out at the time the sample is collected.

4. Samples are always kept on wet ice until delivered to the laboratory.

5. Sample(s) are processed within 24 hours of collection and kept at $\leq$4 ^{o}C until processing.

6. Sample documentation such as field sheets is included with the labeled sample to the laboratory.

A. Field Equipment

Equipment should only be used for water quality sampling. Personal use of the equipment such as the sample cooler is not allowed as can jeopardize the monitor and data quality. Store the equipment in a cool and dry undisturbed location. Air dry the cooler to prevent mildew growth. Inspect equipment regularly for damage and replace as needed. Return unused equipment so it can be provided to another monitoring team. Typical bacteria sampling equipment consists of:

i. Waterproof marker (e.g. Sharpie®)

ii. Ballpoint pen
iii. Field sheet(s)
iv. Insulated cooler
v. Sterile bottle(s) – one for each site and two extra for accidents or QA
vi. Bucket or bridge sampling device (optional)
vii. Handheld sample collection wand (optional)
viii. Latex or nitrile gloves and/or hand sanitizer
ix. Ice sufficient to mostly cover the water samples (provided by the sampler)

B. Before Leaving to Sample

1. All necessary equipment appears clean and in good working order.

2. Field sheets and any other documentation are included.

3. Cooler is filled with sufficient ice (at least 2 inch depth).

4. If severe weather is expected, check to see if conditions may deteriorate while in the field using local news or weather websites like www.wunderground.com.

C. Arriving at the sampling site

1. If driving to the site, park the vehicle in a safe location off of the main roadway. If parking on the road shoulder, pull completely over the white line and activate the hazard signal.

2. Fill out the field sheet with the station number, sample date, conditions, and related information.

3. Record any site conditions as listed on the field sheet.

4. Proceed to the sampling site and sample using one of the appropriate procedures listed below.

Sampling Methods

The following methods should be used based on the conditions of the sampling location and safety of the field teams. If access to a sample site is only possible through private property, landowner permission must be obtained prior to arriving to the site.

A. In situ collection

Applies only to very shallow waterbodies (<2 foot depth) where site access is open to the public (e.g. parks) or where there is landowner permission and it is easy to enter and exit the waterbody. The method is most useful when tracking potential sources of bacteria or where bridge and similar sampling points are not accessible or safe.

1. Enter the water at least 10 feet downstream of the actual sampling location.

2. Wade upstream to the sample location while avoiding excessive disturbance of the sediment.

3. While facing upstream and in the main water channel, remove the sample bottle lid. Do not touch the inner surface of the bottle or lid.

4. Invert the bottle so the opening is facing down and submerge the bottle. With a U shape motion, fill the bottle while the bottle opening moves upstream and away from the sampler.

5. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

6. Go to step E Bottle labeling and transport.

B. Streambank or shoreline sampling

Used when water levels are too high to safely wade or the banks are too steep or overgrown to safely enter and exit the waterbody. A bucket with rope or sampling wand may be used.

Sampling wand

1. Attach the bacteria bottle to the bottle holder at the end of the wand.

2. Remove the sample bottle lid. Avoid touching the inner surface of the bottle or lid.

3. Lower the end of the wand containing the bottle into the main flowing channel and away from debris or disturbed sediment. If there is a current, submerge the wand so the bottle is facing into the current and allow the bottle to fill.

4. Retrieve the wand while allowing the bottle to remain full. Avoid any water running down the pole to flow into the bottle opening.

5. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

6. Go to step E Bottle labeling and transport.

Sample bucket with rope

Note: Not recommended for Level III methods as buckets may retain bacteria from prior sample sites.

1. Toss and retrieve the sample bucket into the water. Be careful not to drag the bucket across the bottom sediment or bank.

2. Rock the bucket side to side so the water rinses the inner surface and toss the water away from the sampling location such as onto the streambank.

3. Toss the sample bucket into the water. Be careful not to drag the bucket across the bottom sediment or bank. If this occurs, discard the sample on the streambank and attempt again.

4. Remove the sample bottle lid. Do not touch the inner surface of the bottle or lid.

5. Invert the bottle so the opening is facing down and submerge into one side of the bucket.

6. Using a U shape motion, fill the bottle while moving to the opposite side of the bucket.

7. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

8. Go to step E Bottle labeling and transport.

C. Bridge sampling

Used when a bridge or similar crossing provides the best available location to collect a mid-channel sample. If sampling from a road crossing, be sure to follow appropriate safety precautions and only if the bridge is wide enough for pedestrians (e.g. sidewalk or shoulder > 3 feet). Whenever safely possible to do so, sample from the upstream side of the bridge that is over the main flow of the waterbody.

Sample bucket with rope

Note: Not recommended for Level III methods as buckets may retain bacteria from prior sample sites.

1. Lower the sample bucket into the water and allow filling to about one-quarter way full.

2. Retrieve the bucket while avoiding having the rope rub against the side of the bridge.

3. Rock the bucket side to side so the water rinses the inner surface and toss the water away from the sampling location such as onto the road shoulder.

4. Lower the bucket into the water into the main flow of the water while avoiding disturbing sediment or collecting floating debris.

5. Retrieve the bucket while avoiding having the rope rub against the side of the bridge.

6. Remove the sample bottle lid. Do not touch the inner surface of the bottle or lid.

7. Invert the bottle so the opening is facing down and submerge into one side of the bucket.

8. Using a U shape motion, fill the bottle while moving to the opposite side of the bucket.

9. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

10. Go to step E Bottle labeling and transport.

Bottle sampling device and rope

1. Carefully remove the bottle lid and place so the inner lid side does not touch another surface.

2. Insert and secure the sample bottle into the device.

3. Lower the sampling device into the main flow of the water while avoiding disturbing sediment or collecting floating debris.

4. Allow the bottle to fill and retrieve. Avoid having the rope rub against the side of the bridge.

5. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

6. Go to step E Bottle labeling and transport.

D. Boat sampling

Boat sampling typically occurs on lakes or estuarine waters away from the shoreline. Monitors should sample away from any water recently disturbed by the boat propeller or handheld paddle. Typically, sampling is done from the side or bow of a boat using one of the following methods.

Direct collection

1. Remove the sample bottle lid. Do not touch the inner surface of the bottle or lid.

2. Invert the bottle so the opening is facing down and submerge the bottle. With a U shape motion, fill the bottle while it moves away from the sampler.

3. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

4. Go to step E Bottle labeling and transport.

Sampling wand

1. Attach the bacteria bottle to the end of the wand.

2. Remove lid from bottle. Avoid touching the inner surface of the bottle or lid.

3. Lower the end of the wand containing the bottle into the water away from debris or disturbed sediment. If there is a current, submerge the wand so the bottle is facing into the current and allow the bottle to fill.

4. Retrieve the wand while allowing the bottle to remain full. Avoid any water running down the pole to flow into the bottle opening.

5. Verify the sample bottle is filled adequately and no more than the bottom of the bottle shoulder. Discard any excess water and cap.

6. Go to step E Bottle labeling and transport.

E. Bottle labeling and transport

1. With a waterproof pen or marker, label the bottle with at least the station ID. Other helpful information may include sample date/time and sampler initials.

2. Immediately place the labeled bottle in the cooler and cover with ice.

3. Complete the field sheet including the time the sample was collected.

4. All samples should be kept in the coolers during transport to the lab and have enough ice to at least mostly cover the water sample bottles to ensure bottle temperature is below 4 ^{o}C.

5. When arriving to the laboratory or drop off location, place the samples in the provided cooler/ sample refrigerator or process immediately.

6. Turn in field sheets at the designated location.

Coliscan Easygel Procedure- *Provided by the Department of Environmental Quality*

A. Sample Preparation and Plating

1. Label the bottom (smaller, taller piece) of the Petri dish using a permanent marker. It is best to label the dishes using small lettering on the outer rim of the dish. The minimum information needed should be the site ID number, sample volume, and replicate number.

2. Mix the water sample in the sterile bottle and then transfer the desired volume (0.5 – 5.0 milliliters) to a bottle of Coliscan medium using a sterile pipette.

3. Gently swirl the bottle of Coliscan media so that it mixes with the sample water. Do not shake the bottle as this will cause the medium to foam and make reading the colonies difficult.

4. Pour the entire contents of the bottle into a Petri dish. It is important to perform this step on a level surface so the solution forms an even layer across the plate.

5. Gently swirl the Petri dish so the solution of Coliscan media and sample water covers the entire plate. Allow the solution to solidify (approximately 60 - 90 minutes) prior to incubation. For safety purposes, it is a good idea to loosely tape each Petri dish shut after the media solidifies.

B. Incubation

Incubate the Petri dishes **upside down** for 24 – 36 hours at 35° - 40° Celsius. This is approximately 95° - 105° F. If no incubator is available, place the Petri dishes in the safest, warmest spot you can find. Depending on the exact temperature, the plates may take 48 – 72 hours for colonies to form analysis.

C. Data Analysis (Scoring)

It is recommended to use white or graph paper as a background to make identifications easier. If there are large number of colonies, drawing quadrants on this paper can help in counting the number of colonies.

1. Count the number of dark blue – royal purple, colonies on each plate and record this number in the column labeled "*# E. coli* Colonies per Plate" on the data form. Do not count teal colored or pink – dark red colonies. Count colonies directly or calculate a representative sample to determine the average number of *E. coli* per plate and record on the data form. The provided color guide on the next page can help with identifying colonies.

2. Calculate the number of *E. coli* cells per 100 milliliters and record on the data form. Use the following formula: (# E. coli colonies/ml sample size) x 100

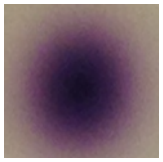
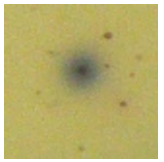
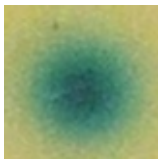
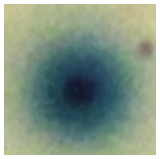
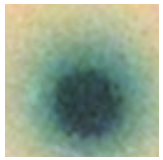
D. Waste Disposal

1. Dispose used pipettes and sample bottles in the household trash. They are also recyclable.

2. Rinse empty bottles of Coliscan medium two – three times with tap water and dispose in your household trash. (This is to wash out all of the media to prevent pathogens from growing.)

3. Wipe down the sample processing area with rubbing alcohol to kill any bacteria from the sample bottles. It is recommended to not perform this test where food is present or prepared.

4. After the results have been recorded, add enough bleach or rubbing alcohol to each Petri dish to completely cover the solid media. Allow to stand for at least 10 minutes to ensure all bacteria have been killed. Place the plates in a zip-lock bag and dispose in the trash.

E. coli	***Not E. coli***
 Purple, with purple halo	 White
 Purple, no halo	 Pink, no halo
 Purple with pink halo	 Pink with pink halo
 Blue with purple or pink halo	 Pinpoints (If after incubation period)
 Blue or dark blue, no halo	 Teal green, no halo
 Dark blue with teal halo	 Teal with teal halo
 Dark blue with blue halo	 Red

Coliscan Easygel Data sheet

Group: **Watershed:**

Sample Site #	Sample Date	Sample Time	Rain Past 24 Hours (Inches)	Incubator Time In	Incubator Temp In	Incubator Time Out	Incubator Temp Out	Sample Volume (ml)	# *E. coli* Colonies (dark blue to royal purple)	Total *E. coli* Count (count/100 ml)	Comments

Instructions: Samples should be run within 48 hours of collection if samples were stored on ice. If not stored on ice, run samples as soon as possible and mark on the comments section of the datasheet. Ideal incubation temperature is 35 ^{o}C.

To calculate the number of *E. coli* colonies: (# *E. coli* colonies/ml sample size) x 100

R-Card Procedure

R-card water samples may be collected with sterile containers and immediately placed on ice to be processed in a lab or may be pipetted directly from the source onto R-Cards. Currently, **at least 3 mL of sample water must be processed to achieve level II data**. Either three 1 mL cards or a single 3 mL card may be used to meet this requirement. Instructions below are specific to 3-mL R-Cards.

A. Sample Preparation

1. Turn on the incubator and set to 35° - 40° C to give it time to reach the desired temperature prior to incubation.

2. Label the R-Card with station ID, date, and replicate number if collecting a replicate.

3. Mix the water sample in the sterile bottle to homogenize. Place the R-Card on a flat surface, and with a gloved hand, carefully lift the clear film away from the card. With the card now exposed, carefully transfer 3 mL of sample water onto the surface of the R-Card using a sterile pipette, dispensing the sample water in small droplets. Take care to not place droplets near the edges of the card. When 3 mL have been dispensed, very slowly roll the film back down over the sample water, allowing the sample to spread evenly over the card.

4. Do not use hands or any objects to spread the sample. After 1-3 minutes, the sample will be finished spreading and solidify. The sample is now ready for incubation.

    a. If pipetting sample water directly from the source onto an R-Card, the card does not need to be stored on ice but should be protected from light and kept below incubation temperatures (< 32 C). Cover sample cards with opaque material and keep cool before incubation. Begin incubation upon returning to the lab.

B. Incubation

1. Record the time and incubator temperature on data collection form. Place the R-Cards face-up in the incubator. Incubate the R-Cards for 20-24 hours at 35° - 40° C.

2. When incubation is completed, record the time and remove the sample card from the incubator.

3. Do not exceed 24 hours of incubation time.

C. Data Analysis (Scoring)

1. **Count the number of dark blue to purple colonies** on each card and record this number in the column labeled "# *E. coli* Colonies per Plate" on the data form (the Coliscan form may be used for this purpose). Pink to dark red colonies represent other coliforms, do not count these unless recording total coliforms as well. Do not count teal-colored colonies.

2. Calculate the number of *E. coli* cells per 100 milliliters and record on the data form. Use the following formula: (# *E. coli* colonies/ml sample size) x 100

D. Waste Disposal

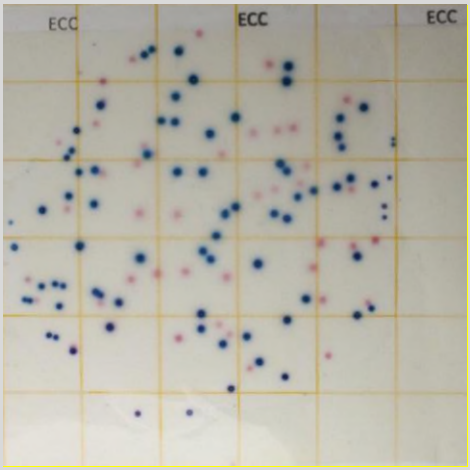
1. Dispose used pipettes and sample bottles in the household trash. They are also recyclable.

2. Wipe down the sample processing area with rubbing alcohol to kill any bacteria from the sample bottles. It is recommended to not perform this test where food is present or prepared.

3. After the results have been recorded, dispose of R-cards by either:

    a. Sterilize cards at 121 C for 30 minutes, then discard. OR

    b. Separate the film from the card and add enough bleach, rubbing alcohol, or dish soap solution to each card. Allow to stand for at least 10 minutes to ensure all bacteria have been killed. Place the cards in a zip-lock bag and dispose in the trash.



A processed R-card with *E. coli* (dark blue-purple colonies) and other coliforms (pink-red colonies).

https://www.rothbioscience.com/collections/r-card-products/products

Colilert/Enterolert Procedure- *Provided by the Department of Environmental Quality*

The Colilert protocol is used to measure *E. coli* bacteria while Enterolert measures Enterococcus bacteria. Both methods are combined into one document as they are nearly identical. ***Steps specific to Enterolert are in bold italics***. Both methods require about 15 minutes preparation time and about 2 minutes to process and seal each sample and about 2 minutes to read each sample during the following day.

A. Equipment

i. 120 mL sterile sample bottles
ii. Sterile transfer pipettes
iii. Colilert ***or Enterolert*** media snap packs
iv. Sterile, non-buffered, water for field and lab blanks.
Note: Bottled spring water may be used if verified sterile and non-inhibiting.
v. 365 nm UV light-6 watt
vi. Quanti-Tray® 2000 97 well
vii. Rubber tray carrier 97 well
viii. Quanti-Tray Sealer
ix. Quanti-Tray Comparators (Colilert)
x. Incubator set to 35 °C +/- 0.5 °C (Colilert) ***or 41 +/- 0.5 °C (Enterolert)***
xi. Non-residue forming disinfectant (e.g. 70% Isopropyl Alcohol)
xii. Latex or nitrile gloves
xiii. UV protective eyewear
xiv. Waste container or bag
xv. Sharpie marker and ballpoint pens
xvi. Temperature log and data reporting lab sheets
xvii. Autoclave or access to a hazardous materials disposal service

B. Sample and Equipment Setup

Confirm incubator is properly set at 35 +/- 0.5 ^{o}C ***or 41 +/-0.5 ^{o}C (Enterolert)*** and record reading on the temperature log sheet.

1. Sterilize the work surface where samples will be processed using the disinfectant.

2. Turn on the Quanti-tray sealer and allow at least 15 minutes for the sealer to warm up.

3. Remove samples from the sample cooler/refrigerator and arrange on the sterilized work surface.

4. Confirm sample bottle labels match information found on accompanying field sheets.

5. Use the marker to write the station ID on the back of a Quanti-Tray and place with each bottle.

6. Have Colilert ***or Enterolert*** media and a container of sterile, non-buffered water ready.

7. Fill out the laboratory analysis form with the required information.

C. <u>Filling and Sealing Quanti-Tray</u>

1. Shake sample bottle to thoroughly mix the sample.

2. Verify the sample bottle is filled to at least the 100 ml fill line and no more than the bottom shoulder of the bottle. **See image:**
   a. If bottle is overfilled, use a sterile pipette to remove excess water from the sample bottle so that the water level rests on top of the 100 ml line.

   b. If underfilled, use a sterile pipette to add sterile, non-buffered water to the bottle so the water level rests on top of the 100 ml line. Record the volume of water added on the sample sheet to properly calculate results.

Note: For Enterolert samples collected in brackish or marine water, use a sterile pipette to transfer 10ml of mixed sample water into a sterile sample bottle and fill to 100 ml with sterile, non-buffered water. Final results will be 10 times greater than reported on the MPN table (e.g., 214.6 on the table is actually 2146). Dilution is necessary as high salinity values may interfere with bacteria growth.

3. Open the sample bottle and place the lid with the inside surface pointing towards the ceiling onto the sterilized work area. Only have one sample bottle open at a time.

4. Shake or tap the media package to ensure media collects to the bottom of the pack.

5. Open the media pack and pour the contents into the sample bottle.

6. Close the bottle tightly and mix well until the media dissolves.

7. Open the sample bottle. Place the lid with the inside surface pointing up onto the sterilized work area. Only have one sample bottle open at a time.

8. Pick up the labeled Quanti-Tray. With the clear plastic well side of the tray facing the palm of the holding hand, gently squeeze until the plastic side bends towards the palm.

9. With the other hand, gently pull the foil tab to separate the foil back from the tray. Do not touch the inner surface of the foil or tray.

10. Pour the media infused sample bottle into the tray opening. Tap the tray to dislodge air bubbles.

11. Without spilling the contents, place the tray into the corresponding rubber tray carrier.

12. Place the rubber tray carrier with the sample onto the sealer tray holder with the plastic well side facing towards the tray holder. Do not spill any contents of the tray while loading into the sealer.

13. Gently push the tray into the sealer until it is grabbed by the sealer.

14. After the tray is sealed, verify the wells are filled at least 1/2 full. The large well at the top of the tray is for overflow and does not need to be at least 1/2 full. If wells are not sufficiently full, note it on the sample calculation and result sheet.

15. After processing no more than 10 trays, record the time the trays are placed in the incubator on the paper back of the tray using a marker. Record times on the associated laboratory sheet.

16. Place the sealed tray(s) in an incubator set to 35°C ± 0.5°C ***or 41 ± 0.5°C(Enterolert)*** and incubate for 24 to 28 hours. Incubate trays plastic well side down. Do not stack more than 10 trays high and have at least 2 inches of clearance from the inner surfaces of the incubator.

17. After processing all samples, disinfect the preparation area and turn off the sealer.

18. Place the used media snap packs, sample bottles and pipettes in the trash.

D. Reading Trays After Incubation

Note: Never look directly at the UV light source when activated or count samples on a reflective or glossy surface. Use UV treated goggles or glasses to avoid possible eye damage.

1. Before retrieving the first set of samples of the day, record the incubator temperature.

2. At 24 to 28 hours, remove sample trays from the incubator. ***Enterolert skip to step 4.***

3. Count the number of yellow wells and record the number of positive small and large wells on the associated laboratory analysis sheet. Yellow wells indicate coliform bacteria.

4. Turn the 325 nm UV lamp on. If necessary, turn off overhead lights or use a darkened light box.

5. Place the Quanti-tray with the wells facing up under the UV lamp.

6. Using the relevant IDEXX comparator tray, refer to Table 1 to identify positive wells.

Table 1. Result Interpretation Table

Colilert	
Yellow less than the Colilert comparator tray	Negative for total coliforms and *E. coli*
Yellow equal to or greater than the comparator	Positive for total coliforms
Yellow and UV fluorescence equal or greater than the comparator	Positive for *E. coli*
Enterolert	
Fluorescence greater than a negative control	***Positive for Enterococcus***

7. Using the 97 well, Quanti-Tray 2000 Most Probable Number (MPN) table, record the bacteria MPN result on the associated laboratory analysis sheet.
    a. Recount the tray if the *E. coli* result is greater than the total coliform result.

8. After tray results have all been confirmed and recorded, dispose of trays as biohazardous material such as sterilizing in an autoclave or use a hazardous materials disposal service.

9. Wipe down the work surface used to process samples with disinfectant.

E. Quality Control Procedures

Field Replicate

At least one sample site per sample series will include a field replicate. A field replicate will be collected either at the same time or immediately after the primary sample is collected. If the sample is collected by bucket, the replicate uses the same bucket of water.

1. Label one sterile sample bottle as normal and a second sample bottle with the same Site ID followed by "Rep". For example, a replicate for Site 4 would be "4 Rep".

2. On the field sheet, note that a replicate was taken.

3. Collect the replicate sample in the same way as the regular sample ideally at the same time or immediately afterwards.

4. Transport and laboratory analysis of results are the same as a normal sample.

5. Record results on the laboratory analysis sheet with the comment of "Replicate"

Note: Environmental water column bacteria results can vary widely based on sample location and bacteria loading making it impossible to reliably use standard relative percent differences to confirm sample results are in control. The laboratory should maintain an ongoing spreadsheet record of duplicate results. These duplicate results are converted to their logarithmic value (e.g. a 100 bacteria count has a log value of 2). The Excel formula **=log** can perform this calculation easily. An absolute difference of the two replicate log values is then obtained. An average of the previous 15 sets of replicate differences is multiplied by 3.27 to determine the current acceptable range of differences. If the current replicate difference is greater than the average value, the duplicate samples are out of control and the associated sample data should be flagged.

Laboratory Blank

A laboratory blank should be performed whenever using a new batch of sample bottles or bacteria media. In addition, a blank should be performed for every 20 samples that require dilution. This ensures there are no laboratory based contamination issues with the dilution water or equipment.

1. Label a sterile 100mL sample bottle as "Lab Blank".

2. Open a container of sterile, non-buffered water.

3. Fill the labeled sample bottle to the 100 ml line with the sterile water.

4. Process the sample as normal.

5. Record results on the laboratory analysis sheet.

Note: An acceptable laboratory blank has a zero bacteria result. If any bacteria are observed, flag all samples processed as part of the associated laboratory blank.

Media and Technician Performance Verification

Each lot of media received should be tested to ensure it is properly formulated. This test can also be used to gauge the analytical technique of laboratory personnel.

1. Remove a set of IDEXX-QC vials from the freezer and ensure the expiration dates are valid.

2. Remove the associated vials from the IDEXX-QC kit and allow 15 minutes to warm the vials to room temperature. Place unused vials back in the freezer.

3. Open a vial and aseptically transfer the colored disk located at the top of the cotton plug into a labeled 100 ml bottle of sterile, non-buffered water. If the disk sticks to the vial, flame sterilize a pair of tweezers and after they are cool, gently remove the disk and place in the bottle.

4. Cap the bottle and swirl for 15 minutes until the entire disk dissolves. After the disk dissolves mix 10 times by inverting the bottle.

5. Add the media to the bottle, mix and process as a normal sample.

Note: Refer to the IDEXX-QC lot number to obtain the acceptable range of results. For Colilert a result for *E. coli* (yellow color with blue glow under UV) and *K. pneumoniae* (yellow color) should be observed. ***For Enterolert, only a blue glow should be observed.*** If results are outside the listed range, the media or testing equipment may be contaminated or the technician may require retraining.

F. References

1. ***Colilert method***- https://www.idexx.com/en/water/water-products-services/colilert/

2. ***Enterolert method***- https://www.idexx.com/en/water/water-products-services/enterolert/

Colilert Lab Sheet

					Coliform			E. coli			
Media Lot #	**Sample _ID**	**Vol_ml**	**Incubation_hrs**	**Temp**	**# Large**	**# Small**	**Coliform MPN**	**# Large**	**# Small**	**E. coli MPN**	**Comments**
	1	100			0.0	0.0	**0.1**	49	47	**2419.6**	Example.
	2	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	3	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	4	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	5	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	6	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	7	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	8	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	9	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	10	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	11	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	12	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	13	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	14	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	15	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	16	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	17	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	18	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	19	100			null	null	**#VALUE!**	null	null	**#VALUE!**	
	20	100			null	null	**#VALUE!**	null	null	**#VALUE!**	

Media Lot- List the lot number used to process the days sample, if using multiple lots of media, identify which sample a particular lot was used.
Sample ID- Replace entered values with the sample ID used by the lab
Sample Volume- Keep at 100 unless a sample was diluted or blank water used to bring up to volume. Enter the volume of sample processed (e.g. if adding 6 ml of blank water to bring to 100 ml, enter 94)
Incubation hrs- Hours sample was incubated, should be 24 +/- 2 hrs.
Temp- Incubation temp in degrees C. Record incubator temp prior to pulling the first sample from the incubator.
#Large, #Small- Enter the number of large and small cells that are positive. MPN result will be calculated from this value along with factoring in the sample volume using the attached MPN table. DO NOT modify or delete the MPN table. Reported values below 1 should be reported as <1.

Enterolert Lab Sheet

Enterococcus

Media Lot #	Sample ID	Vol ml	Incubation hrs	Temp C	# Large	# Small	E. coli MPN	Comments
	1	10			49	47	**24196.0**	Example.
	2	10			null	null	**#VALUE!**	
	3	10			null	null	**#VALUE!**	
	4	10			null	null	**#VALUE!**	
	5	10			null	null	**#VALUE!**	
	6	10			null	null	**#VALUE!**	
	7	10			null	null	**#VALUE!**	
	8	10			null	null	**#VALUE!**	
	9	10			null	null	**#VALUE!**	
	10	10			null	null	**#VALUE!**	
	11	10			null	null	**#VALUE!**	
	12	10			null	null	**#VALUE!**	
	13	10			null	null	**#VALUE!**	
	14	10			null	null	**#VALUE!**	
	15	10			null	null	**#VALUE!**	
	16	10			null	null	**#VALUE!**	
	17	10			null	null	**#VALUE!**	
	18	10			null	null	**#VALUE!**	
	19	10			null	null	**#VALUE!**	
	20	10			null	null	**#VALUE!**	

Media Lot- List the lot number used to process the days sample, if using multiple lots of media, identify which sample a particular lot was used.
Sample ID- Replace entered values the sample ID used by the lab
Sample Volume- Typically Enterococcus samples are collected in high salinity waters. Samples are typically diluted so 10 ml of sample in 90 ml of sterile dilution. The final result is 10 times greater than a traditional 100 ml sample.
Incubation _hrs- Hours sample was incubated, should be 24 +/- 2 hrs.
Temp- Incubation temp in degrees C. Record incubator temp prior to pulling the first sample from the incubator.
#Large, #Small- Enter the number of large and small cells that are positive. MPN result will be calculated from this value along with factoring in the sample volume using the attached MPN table. DO NOT modify or delete the MPN table. Reported values below 1 should be reported as <1.

Chapter 9

Chlorophyll *a*

What is Chlorophyll a?

Chlorophyll is the pigment that allows plants (including algae) to undergo photosynthesis. Chlorophyll *a* is the predominant type of chlorophyll found in algae and phytoplankton (microscopic plants).

Why Monitor Chlorophyll a?

Chlorophyll *a* is measured to estimate the abundance of algae and phytoplankton in the water. Since chlorophyll *a* concentrations can vary among algal species and with differing light conditions, chlorophyll *a* is not considered a precise measurement of the abundance of algae. Large amounts of chlorophyll *a* indicate algal blooms that are caused by excessive nutrients as discussed in Chapter 6.

In lakes, chlorophyll *a* can be used to evaluate the trophic (aging) status of the lake. As lakes "age", the amount of plant and algal life that the lake can support increases as nutrients are added. Nutrients introduced from human activities can lead to an excessive amount of plant and algal life, which decreases water clarity and leads to interference with recreational activities and decreased dissolved oxygen levels as the plants decay.

What Do Your Chlorophyll a Results Mean?

The Department of Environmental Quality (DEQ) has begun to monitor for chlorophyll *a* suspended in the water column at some of its chemical (ambient) water quality monitoring stations, particularly in estuarine areas. DEQ currently designates "nutrient enriched waters" where there is degradation due to excessive nutrients. For tidal fresh waters, estuaries and lakes, the screening value for chlorophyll *a* typically used by DEQ is 50 ug/L (micrograms/liter), or 0.50 mg/L, however evaluations of chlorophyll a are water body specific. Contact Stuart Torbeck for more information on how your chlorophyll a data (or any other data) may be used by DEQ for water quality evaluation.

The higher the concentration of chlorophyll *a* present, the more algae and phytoplankton present. Although large amounts of chlorophyll *a* indicate algal blooms, too little chlorophyll *a* may mean that not enough food is available for fish and aquatic animals.

Sample collection and test methods

There are no test kits to detect chlorophyll *a* in the field since the pigment needs to be extracted. There are two methods available to determine the concentration of chlorophyll *a* in the laboratory: Spectrophotometric and Fluorometric methods.

Sample Collection

Water samples for chlorophyll *a* analysis can be collected as grab samples (where a sample bottle is used to collect water at a particular depth) or as integrated samples

(where a series of grab samples are taken at different depths and mixed together). An integrated sample may be collected by various methods: lowering a weighted sampler that collects water as it is lowered through the water column, using a pump to collect a water sample, or using a weighted hose that is crimped to capture the water.

Collecting a grab sample may be easier and less expensive; but in some situations, a single grab sample near the surface may not be representative of the algal biomass present. In shallower waters that are well-mixed, algae may be distributed evenly and a grab sample may be representative. However, in some waters algae may be distributed unevenly in the water column and an integrated sample would be preferable.

Filtering the sample

Concentrate the sample by filtering as soon as possible after collection. If processing must be delayed, hold samples on ice or at $4^{O}C$ and protect them from exposure to light. Use opaque bottles because even brief exposures to light during the storage will alter the sample results. Samples obtained from acidic water must be processed promptly after filtration to prevent possible chlorophyll degradation due to residual acidic water on the filter. Filters from samples taken from water having a pH 7 or higher may be placed in airtight plastic bags and stored frozen for three weeks.

Depth

If you decide to collect an integrated sample, you will need to decide how deep to collect the water sample. Some programs, such as the Smith Mountain Lake Water Quality Monitoring Program coordinated by Ferrum College, collect the integrated sample through the photic zone. This is the depth in the water column where enough light penetrates to allow photosynthesis to occur and is usually estimated based on Secchi disk depth (usually one to 3.5 times the Secchi depth). Please see Chapter 12 for a description of how to measure water clarity using a Secchi disk. Sampling the upper warm water (epilimnion) and transitional water layers (thermocline) may also be appropriate. The thermocline is just below the epilimnion which prevents mixing of the warm epilimnion and the cooler bottom water of a lake.

Quality Assurance/Quality Control Issues

Chlorophyll *a* must be analyzed in a laboratory. The laboratory needs to use EPA-approved or recognized methods and the lab SOP need to be approved by DEQ for DEQ to use the data for water quality assessment. Recommended QA/QC protocols for sample collection include:

- Proper Preservation: Samples should be filtered as soon as possible after collection. Filters can be frozen and kept in the dark for up to 21 days.

- Field duplicates: A field duplicate is simply a second water sample taken at the same time as the first sample to measure the reproducibility of the

collector, method and/or analyst. It is recommended that you collect field duplicates randomly for 10% of your samples (for a large sample size, 5% is acceptable). For example, if you collect 50 samples, you should collect field duplicates at 5 of those sites and label the duplicate samples.

- Equipment blanks are only necessary if water samples are collected in a bucket or other sampling device and transferred into the sample container. An equipment blank uses a chlorophyll free sample (distilled or deionized water) to check the effectiveness of cleaning procedures and for cross-contamination between sites. An equipment blank is collected and transferred in the same manner as the stream water sample. It is recommended that equipment blanks are collected randomly for 10% of your samples (for a large sample size, 5% is acceptable).

Summary of Chlorophyll a Monitoring Methods

Method	**Monitoring Level (see Appendix 7)**
Spectrophotometric or Fluorometric	I, II or III

Chapter 10

Submerged Aquatic Vegetation (SAV)

What Are Submerged Aquatic Vegetation (SAV)?

Submerged aquatic vegetation are rooted vascular plants found in the waters of estuaries where the water is shallow and clear enough for sunlight to penetrate the water column so that photosynthesis can occur. SAV is completely submerged and does not include algae or floating plants. Salinity, temperature and substrate determine where each species of SAV can grow. Over the years, SAV beds have declined in the estuarine waters of the Chesapeake Bay and its tributaries. Nutrients, sediments from runoff, and herbicides cause a decline in SAV population.

Why Are SAV Important?

SAV beds provide food and habitat for waterfowl, fish, shellfish, and invertebrates. Juvenile blue crabs and fish use the SAV beds for cover, while the leaves of the plants serve as attachment sites for eggs and small organisms. SAV use up excess nutrients that might contribute to eutrophication of an estuary by storing a summer pulse of nutrients for later release in the fall as the plant material decomposes. SAV beds trap sediment and reduce shoreline erosion by reducing the energy of incoming waves. Photosynthesis of SAV adds oxygen to the water.

Monitoring the Habitat Requirements for SAV

The Alliance for the Chesapeake Bay (ACB) coordinates the monitoring of the water quality requirements for SAV with several other volunteer monitoring organizations. Since available sunlight is the most important factor affecting SAV growth, the amount of light available is measured by various means. ACB uses five measures to define the amount of light available to SAV. Light penetration is measured with a Secchi disk or turbidity tube. Total suspended solids (TSS) and chlorophyll *a* (estimates the amount of algae and plankton) are measured because they block sunlight from SAV. Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) are measured because they can lead to algal blooms that can also block sunlight from SAV. All of these parameters, except for light penetration (as measured by the Secchi disk), must be measured in a laboratory from samples collected in the field. Salinity is also recommended as a monitoring parameter in order to determine the basic salinity regime of the site. Please see the chapters in this manual specific to these parameters for more information.

Volunteers filtering water sample for analysis of the water quality requirements for SAV (*photo courtesy of Alliance for the Chesapeake Bay).*

What Do Your SAV Habitat Requirement Results Mean?

This section was adapted from the Chesapeake Bay Program document entitled *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis* (August 2000).

The Chesapeake Bay Program is the regional partnership that directs and conducts the restoration of the Chesapeake Bay. Monitoring, both pre and post planting, is a crucial component of any SAV planting project. Monitoring is important to identify and prioritize potential restoration sites with sufficient water quality. Likewise, monitoring is important to avoid restoration at a site with poor water quality. Post planting monitoring, including plant survival monitoring, is important in order to provide information about why a restoration project was unsuccessful or successful.

Water quality monitoring results are compared to habitat requirements developed by Chesapeake Bay Program scientists that are believed to be indicative of good water quality conditions conducive to SAV growth and survival (Table 10-1). SAV habitat parameters include primary and secondary requirements. The primary light requirement is the *minimum light requirement*, also known as the *percent light at the leaf* (PLL). This refers to the percent of light measured just below the surface of the water that reaches the surface of an SAV leaf growing at the sediment surface, after passing through the water column and any material that is accumulated on the SAV leaf surface. PLL can be calculated using water quality data of the five parameters collected by ACB volunteers: Secchi depth, dissolved inorganic nitrogen, dissolved inorganic phosphorous, total suspended solids, and chlorophyll *a*. Secondary requirements included these five parameters as well as the *water column light requirement*, also referred to as the *percent light through the water column* (PLW). This refers to the percent of light measured just below the surface of the water that reaches the sediment surface after passing through the overlying water column, but not through the accumulated material on the SAV leaf surface. PLW should only be used to evaluate water quality conditions only if the parameters necessary to calculate PLL are not available. Other secondary habitat requirements include the four laboratory parameters needed in order to calculate PLL (TSS, DIP, DIN, and Chlorophyll *a*). These four parameters are useful as diagnostic tools used to determine possible explanations of non-attainment of the necessary PLL value.

Table 10-1. Habitat requirements for SAV

For More Information about SAV

- Bay grasses info: https://www.cbf.org/about-the-bay/more-than-just-the-bay/chesapeake-plants/bay-grasses.html
- SAV monitoring, mapping, and research: https://www.vims.edu/research/units/programs/sav/index.php

Habitat Requirement	How Measured	Minimum Level
Primary		
Minimum Light Requirement, also referred to as the Percent Light at the Leaf (PLL)	Calculated using Secchi depth, DIN, DIP, TSS, and Chlorophyll *a*	>9 % (tidal freshwater and low salinity regime) - >15% for medium to high salinity regimes
Secondary		
Water Column Light Requirement, also referred to as the PLW (Percent Light through the Water Column)	Calculated using Secchi Depth or light meter	>13 % (tidal freshwater and low salinity regime) - >22% for medium to high salinity regimes
Dissolved inorganic Nitrogen (DIN)	Filtered water sample	<0.01-0.02 mg/L, depending on salinity regime
Dissolved inorganic Phosphorous (DIP)	Filtered water sample	<0.15 mg/L
Total Suspended Solids (TSS)	Water drawn through a filter	<15 mg/L
Chlorophyll *a* (Chl *a*)	Water drawn through a filter	<15 µg/L (micrograms per liter)
Epiphyte biomass	Lab measurement of epiphyte growth on Mylar strips	__N/A_

Summary of SAV Habitat Requirement Monitoring Methods

Method	Monitoring Level (see Appendix 7)
SAV Habitat Requirement Monitoring: 1. Field measurements: - Secchi depth and/or turbidity tube - salinity 2. Lab analysis of dissolved parameters for: ammonia, nitrate, nitrite, orthophosphate, total suspended solids, and chlorophyll *a*	I or II

Section 4: Physical Measures

Photos Courtesy of Katie Register and the Loudoun Wildlife Conservancy

Chapter 11

Temperature

Why Monitor Water Temperature?

The rates of biological and chemical processes depend on temperature. Temperature affects the oxygen content of the water (oxygen levels become lower as temperature increases); the rate of photosynthesis by aquatic plants; the metabolic rates of aquatic organisms; and the sensitivity of organisms to toxic wastes, parasites, and diseases.

Aquatic organisms are dependent on certain temperature ranges for optimal health. Optimal temperatures for fish depend on the species as some survive best in colder water. Benthic macroinvertebrates are also sensitive to temperature and will move in the stream to find their optimal temperature. For fish, there are two kinds of limiting temperatures: the maximum temperature for short exposures and a weekly average temperature that varies according to the time of year and the life cycle stage of the fish species. Reproductive stages (spawning and embryo development) are the most sensitive stages. If temperatures are outside this optimal range for a prolonged period of time, aquatic organisms are stressed and can die. Also, dramatic shifts in water temperature can cause stress to aquatic organisms.

What Do Your Water Temperature Measurements Mean?

Temperature changes can be caused by weather, removal of stream bank vegetation (which provides shade), impoundments (caused by barriers such as dams), cooling water discharge, urban storm water, and groundwater flowing into the stream. The water quality standards for water temperature in Virginia can be found in Table 11-1 below. Water temperature readings above these numbers indicate a violation of our state's water quality standards.

Table 11-1. Virginia Water Quality Standards for Temperature.

Estuarine Waters	**Nontidal Waters – Coastal / Piedmont**	**Mountainous Zones**	**Stockable Trout Waters**	**Natural Trout Waters**
Rise above natural temperature (arithmetic average over one hour) should not exceed 3°C.	32°C (maximum)	31°C (maximum)	21°C (maximum)	20°C (maximum)

Sampling and Quality Assurance/Quality Control (QA/QC) Considerations

Chapter 1 outlined a number of factors that every volunteer water quality monitoring program should consider. In addition to those summarized in Chapter 1, several considerations specific to monitoring for temperature are discussed below.

Air Temperature

If air temperature is measured in addition to water temperature, then the air temperature reading should be measured prior to the water temperature. A wet thermometer can alter the air temperature reading. Air temperatures should be measured in the shade.

Choosing a Method

Temperature must be measured in the stream and may be measured with a thermometer or a meter. Temperature is measured in degrees Fahrenheit (F) or degrees Celsius (C). Temperature should be measured at the same place every time.

Thermometer

Alcohol-filled thermometers are preferred over mercury-filled because they are less hazardous if broken. Armored thermometers for field use can withstand more abuse than unprotected glass thermometers. Thermometer increments should be no more than 1°C.

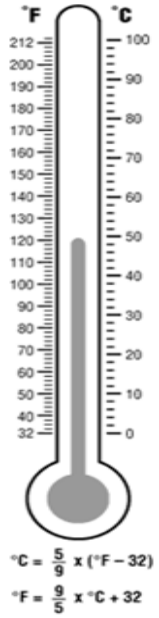


Figure 11-1. Scale for temperature conversion *(from Volunteer Estuary Monitoring: A Methods Manual, Second Edition).*

Thermistor

Thermistors can be stand-alone meters or combined with other parameters, such as pH or dissolved oxygen.

> Located at the end of this chapter are procedures developed by the Alliance for the Chesapeake Bay for measuring water temperature and yearly calibration of thermometers and thermistors.

Quality Assurance/Quality Control Issues

To assure accuracy, thermometers and thermistors should be verified annually with a National Institute of Standards and Technology (NIST) certified traceable thermometer. You should compare these instruments at varying temperatures: an ice bath, room temperature, and warm water bath. If the difference between your equipment and the certified thermometer is greater than 1º C during any of the comparisons, your equipment does not meet the Department of Environmental Quality's (DEQ) QA/QC requirements for data use in water quality assessments.

Where Can You Find a Certified Thermometer?

- DEQ Regional Office
- Local college/university
- Local EPA-certified laboratory

Summary of Water Temperature Monitoring Methods

Method	**Monitoring Level (see Appendix 7)**
Field Thermometers (non-mercury)	I, II, or III
Thermistor (usually included with pH and dissolved oxygen probes)	I, II, or III

Water Temperature Measurement- *Provided by the Alliance for the Chesapeake Bay*

Equipment: armored thermometer

Method (no bucket):

1. If you are not using a bucket, hold the thermometer by the top with the thermometer submerged in the stream.

2. Wait 3-5 minutes to allow the thermometer to equilibrate (but not long enough for water temperature to change).

3. Record water temperature to the nearest 0.5 ºC.

Method (with bucket):

If you have collected the water sample in the bucket, hang thermometer in the bucket and follow steps 2 and 3 above.

Equipment: Thermistor Probe

Method:

1. Place the thermistor in the waterbody being measured

2. Wait 1-2 minutes to allow the probe to stabilize. It may help to slowly move the probe side to side to provide a uniform measurement

3. Record water temperature to the nearest 0.1 ºC.

Thermometer Calibration: (for Level III compliance)- *Provided by the Alliance for the Chesapeake Bay*

Every year, thermometers and electronic probes should be validated against a NIST-certified thermometer. This is necessary to ensure the thermometers and probes are recording accurate temperature readings. The Virginia Department of Environmental Quality (DEQ) and other organizations can assist monitoring groups in this process.

Before You Begin

You will need the following materials:

1. Thermometer needing validating
2. NIST-certified thermometer calibrated within 1 year of the date of the calibration
3. hot plate or other source for heating water
4. 2 beakers or containers of water
5. clamps to suspend the thermometers
6. stir rod

Prior to starting the calibration, you will need to adjust the temperature of the water in each beaker:

a. For the first beaker, pour the water into the container and allow it to adjust to room temperature. The temperature should be between 20-25^{o}C. (Note: You can leave the beaker of water out overnight prior to validating the thermometers so that it can reach room temperature).
b. Place the second beaker of water onto the hotplate or warm up in a microwave or similar device. The final temperature should be between 32-35^{o}C. (Note: this may take 15-45 minutes if using a hot plate).

You can use the stir rod to mix hot water beaker to achieve a uniform temperature.

Thermometer physical check

Perform the following checks to the thermometer prior to calibration:

a. Check both the NIST and thermometers for nicks and scratches.
b. Check the column of both thermometers to ensure that the column does not have breaks or separations.
c. Observe to see if the NIST or the thermometer being validated has a solid line drawn or etched near the bottom quarter of the glass body. If so, this is a **partial immersion thermometer**. For a partial immersion thermometer, you should only submerge the thermometer to this line. If you do not see a line, the thermometer is a **full immersion thermometer**. You can submerge this type of thermometer into the water filled beakers to about one inch from the bottom.

Validation

Room temperature beaker-

1. Carefully remove both thermometers and place them into the beaker of water set at room temperature. Ideally, the water should be between 20-25^{o}C.

2. Allow two minutes for the thermometers to adjust to the temperature. You should observe a result between 20-25^{o}C. Do not touch or hold the thermometer with your hands or remove the thermometer from the water. Doing this will raise the temperature and give you an inaccurate reading.

3. Record the result of the NIST thermometer onto your log sheet. To read the thermometer correctly, keep it immersed in the water and look at the top of the column at eye level. Record the values to the nearest unit. Usually this is 0.2 or 0.5 ^{o}C.

4. Repeat this process for other thermometers or probes needing validation.

Hot water beaker-

1. Remove the thermometers from the room temperature beaker and immerse them into the beaker of hot water. The temperature of the water should be between 32-35^{o}C.

2. Record the NIST certified and thermometer being verified temperatures using the same procedure outlined in the room temperature beaker.

Once you have removed the thermometers, allow them to cool down to room temperature. Do not try to cool down the thermometers quickly as it may separate the column.

Compare the results between the NIST and the thermometer. If difference of temperature is less than 1.0 ^{o}C, record the difference on the log sheet and use the correction when using the now validated thermometer. It is a good idea to mark this difference on the thermometer using masking tape or other means. If the difference is greater than 1.0^{o}C, retest the thermometers. If temperatures are still off by more than 1.0^{o}C, discard and replace the thermometer.

Thermometer Validation Log Sheet

Group name: _____ Date of Validation: _____

Validated by: _____ NIST Cal/Val Date: _____

Thermometer Type or Model	Thermometer ID	NIST Reading (~Room Temp)	Thermometer Reading	Difference	Within 1 C? (Circle One)		NIST Reading (~35 C)	Thermometer Reading	Difference	Within 1 C? (Circle One)	
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO
					YES	NO				YES	NO

Chapter 12

Turbidity/Transparency

What Are Turbidity/Transparency?

Although the terms "turbidity" and "transparency" are often used interchangeably, they are different measurements. Turbidity is the cloudiness of water determined by measuring how the material suspended in water affects the water's clarity (how well light passes through the water column). Turbidity does not measure the amount of materials suspended in the water (such as soil, algae, and plankton); but it does measure the amount of light scattered by these particles. Turbid water appears murky or cloudy. Transparency, however, is the clarity (clearness) of the water determined by measuring how well light passes through the water. Both color and suspended materials can affect transparency.

Why Monitor Turbidity/Transparency?

Turbidity/transparency and total solids can be useful indicators of discharges and runoff effects from construction, agricultural practices, logging activity, and waste discharges. Monitoring these parameters may help indicate whether erosion is increasing in a watershed. Turbidity can be caused by any activity that disturbs the stream banks, streambed, or surrounding land that causes sediment runoff into the stream. Turbidity often increases during and just after rainfall, especially in watersheds with a large number of impervious surfaces (rooftops, pavement, parking lots). Stormwater runoff from impervious surfaces rapidly increases the volume and velocity of stream flow, which erodes stream banks.

Sources of Turbidity

- Excessive algal growth due to nutrient enrichment
- Soil erosion from logging, agriculture, or construction
- Stormwater runoff
- Eroding stream banks
- Disturbance of bottom sediments
- Waste discharges

High turbidity levels affect SAV and dissolved oxygen levels. Turbidity reduces the amount of light penetrating the water, reducing photosynthesis and lowering the production of dissolved oxygen. Therefore, high turbidity can reduce SAV. Water temperature also increases with high turbidity levels because suspended particles absorb heat, which reduces dissolved oxygen levels (please refer to Chapter 4). Large amounts of suspended materials can clog fish gills, reduce disease resistance in fish, lower growth rates, and negatively affect egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, smothering fish eggs, benthic macroinvertebrates and the streambed habitat. Toxins also attach easily to suspended solids. The concentration of dissolved solids (such as chloride, nitrate, phosphate, iron, sulfate, magnesium, and calcium) may affect the water balance in the cells of aquatic organisms making it difficult for them to keep their position in the water column. This will in turn affect the organism's ability to maintain the proper cell density.

What Do Your Turbidity/Transparency Results Mean?

Although there are no water quality standards in Virginia for or turbidity, this information can be useful when looking at trends and can provide information about local land use and sediment control programs. It is important to remember that turbidity/transparency does not measure the amount of suspended solids or the rate of sedimentation. Since algae can be the major source of

suspended solids in estuarine waters, seasonal variations must also be taken into consideration when analyzing turbidity.

Sampling and Quality Assurance/Quality Control (QA/QC) Considerations

Chapter 1 outlined a number of factors that every volunteer water quality monitoring program should consider. In addition to those summarized in Chapter 1, several considerations specific to monitoring for turbidity/transparency are discussed below.

When to Sample

To gain information that would be useful for looking at trends, turbidity should be monitored relatively frequently year-round for several years. Since turbidity often increases during and immediately after a rainfall, you may consider collecting additional turbidity data to capture the effects of runoff.

Choosing a Method

Secchi Disk

This weighted disk is used to measure transparency (an integrated measure of light scattering and absorption) by lowering the disk into the water and measuring the depth where the disk disappears (Secchi depth). The clearer the water the greater the Secchi depth. Many volunteer programs in lakes or tidal, estuarine waters use the Secchi disk because it is inexpensive and easy to use. Secchi disk lines may shrink over time and lines that are marked for measurements should be calibrated regularly. Using a rope that has minimal shrinkage is also recommended. The Secchi disk is not appropriate for use in shallow, fast moving waters.

Secchi disk *(photo courtesy of Alliance for the Chesapeake Bay).*

Located at the end of this chapter are procedures developed by the Alliance for the Chesapeake Bay for measuring Secchi depth.

Transparency Tube

This is a clear, plastic tube with a pattern on the bottom (sometimes a miniature Secchi disk). Water is poured into the tube and the measurement (usually in centimeters) where the pattern disappears is recorded. Waters with extreme colors can interfere with this measurement. The readings from transparency tubes from different manufacturers cannot be compared. This instrument was

developed to measure transparency in waters where the Secchi disk is not appropriate (site is too shallow, the flow is too rapid, or there is no dock or pier).

> Located at the end of this chapter are procedures developed by the Alliance for the Chesapeake Bay for using transparency tubes.

Turbidity Probes

A turbidity probe usually measures turbidity in Nephelometric Turbidity Units (or NTUs). A turbidity probe can be calibrated by using known standard concentration and is used in the field to measure the turbidity of water samples.

Laboratory Analysis

Lab analysis can be used to determine turbidity

Summary of Turbidity/Transparency Methods

Method (Vendor and Model #)	**Monitoring Level (see Appendix 7)**
Secchi Disk	I
Transparency Tube	I
Turbidity probe	I
Laboratory Analysis	I

Secchi Transparency Measurement- *Provided by the Alliance for the Chesapeake Bay*

The Secchi disk provides a convenient method for measuring light penetration below the water surface and is widely used as a basic measure of water clarity. The Secchi disk is a black and white disk attached in the center to a marked line that is used to determine the transparency or limit of visibility of the water. The line is measured and marked in decimeters (tenths of a meter) and meters. When the weighted disk is lowered slowly straight down into the water, the exact depth just before the disk disappears from view is observed. This depth is known as the "Secchi disk transparency." The less algae and silt in the water, the deeper the Secchi disk will be visible. Alternately, shallow readings will occur in water with significant amounts of suspended algae and silt.

Equipment: 8" Secchi disk with attached line (nylon or other material that does not stretch)

Method:

1. Remove sunglasses if you are wearing them and stand with the sun to your back. Try to lower the disk into a shaded area.

2. Lower the disk into the water until the disk barely disappears from sight. Note the depth reading, in meters, based on the length of line submerged. Each black mark is one-tenth (or 0.1) meter, and each red mark is one (1) meter.

3. Slowly raise the disk and record the depth at which it reappears (i.e. is barely perceptible).

4. Average the two depth readings obtained above. The average of the two readings is considered to be the limit of visibility, or index of transparency. Record this average to the nearest tenth of a meter on your data form.

Yearly Calibration:

1. Lay out the Secchi disk and line on a table with a tape measure or ruler attached to the table. Tape measures or ruler units should be in meters.

2. Measure the marks on the line. Each mark should be 0.1 meters apart.

    a. It is recommended to use cable ties as they can be cut off and replaced. Markers tend to fade over time. If adding new cable ties, tighten them on the cable as much as possible to prevent them from moving

    b. Mark 0.1 meter (10 centimeter) graduations with one color and 1.0 meter graduations in another color to help with measuring Secchi depth.

Transparency Tube Measurement- *Provided by the Alliance for the Chesapeake Bay*

Transparency tubes are a type of equipment used for measuring transparency of water in streams and rivers. They are helpful for measuring transparency in situations where the stream is too shallow for the Secchi disk to be practical and for running waters where flow is too fast that the Secchi disk cannot remain vertical. Sample water collected either directly from the stream or from the sampling bucket is analyzed.

Equipment: Transparency tube- 60 or 120 cm long with drain tube

Method:

1. Close the drain tube by squeezing the crimp.

2. Fill the transparency tube with your sample water. Water may be collected directly from the stream in the vicinity of the sampling location if the stream is too small to fill the bucket, or sample water collected in the sampling bucket may be used (See 5.4, "Collecting the Water Sample"). To collect water directly from the stream, point the top of the tube in the upstream direction and collect surface water, being careful not to disturb the stream bed. To analyze water collected in the bucket, pour sample water from the bucket water directly into the transparency tube.

3. While looking down through the opening of the tube, partially open drain crimp, slowly draw off sample (Control flow by squeezing the crimp).

4. When the black and white pattern begins to appear, immediately tighten the crimp.

5. Record the level of water remaining via the centimeter ruler found on the side of tube.

Yearly Calibration:

1. Prepare a solution of water dyed with food coloring. The recommended mixture is 50 drops of red coloring with 10 drops of green coloring in 5 quarts (1 ¼ gallons) of water.

2. Slowly pour colored solution into the turbidity tube to the top.

    a. If you are able to see Secchi pattern at bottom when tube, empty the tube and add more food coloring and try attain.

    b. If you pour in water too quickly, bubbles can form causing difficulty in reading the results

3. Slowly drain the tube until the volunteer can just make out the Secchi disk pattern.

4. Repeat steps 1-3 again to confirm results

Chapter 13

Salinity

What is Salinity?

Salinity is the amount of dissolved salts in water. Salinity of tidal rivers and estuaries gradually increases as you move from freshwater tributaries toward the ocean. Salinity is usually measured in parts per thousand (ppt). Freshwater streams and rivers have salinity levels of 0.5 ppt or less. Salinity of seawater is relatively constant at more than 30 ppt.

Why Monitor Salinity?

Salinity levels affect the distribution of plants and animals in estuarine environments. Some species can only tolerate certain levels of salinity while others may be able to adjust to any salinity ranging from freshwater to saltwater.

Salinity influences the saturation levels of dissolved oxygen. The amount of dissolved oxygen (DO) the water can hold decreases as the salinity increases. If you are using a probe to measure DO in estuarine waters, you may need to know the salinity level in order to properly calculate percent saturated DO. Salinity can have a role in increasing turbidity by causing dissolved particles in fresh water to clump together upon entering the saltwater. Salinity and water temperature determine the stratification of estuarine waters. Cold, saltwater is denser than warm, freshwater and will sink below the freshwater. Tides and the wind can mix these waters and eliminate the stratification.

What Do Your Salinity Results Mean?

Although there is not a water quality standard in Virginia for salinity, this information can be useful when you are looking at trends, distribution of plant and animals, and other water quality parameters.

Sample Collection and Test Methods

Weather and Season

During wet weather periods, freshwater enters the estuarine waters lowering salinity levels. Higher salinity levels are found during dry weather periods since less freshwater dilutes the estuarine waters allowing saltwater to intrude into tidal rivers and streams. Seasonal variations and storms also help mix these waters.

Choosing a Method

Density Using a Hydrometer

Hydrometers are inexpensive, fragile and very consistent over time. The hydrometer measures the specific gravity of the water sample, which is the sample's density compared to the density of freshwater. As the salinity of water increases so does its density. Specific gravity is affected by both dissolved and suspended solids; whereas, salinity is based upon dissolved solids only. Therefore, salinity readings measured with a hydrometer are higher when suspended solids are present, especially in low salinity waters.

Figure 13-1. A hydrometer can be used to calculate salinity based upon the density of the water *(from Volunteer Estuary Monitoring: A Methods Manual, Second Edition).*

Refractivity Using a Refractometer

A refractometer is not influenced by suspended solids like the hydrometer. As light travels from air into water, the refractometer measures the change in the light's direction. The extent of this change in direction is influenced in a predictable manner by the salinity of the water. To yield accurate results, the refractometer must be close to the temperature of the sample water.

> Located at the end of this chapter are procedures developed by the Alliance for the Chesapeake Bay for using Hydrometers or Refractometers.

Probes

Salinity can be calculated from the conductivity reading (conductivity is discussed in Chapter 14). Samples may be collected and transported to a central location for measurement when using a probe. See chapter 14 for more information on using a conductivity meter.

Summary of Salinity Monitoring Methods

Method	Monitoring Level (see Appendix 7)
Hydrometer	I
Refractometer	I
Conductivity probe	I

Salinity Measurement- *Provided by the Alliance for the Chesapeake Bay*

Equipment: LaMotte Hydrometer #3-0025

Method:

1. Fill plastic hydrometer jar about 3/4 full with water to be tested.

2. Hang the thermometer in the jar.

3. Lower hydrometer into the jar. Allow it to float.

4. Read and record temperature in jar.

5. Read and record temperature in hydrometer jar.

6. Read and record specific gravity to the fourth decimal place.

7. When reading the hydrometer, it is easier if you are eye level with the hydrometer. Note that the water climbs the hydrometer stem and should be read at the water level not the point where it climbs.

8. Record your temperature and salinity readings.

To calculate Salinity:

Refer to the table provided in the LaMotte hydrometer instruction booklet. Follow the example below.

Example:

Observed hydrometer reading is 1.0110, and the water temperature in the hydrometer jar is 25.5ºC. Locate observed density of 1.0110 on the left hand column of Table 1 in the LaMotte hydrometer instruction booklet. Follow the row across until finding the 25.5ºC column. The point at which the row and column meet is the resulting salinity of the sample, in this case 17.0 ppt. Observed densities and temperatures falling between those shown in the table may be interpolated.

Salinity Measurement- *Provided by the Alliance for the Chesapeake Bay*

Equipment: Refractometer

Calibrate Your Refractometer*

* The refractometer must be calibrated before taking salinity measurements.

1. Check the refractometer with distilled water. If it does not read 0 o/oo (another notation for ppt), you must calibrate the instrument. DO NOT PERFORM CALIBRATION IN THE FIELD. Calibration must take place in controlled environment at approximately 20 ^{o}C (room temperature) using distilled water of the same temperature.

2. Lift the cleat plate and add 1-2 drops of distilled water to the oval blue prism. Hold the prism at an angle close to parallel so the water drops will not run off.

3. Close the plate gently. The water drops should spread and cover the entire prism. Repeat the process if there are any gaps or if the sample is only on one portion of the prism.

4. Look through the eyepiece. If the scale is not in focus, adjust it by turning the eyepiece either clockwise or counterclockwise.

5. The reading is taken at the point where the boundary line of the blue and white fields crosses the scale.

6. If the reading is not at "0" turn the calibration screw with the included screwdriver while looking through the eyepiece until the boundary line falls on "0."

7. When the measurement is complete, the sample must be cleaned using tissue paper and distilled water.

NOTE: The refractometer needs to be at the same approximate temperature as the sample water. If the refractometer has been sitting in an air-conditioned environment prior to sampling, allow it to warm to the outside air temperature.

Method:

1. Rinse the refractometer with water sample.

2. Apply drops from water sample on refractometer and hold up to light to read salinity (right side of circle).

3. Record as parts per thousand (o/oo) using the scale located on the right hand side of refractometer view scope.

Chapter 14

Conductivity

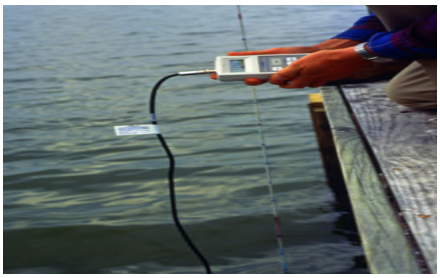
What is Conductivity?

Conductivity is the ability of water to pass an electrical current. Conductivity is affected (raised) by inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge); and sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Oils and many organic compounds do not conduct an electrical current very well and therefore, do not affect conductivity. When the conductivity value is corrected to $25^{O}C$ the corrected value is called specific conductance. Conductivity usually is reported as specific conductance and is measured in micromhos per centimeter or microsiemens per second.

The geology of the area through which a stream flows is one of the most important factors affecting conductivity. Streams in areas with granite bedrock usually have lower conductivity levels because granite is composed of relatively inert material that does not conduct an electrical current very well. Alternatively, streams in areas with clay soils usually have a higher conductivity because of the presence of materials that conduct electrical currents. Ground water inflows can have the same effects depending on the bedrock they flow through. Warmer water has a higher conductivity than colder water.

Why Monitor Conductivity?

Conductivity is a useful measure of general water quality. Each stream generally has a relatively constant range of conductivity. Once you establish the baseline conductivity range for a stream, you can compare regular conductivity measurements. Significant changes in conductivity may indicate a discharge or another source of pollution is affecting the stream.



Volunteer measuring conductivity with a meter *(photo courtesy of Alliance for the Chesapeake Bay).*

Discharges to streams can affect the conductivity depending on the type of discharge. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate (which would conduct an electrical current well). An oil spill, however, would lower the conductivity. Heavy rains also lower the conductivity since rainwater has a very low conductivity.

What Do Your Conductivity Results Mean?

Although there are no water quality standards in Virginia for conductivity, this information can be useful when you are looking at trends and general water quality. As discussed in the section above, significant changes in conductivity measurements can indicate potential problems that may need further investigation.

Sampling and Quality Assurance/Quality Control (QA/QC) Considerations

Conductivity may be measured in the field or samples may be transported to a laboratory for determination with a probe.

Conductivity probes should be calibrated with conductivity standards for the expected range in the field. Additionally, the calibration should be confirmed at the end of the sampling day (this is referred to as a "post check") to determine if the probe has drifted during the sampling day. The post check should be conducted similar to the calibration without pressing the calibration button.

Located at the end of this chapter are instructions and a sample calibration log sheet developed by DEQ for using conductivity probes.

Summary of Conductivity Monitoring Methods

Method	**Monitoring Level (see Appendix 7)**
Probe (a multi-parameter meter is more cost-effective than a single parameter meter)	I

Calibrating Conductivity Probes and Meters- *Provided by the Virginia Department of Environmental Quality*

Equipment: Various models of conductivity probes and meters

Most probes that test for conductivity use a pre-made calibration solution with a specific conductivity value. The probe is immersed in the solution and calibrated to the value of the solution. It is good to use a calibration solution concentration similar to what you may find in the field to ensure accuracy.

Date- Record the date of calibration. Calibration must be done each day you perform samples.

Temp C Pre Cal- Temperature of the probe while you are calibrating the probe.

Cond Pre Cal- Write down the conductivity listed on the probe when you immerse the probe into the conductivity solution and record the value prior to calibration.

Cond Cal Solution (mS/cm)- Record the conductivity solution that you will use to calibrate the probe. The standard unit for these solutions is in microsiemens per centimeter (mS/cm) but probes may use different units.

Cond to Cal- Write down the conductivity reading after you have calibrated the probe in the solution. The probe should be very close to the calibrated buffer solution but may be off by a couple of units.

Temp C Post Check- Record the temperature of the probe at the end of the day when you are performing the calibration check.

Cond Post Check- Record the conductivity value of the probe you place the probe into the conductivity calibration solution. The value should be near the morning calibration solution.

Difference m/S- DEQ does not have specific standard to know if the probe is functioning properly or not. However, the standard rule of thumb is if the probe difference is less than 10.00%, you should be confident of the probe values. To calculate the **percent difference** use the formula found under QA/QC section of Appendix 15.

Initial- Please initial the person calibrating and using the probe for your records. This is good to know in case something happens to the probe that you may not be aware of due to someone else is using it.

Notes- Space provided for any notes or comments regarding the probe.

Conductivity Probe Calibration Form

Group Name:						**Probe Model:**			
<10% Difference probe OK						**>10% Difference Flag data and service probe**			
Date	**Temp C in Morning**	**Cond Before Cal**	**Cond cal solution (mS/cm)**	**Cond to Cal**	**Temp C End of Day**	**Cond at End of Day**	**Difference m/S**	**Initials**	**Notes**
1/1/2004	20.4	134	147	147.1	20.6	150	**101.97%**	JEB	This is an example
1/2/2004	22	140	147	147	20.1	125	**85.03%**	JEB	This is an example

Chapter 15

Stream Flow

What is Stream Flow?

Stream flow (discharge) is the volume of water that passes a given stream cross section (total width of stream) within a given period of time. Flow is measured by determining the depth and width of a stream and the velocity (speed at which water travels). The area (width multiplied by depth of a stream) multiplied by the velocity gives the discharge. Flow is affected by weather (increases during rain events), seasons (decreases during summer due to evaporation and uptake by vegetation), water withdrawals, water discharges, and the groundwater table level.

Why is Stream Flow Important?

Stream flow impacts water quality and the living organisms and habitats in the stream. The amount of pollution a stream can receive without significantly affecting the water quality partially depends upon the stream flow. Swiftly flowing, large rivers have a greater capacity to dilute pollution than small streams. Stream velocity, which is partly determined by the volume of water in the stream, affects the kinds of organisms that live in the stream (some organisms prefer faster flowing streams while others prefer slower flowing streams). Sediment entering slow flowing streams will settle quickly, while sediment in fast flowing streams will remain suspended longer. Dissolved oxygen is also affected by stream flow since fast moving streams are better aerated, which results in higher dissolved oxygen levels.

What Do Flow Measurements Mean?

Since flow is a function of water volume and velocity, it is usually expressed as cubic feet per second (ft^3/sec). Stream flow is needed to calculate how much of a pollutant the stream can receive without violating a water quality standard.

Flow data collected by volunteer monitoring programs is not typically used for TMDLs and permit applications. Data users that generally use flow data for scientific analysis (rather than permitting or other legal matters) have demonstrated an interest in any flow data. Potential uses include: conducting minimum in-stream flow analysis; relating flow measures to Wolman Pebble Counts (and Riffle Stability Index develop by the United States Forest Service); and relating flow measures to benthic macroinvertebrate populations.

Measurement Considerations

When considering measuring flow in your watershed, it is recommended that you first determine if your watershed has a stream gauge collecting flow data operated by the Department of Environmental Quality (DEQ) or the U. S. Geological Survey (USGS). USGS and DEQ work cooperatively to maintain a network of approximately 161 continuous stream flow gauging stations across Virginia. By going to the USGS Water Resources website at http://va.water.usgs.gov, users can find flow data for most of these stations which can be found in real-time (updated every 1-4 hours). The flow of most streams in Virginia is not determined on a consistent basis. In most cases where real flow data does not exist, flow is estimated by interpolating flow data from an existing gauge to the stream in question. DEQ and USGS

measure flow using methods derived from USGS (as outlined in Rantz, S.E., and others, 1982, *Measurement and Computation of Streamflow: Volume 2. Computation of Discharge.* U. S. Geological Survey Water-Supply Paper. 2175).

The Virginia Save Our Streams Program (VA SOS) evaluated how flow measures are collected across the country and how flow measures collected by volunteers can be used. From this research, VA SOS found that flow is not commonly measured by volunteer monitoring programs due to the difficulty in obtaining data that is useful to water quality professionals. It is important for volunteer monitoring programs to obtain the most accurate estimate of stream flow possible with the equipment and expertise of the organization.

Located at the end of this chapter are instructions provided by DEQ on how to perform basic stream flow measurements.

Summary of Stream Flow Monitoring Methods

Method	**Monitoring Level (see Appendix 7)**
Estimate using float and cross sectional area, length, and velocity	I
Flow Meters	I

Flow Measurement Guide- *Provided by the Virginia Department of Environmental Quality with material from the United States Environmental Protection Agency*

Caution! Measuring flow may require entering the stream. Do not perform this measurement if the stream is deep or has fast flowing water. In addition, if the stream is located on private property, seek landowner permission. Follow all safety guidelines as outlined in Chapter 1.

Materials you will need:

1. String or rope
2. Two stakes and hammer
3. Tape measure (at least 20 feet but preferably 50 to 100 feet)
4. Waterproof yardstick or tape measure to measure stream depth
5. Orange or small stick that will float in the water or flow meter
6. Stopwatch, notepad, pen or pencil
7. Waders, hip boots, or sneakers that you won't mind getting wet

Selecting a Site

Select a segment of stream that can be accessed safely and has a long straight section of at least 20 feet with a minimum depth of six inches. Good locations are near bridges, but other good locations are along riffles or stream runs. If possible, it is recommended to set up a flow station at or near a sampling station so you can use stream flow data with your sampling program.

Establishing a Transect

1. Observe the banks where you will set the stakes. Use the stakes and drive them into the ground where you believe the bank ends. Usually this is marked by dry ground with grass or shrubs growing and is free of debris

2. Tie the string taught between both stakes. Mark the string starting from one bank going towards the other with twist ties or markers. These marks will be where you perform the transects. The recommended minimum number of segments should be three. Most monitoring programs perform transects every two feet. Figure 15-1 shows a general transect scheme.

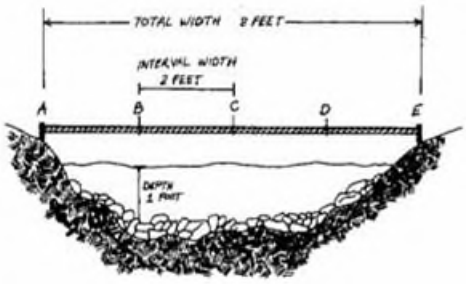


Figure 15-1. Stream transect *(from Volunteer Stream Monitoring: A Methods Manual, Second Edition).*

3. Record stream depth at each transect mark. Record the depth of water from the bottom of the stream at each mark. Record 0 if there is no water at a transect mark. You can also record the total height from the bottom of the stream to the transect line to determine the bank capacity of the stream.

4. To calculate the average depth of the stream, average your transect values and then multiply the value by the length of the stream.

Measuring Velocity

Using Orange or Other Floating Device

1. Go up a measured distance upstream from the transect site (usually 20 to 50 feet). The longer the distance, the more accurate the results.

2. With one volunteer at the transect site with a stopwatch, hold the float in the stream where the greatest amount of water flows. Most often, this is the middle of the stream.

3. Release the float when the downstream volunteer is ready to start timing with the stopwatch.

4. Time the float until it reaches the transect site. Discard results if the float became entangled with debris or stopped due to running aground.

5. Retrieve the float.

6. Repeat steps 1-4 to make at least three observations.

7. Average results to get the average rate of flow.

Using Flow Meter

1. At each transect point; place the flow meter in the stream as specified by instructions provided by the manufacturer.

2. Count the number of clicks or report the number of revolutions the flow meter records for 1 minute.

3. Repeat steps 1 and 2 at each transect station.

4. Determine the rate of flow based on the manual provided by the manufacturer. Often the result will be feet per second or meters per second.

Calculating Stream Flow

Calculating stream flow using oranges or similar floats, use the following formula

Flow = ALC / T

A =	Area of stream (stream depth x stream width)
L =	Distance covered by float run
C =	0.9 if the streambed is smooth (silt, sand, or bedrock) 0.8 if the streambed is rough (rubble, stones, gravel)
T =	Average time of float run

Example: A= 10 ft^2, L =100 ft, C= 0.8, and T =60 seconds

Flow = (10 ft^2 x 100 ft x 0.8) / 60 seconds

Flow = 800 cubic feet / 60 seconds = **13.34 ft^3/sec**

Calculating stream flow using flow meters, use the following formula

Flow = AMC

A =	Area of stream
M =	Measured flow rate based on average flow meter readings
C =	0.9 if the streambed is smooth (silt, sand, or bedrock) 0.8 if the streambed is rough (rubble, stones, gravel)

Example: A = 5 ft^2, M = 1.2 feet per second, C = 0.9

Flow = (5 ft^2 x 1.2 ft/sec x 0.9)

Flow = 5.40 ft^3/sec

Chapter 16

Visual Stream Assessments

(Stream Walks)

What is a Visual Stream Assessment?

A visual stream assessment is basically a "stream walk" to evaluate stream health by assessing the physical habitat and potential impacts along a stream channel. A stream walk may be done on foot or by using a boat or canoe depending on the stream.

Why Conduct a Stream Walk?

Conducting a stream walk can produce valuable information about your stream. You may wish to conduct a stream walk prior to water quality monitoring to determine where to focus monitoring efforts. A stream walk may be performed in conjunction with water quality monitoring to help you formulate some theories about what may be impacting the monitoring data. Some stream walks may be conducted to determine potential impacts on stream health with no plans of monitoring.

How Can You Use the Information from a Stream Walk?

Stream walks may collect qualitative (such as rating erosion) or quantitative (such as mapping pipe outfalls) information which will ultimately determine the use of the information gathered. This information can be used to establish baseline conditions and then later stream walks can document changes over time. Some organizations may use the information to determine areas where best management practices (BMPs) are needed. BMPs are pollution control techniques used to reduce pollution from agriculture, timbering practices, construction, marinas, and stormwater. For impaired streams, the stream walk information may be useful background information for developing Total Maximum Daily Load (TMDL) Plans and TMDL Implementation Plans.

How Do You Conduct a Stream Walk?

There are several methods utilized for conducting stream walks, which are based upon similar elements. These methods often are adapted specifically to the stream and the goals of the organization conducting the stream walk.

Chapter 17

Riparian Forests and Stream Health

This chapter has been excerpted and adapted, with permission, from Austin, Samuel H. 1999. *Riparian Forest Handbook 1,* Virginia Department of Forestry, December.

What is a Riparian Forest and Why is it Important?

A riparian forest is simply a streamside forest. The benefits of riparian forests are numerous, from protecting the physical stream environment to removing or transforming nutrients, sediments and pollutants. Overall, riparian forests lead to improved water quality.

Riparian forests protect the physical stream environment in a number of ways:

- Riparian forests help reduce fluctuations in water temperature and regulate light levels reaching a stream resulting in a more stable habitat for plant and animal life.
- Riparian forests provide woody debris for increased habitat diversity for benthic macroinvertebrates and fish.
- Leaf litter and algal (microscopic plant) production, the two primary sources of food energy inputs to streams, are intimately tied to the presence of riparian forests. Studies show that the algal community of a stream well-shaded by older trees is dominated by single-celled algae (diatoms) throughout the year. Streams in deforested areas often contain many thread-like (filamentous) green algae, and few diatoms. While some macroinvertebrates such as crayfish readily consume filamentous green algae, most herbivorous species of stream macroinvertebrates have evolved mouth parts specialized for scraping diatoms from the hard surfaces and cannot eat filamentous algae. Streamside deforestation is one factor that can cause macroinvertebrate diversity to decline.
- Absence of a streamside forest can change channel morphology (the dimension, pattern, and profile of a channel) resulting in habitat loss.

Healthy forest streams have a stable dimension, pattern, and profile that fit the natural landform of the surrounding landscape. Stable natural channels tend to be sinuous and relatively narrow with little exposed or eroding stream bank. They also have access to an active flood plain. Without trees, stream banks may erode creating an unnaturally wide channel. Water velocities may increase as water moves without woody debris to absorb the energy. Faster water combined with altered channel shape can cause bank scour, stream straightening, and excess sediment deposition in the streambed. Each of these can create a degraded environment that supports fewer aquatic plant and animal species.

Eroded stream bank *(photo courtesy of Alliance for the Chesapeake Bay).*

Stream systems are dynamic, but the change in stable stream systems occurs very slowly within the context of the landscape. Throughout history, humans altered the landscape causing profound effects on the landscape, streams, and rivers. Sections of streams and rivers within many watersheds shifted from a stable geometry to an unstable geometry. These adjustments continue

today. The effects of human activity within the watershed are pronounced and visible on the landscape. As land is cleared, a cycle of events evolves that continues to degrade the stream system.

Why Evaluate Riparian Forests?

Evaluation of your stream's riparian forest may require additional training and technical expertise. However, this activity may be particularly rewarding for volunteer organizations interested in taking water quality monitoring to another level - restoration.

How Can You Use the Information from Your Evaluation?

The Virginia Department of Forestry (DOF) developed *Riparian Forest Handbook 1* along with a companion computer disk to guide you in evaluating a portion of a stream that you may wish to restore. There are regulations and permits required in most localities that pertain to stream restoration. It is strongly recommended that volunteer organizations conduct these evaluations and any restoration work with the assistance of a professional organization, such as a local government or local soil and water conservation district. The computer disk contains programs to assist you in characterizing your stream. Information from your measurements can help you select appropriate restoration activities. Restoration activities include:

The *Riparian Forest Handbook 1* and companion programs may be obtained here or by contacting the Virginia Department of Forestry at (434) 977-6555.

- Exclusion: Limiting activity near the stream, such as fencing out livestock.
- Planting: Establishing trees along the bank of a stream.
- Channel Modification: Changing the shape of the channel to restore its natural meander, width and depth.

How Do You Evaluate Riparian Forests?

The aforementioned handbook and companion computer disk provide a detailed methodology to evaluate a riparian forest. For evaluating riparian forests, the handbook describes how to measure the departure from desired conditions using three benchmarks (discussed in detail below): the three zone riparian buffer; normal values of stream dimension, pattern, and profile; and normal values of stream particle size and distribution. In any investigation of the departure from desired conditions, it is important that measurements are made and compared for all three benchmarks.

First, select a stream area to evaluate while considering the questions in Chapter 1. As with conducting water quality monitoring, you should research existing information about your stream before collecting your measurements. Take time to review regional climate data, geology, land types, vegetation, historic land use and any forest plan guidance.

Benchmark 1: Streamside Vegetation in the 3 Zone Riparian Buffer

The 3 zone riparian buffer is an accepted minimum standard for vegetation adjacent to streams and rivers. The area immediately adjacent to the stream (Zone 1) should be comprised of larger woody plants and trees. The roots of this vegetation provide structural support for the stream bank. Zone 2 (the next 60 feet beyond Zone 1) should be a contiguous forest to filter sediments and nutrients from runoff. Beyond Zone 2 should be an area of contiguous forest, perennial grasses, or non-woody plants. To evaluate this benchmark, you will determine the dominant type of plant cover and the density of that cover.

Benchmark 2: Stream Channel Dimension, Pattern, and Profile

Measurements of stream dimension (shape of stream when viewed in cross-section), pattern (shape of stream when viewed from above), and profile (shape of stream when viewed from the "side" along its gradient, i.e. pools and riffles) are used to determine if a stream has a stable "hydrology" and "geology." A stable stream migrates slowly across its valley over thousands of years. Having evolved slowly in an undisturbed landscape, the dimension, pattern, profile, and water regime of a stream achieve a dynamic equilibrium within the surrounding environment. This equilibrium is an integration of the landscape and historic rainfall patterns upstream.

The first step is to determine hydraulic geometry by measuring a cross-section and a longitudinal profile of the stream channel, using surveying equipment. Calculations based upon these measurements (the software for the *Riparian Forest Handbook 1* includes a program that makes the calculations) are used to categorize the stream according to the Rosgen stream classification system. This classification system is commonly used to group streams with similar configurations.

Benchmark 3: Stream Channel Particle Size Distribution

In addition to streamside vegetation and hydraulic geometry, the sediment load of a stream is a useful benchmark of stability. As a stream system evolves over time, it develops a characteristic set of sediment particle sizes in the streambed. These particles move through the channel over time. The quantities of each size of material depend on the geology of the watershed and the energy of water flow in the system. In an undisturbed stream system, the distribution of particle sizes indicates the natural sediment load of the streambed (known as "bed load"). Any abrupt change in vegetation, land surface features, or length, width, depth and shape of portions of the stream channel can cause streams to adjust to recapture a stable shape. A frequent consequence of these adjustments is a shift away from the normal sediment particle size distribution. A pebble count (where particles are selected and measured) is typically used to determine particle size distribution.

Appendices

Photo Courtesy of Virginia Save Our Streams

Appendix 1

Contacts

Virginia Volunteer Water Quality Monitoring Program Contacts

Alliance for the Chesapeake Bay
https://www.allianceforthebay.org/

Department of Environmental Quality
https://www.deq.virginia.gov/our-programs/water/water-quality/monitoring/citizen-monitoring

Department of Conservation & Recreation
https://www.dcr.virginia.gov

Virginia Save Our Streams Program
https://vasos.org/

Regional Volunteer Monitoring Groups

Appomattox River Water Quality Monitoring Program
Clean Virginia Waterways
Longwood University
https://www.longwood.edu/cleanva

Assateague Coastal Trust
http://www.actforbays.org
P.O. Box 731
Berlin, MD 21811
(410) 629-1538

Audubon Naturalist Society
https://anshome.org/water-quality-monitoring/

Ferrum College
Smith Mountain Lake and Claytor Lake
https://www.ferrum.edu/smith-mountain-lake-water-quality-program/

Friends of the Shenandoah River
https://fosr.org/
1460 University Drive / Gregory Hall
Winchester, VA 22601
(540) 665-1286
friendsofshenandoahriver@gmail.com

James River Association
https://thejamesriver.org/
211 Rockets Way, Suite 200
Richmond, VA 23231
info@thejamesriver.org
(804) 788-8811

Lake Anna Civic Association
https://www.lakeannavirginia.org/Water-Quality
P.O. Box 217
Mineral, VA 23117-0217
LACA@lakeannavirginia.org

Loudoun Wildlife Conservancy
https://Loudounwildlife.org/
P.O. Box 1982
Leesburg, VA 20177
(703) 777-2575

Mattaponi and Pamunkey Rivers Association
https://www.mpra.org
P.O. Box 115
Walkerton, VA 23177
matpamrivers@gmail.com
(804) 769-0841

McClure River Restoration Project
https://mrrp.weebly.com/
130 Clintwood Main Street
Clintwood, VA 24228
(276) 926-8527

Northern VA Soil & Water Conservation District
https://www.fairfaxcounty.gov/soil-water-conservation/volunteer-stream-monitoring
12055 Government Center Pkwy #905
Fairfax, VA 22035-5512
(703) 324-1425

Culpeper Soil and Water Conservation District
Upper Rappahannock Watershed Stream Monitoring Program
http://www.culpeperswcd.org/education-programs/stream-monitoring/
StephanieD@culpeperswcd.org
(540) 825-8591

RappFLOW
https://rappflow.org/
P.O. Box 150
Sperryville, VA 22740
info@rappflow.org

Appendix 2

Letter of Agreement

2015 Partnership Agreement
To Implement the Virginia Volunteers Water Quality Monitoring Program

In 2015, DEQ renewed a letter of agreement between the Alliance for the Chesapeake Bay, Department of Conservation and Recreation, Virginia Citizens for Water Quality, Virginia Water Monitoring Council and the Izaak Walton League of America, Save Our Streams Program. The purpose of this agreement is to continue to promote and enhance volunteer monitoring in Virginia.

LETTER OF AGREEMENT

Between

The Virginia Department of Environmental Quality,

The Virginia Department of Conservation and Recreation,

Alliance for the Chesapeake Bay,

Izaak Walton League of America, Virginia Save Our Streams Program,

Virginia Citizens for Water Quality, and the

Virginia Water Monitoring Council

Purpose

This document continues the collaborative partnership, which began in 1998 and reaffirmed in the 2002 Letter of Agreement, between the Alliance for the Chesapeake Bay (the Alliance); Virginia Department of Environmental Quality (DEQ); Virginia Department of Conservation and Recreation (DCR); and the Izaak Walton League of America, Save Our Streams Program (VA SOS) for the purpose of supporting and implementing the Virginia Volunteer Water Quality Monitoring Program.

While many government agencies and other organizations participate in and support this cooperative effort, this Agreement defines the roles of the above agencies and organizations and the Virginia Citizens for Water Quality (VCWQ) and the Virginia Water Monitoring Council (VWMC) in the implementation of the Virginia Volunteer Water Quality Monitoring Program.

Shared Goals

We recognize that cooperative efforts strengthen volunteers' commitment to water quality and therefore enhance Virginia's ability to protect and restore the Commonwealth's water resources.

Therefore, we resolve to support the Virginia Volunteers Water Quality Monitoring Program and work together towards the following goals:

1. To have a comprehensive understanding of all water quality monitoring efforts in the Commonwealth, including types, location, and results.
2. To ensure volunteer water monitoring data can supplement DEQ monitoring efforts in the biennial production of Virginia's 305(d)/303(b) Integrated Water Quality Assessment Report and help to evaluate the effectiveness of conservation and restoration efforts - including

nonpoint source pollution prevention measures and TMDL implementation - and to document the listing and de-listing of impaired waters.

3. To encourage volunteer monitoring efforts by providing resources, when available, including training, supplies and equipment, funding and technical assistance.
4. To foster volunteer water quality monitoring activities by highlighting the many uses of data including the following: education and outreach; baseline data to establish background conditions and prioritize monitoring needs; contribute to local land use decisions; alerting unusual conditions resulting from land use or resource management; and documenting water quality improvement projects.
5. To promote coordination and collaboration among organizations involved in volunteer water quality monitoring activities so that efforts complement each other.
6. To provide user-friendly access and to effectively disseminate water quality information and data between the partners and the public.
7. To promote the highest quality controlled and quality assured data appropriate for the intended use of the data obtained by volunteer monitors.

Partner Responsibilities

Alliance for the Chesapeake Bay

The Alliance provides assistance to watershed groups, volunteers, and volunteer organizations by providing training and organizational development in order to build restoration capacity at the local watershed level. The Alliance provides training in water quality monitoring methods; provides quality assurance oversight of data and methods for volunteers and watershed groups participating in the Alliance's quality assurance program; and identifies new opportunities for volunteer monitoring and assessment activities. While the mission of the Alliance is to protect and restore the Chesapeake Bay watershed, the Alliance is committed to supporting all volunteer water quality monitors in the Commonwealth of Virginia.

Virginia Citizens for Water Quality

The mission of VCWQ is to coordinate citizen water quality monitoring efforts and monitoring methodologies and promote watershed water quality and stream health needs and issues. Through their online outlets VCWQ will provide a central place for agencies and other interested parties to distribute water quality information. VCWQ holds annual summits that provide an opportunity for information sharing among citizens and water quality data users. In addition, VCWQ will provide leadership to continue and expand funding opportunities for volunteer water quality monitoring.

Virginia Department of Conservation and Recreation

As part of the Department's statewide responsibilities, DCR will continue to provide technical expertise and general information primarily on matters concerning agricultural nonpoint source pollution. Specifically, DCR will assist in the development and implementation of the Chesapeake Bay 2014 Agreement commitments and, in cooperation with DEQ, will provide technical expertise and general information on Total Maximum Daily Load development and implementation. DCR will promote the use of volunteer data to meet the Commonwealth's water quality data needs and will assist in identifying appropriate uses for volunteer-generated data. DCR will promote the delivery of volunteer stewardship activities on a watershed basis and will work to identify new opportunities for volunteer stewardship efforts. DCR will work to engage volunteers and volunteer organizations in water quality monitoring and related stewardship activities. DCR will continue to provide technical expertise and general information on grant writing, sources of funding, public outreach techniques, environmental education, organizational development, strategic planning and marketing.

Virginia Department of Environmental Quality

As part of the Department's statewide responsibilities, DEQ will provide technical expertise and general information on matters concerning point source pollution and regulated sources of nonpoint source pollution (e.g., urban stormwater, confined animal feeding operations, erosion and sediment control). In cooperation with the Department of Mined Land Reclamation and DCR, DEQ will provide technical expertise and general information on Total Maximum Daily Load development and implementation. DEQ will continue to provide technical expertise and general information about monitoring water quality including monitoring protocols, planning water quality monitoring programs, existing agency monitoring locations, site selection, data management, and quality assurance and quality control measures. DEQ will maintain the Virginia Volunteer Monitoring Methods Manual and may provide volunteer water quality monitoring grants to support volunteer efforts, subject to the availability of funds. In addition, DEQ will offer guidance so volunteer groups and other organizations can upload, store, and retrieve water quality data from an online database. DEQ will promote the use of volunteer data to meet the Commonwealth's water quality data needs and will assist in identifying appropriate uses for volunteer-generated data. DEQ will continue to assist in identifying new opportunities for volunteer stewardship efforts such as maintaining an online map showing locations of volunteer monitoring groups.

Virginia Save Our Streams

VA SOS engages volunteers in biological monitoring of streams and stewardship activities to improve water quality and wildlife habitat. VA SOS recruits volunteers to monitor water quality, trains volunteer monitors in water quality monitoring methods, coordinates a network of regional trainers, provides quality assurance oversight for participating volunteers, and assists in identifying new opportunities for volunteer stewardship activities. VA SOS will continue to promote volunteer stewardship efforts, recruit and train volunteers and organizations desiring to participate in volunteer water quality monitoring and related activities. VA SOS also will assist organizations in identifying sources of funding and organizational development.

Virginia Water Monitoring Council

The VWMC will continue to promote water quality monitoring efforts in Virginia by acting as a forum for volunteer monitoring organizations; local and state government agencies; private businesses; and academic institutions to meet and work together. The VWMC will continue to provide information on upcoming water quality meetings and water quality monitoring activities in Virginia.

Implementation

To ensure success in achieving these common goals, we agree to meet at least once a year to coordinate efforts; outline tasks to meet shared goals; and evaluate progress towards achieving shared goals. We understand that each partner has a unique and specific organizational mission and responsibility with respect to water quality monitoring and how volunteer water quality monitoring can best interface with each partner's mission as described above.

This Agreement reflects the partners' plan for cooperation and is not to be construed as a binding contract. Any party may leave this cooperative program at any time and for any reason and may enter into similar agreements with other organizations. This agreement will continue for a period of four years, at which time it will be updated and renewed upon mutual agreement of the partners.

Nothing in this agreement prohibits the partners from implementing other programs for which they are responsible. Additional parties may be added to this agreement upon the mutual consent of the partners.

We hereby agree to work together to promote and sustain volunteer water quality monitoring in the Commonwealth of Virginia as described by this 2015 Letter of Agreement:

Al Todd
Executive Director, Alliance for the Chesapeake Bay, Inc.

Leah Miller
Coordinator, Virginia Save Our Streams, Izaak Walton League of America

Wayne Kirkpatrick
Chairman, Virginia Citizens for Water Quality

Clyde Cristman
Director, Virginia Department of Conservation and Recreation

David Paylor
Director, Virginia Department of Environmental Quality

Chris French
Co-Chair, Virginia Water Monitoring Council

Weedon Cloe
Co-Chair, Virginia Water Monitoring Council

Appendix 3

Legislation Establishing the Virginia Citizen Water Quality Monitoring Program in the *Code of Virginia*

Legislation Establishing the Virginia Citizen Water Quality Monitoring Program in the Code of Virginia

HB497 and HB1859 Text as Enacted by the General Assembly of Virginia

Code of Virginia § 62.1-44.19:11. Citizen water quality monitoring program

A. The Department of Environmental Quality shall establish a citizen water quality monitoring program to provide technical assistance and may provide grants to support citizen water quality monitoring groups if (i) the monitoring is done pursuant to a memorandum of agreement with the Department, (ii) the project or activity is consistent with the Department of Environmental Quality's water quality monitoring program, (iii) the monitoring is conducted in a manner consistent with the Virginia Citizens Monitoring Methods Manual, and (iv) the location of the water quality monitoring activity is part of the water quality control plan required under § 62.1-44.19:5. The results of such citizen monitoring shall not be used as evidence in any enforcement action.

B. It shall be the goal of the Department to encourage citizen water quality monitoring so that 3,000 stream miles are monitored by volunteer citizens by 2010.

Appendix 4

Template for Submittal of Volunteer Monitoring Data to the Virginia Department of Environmental Quality

Data Submittal to DEQ Guide

Best practices for submitting volunteer water quality monitoring parameter data to the Virginia Department of Environmental Quality

The purpose of this document is to provide a process for groups who collect volunteer water quality monitoring parameter data to submit their data to DEQ in a format that ensures accuracy and the fullest use of the data.

Why is this important? During the biennial water quality assessment process DEQ staff across the state review tens of thousands of data points to generate Virginia's 305(b)/303(d) Water Quality Assessment Integrated Report. To facilitate this process, DEQ converts as much of the water quality monitoring data as possible into a standardized format to allow its use in automated assessment tools which have been developed.

DEQ released the **Virginia Data Explorer** (**VDE**) in 2022, a collaboration between DEQ and the Chesapeake Monitoring Cooperative (CMC), as a platform for submitting water quality data collected by volunteers and other monitoring groups outside of DEQ. The VDE is the preferred method **for groups with a DEQ approved QAPP in place to submit their Level II or Level III** monitoring data to DEQ for use in the water quality assessment process. Groups without a DEQ approved QAPP in place or those generating Level I data should submit their data in the spreadsheet format below.

Data Submittal Through the Virginia Data Explorer: Level II and Level III data

The VDE is a data portal that mirrors the CMC data portal, which is limited to groups within the Chesapeake Bay Watershed. Groups outside of the Chesapeake Bay Watershed can now submit data through the VDE. Groups who already submit data through the CMC portal can choose either portal for managing their Virginia data, your login information will work for either portal.

DEQ accesses data annually from groups who use the VDE. DEQ and CMC provide technical, programmatic, and outreach support to integrate volunteer-based water quality and macroinvertebrate monitoring data into the VDE. The Virginia Data Explorer can be found at this link:

https://cmc.vims.edu/va

Questions about submitting water quality monitoring data to the VDE may be sent to citizenwater@deq.virginia.gov, or by contacting Reid Downer (email: horace.downer@deq.virginia.gov; telephone: 804-217-4777).

Data Submittal Directly to DEQ: Level I data

This option is only for volunteer monitoring groups who have collected Level I data or data collected without a DEQ approved QAPP.

A complete example of how the data should be submitted directly to DEQ is shown at the end of this document. Detailed submittal information is presented in the following sections.

General Information

All data should be included in one spreadsheet (all stations and samples together for collections made in the calendar year. MS Excel, Apple Numbers, or CSV file formats are requested; if another format is needed to provide the data, please contact DEQ. Please do not divide the data into different tabs in the workbook by station or parameter. Any additional information (i.e. graphs, charts, etc.) can be provided on additional tabs within the workbook. Any formatting (highlighted cells, bolded text, etc.) will be ignored as the data will be pulled into a database.

Each monitoring event should be entered in a separate row in the spreadsheet with the data (station, sample, parameter, and other data) in the columns. Replicate samples, when collected, must be on separate rows. In these cases, the Sample Date/Time would be the same for each row and the replicate number would be indicated in the Sample Comment column (i.e. Replicate 1).

Below is a list of columns that should be included in the data reporting spreadsheet. They have been grouped together for ease of discussion in this document but in the spreadsheet the data should be a continuous set of columns (as shown on the last page).

Note that the examples below, while sometimes partially taken from previously submitted data, are not real data.

Station Data

The first set of columns are for data that identify the station where the monitoring takes place. These data will be duplicative when there are multiple sampling events, and for each individual station, the data will be exactly the same on each row.

The required data elements are:

- **Station ID:** This value should be unique for each station monitored by a specific volunteer group. The station ID should not change from one sampling event or data submittal year to another if the sampling is done in the same location. If monitoring is done at multiple locations along the same waterbody, each location should have a unique Station ID. Maintaining the Station ID (for the same monitoring location) year to year greatly simplifies processing the data for DEQ.
- **Station Waterbody:** The name of the waterbody that the station is located on as identified from a USGS topographic map or other standard reference. If the site is on an unnamed tributary to a named waterbody, please state “Unnamed tributary to (insert name of waterbody)”.
- **Station Description:** A detailed station location description so the station can be located on a map (i.e. Rt. 619 bridge or, 0.5 miles downstream of Rt. 619 bridge). If the

monitoring station is co-located with a DEQ water quality monitoring station, and DEQ station ID is known, please include the DEQ station ID in this data column.

- **Latitude/Longitude:** The coordinate pair locating the station using **decimal degrees** (i.e. 38.4412, -78.0011). If the station coordinate pair is in another format (i.e. degrees/ minutes/seconds) please convert to decimal degrees. A Google search will return several free online tools to help make this conversion. Please also check the accuracy of the latitude/longitude (Google Maps is a simple way to do this) before the submission of the data. If assistance is needed with either of these items, please contact DEQ.

Below is an example of data in this format:

Station_ID	Station_Waterbody	Station_Description	Latitude	Longitude
ACB.BUFCRE10	Buffalo Creek	Buffalo Creek at intersection with Mateer Rd/670	37.7425	-79.5066
ACB.BUFCRE10	Buffalo Creek	Buffalo Creek at intersection with Mateer Rd/670	37.7425	-79.5066
ACB.BUFCRE12.5	Colliers Creek	Buffalo Creek at Colliers Creek	37.7568	-79.5431
ACB.BUFCRE12.5	Colliers Creek	Buffalo Creek at Colliers Creek	37.7568	-79.5431
ACB.BUSMILCRE	Great Wicomico River	Bush Mill Creek at the dock at the end of Heron Court.	37.8750	-76.4413
ACB.BUSMILCRE	Great Wicomico River	Bush Mill Creek at the dock at the end of Heron Court.	37.8750	-76.4413
ACB.CEDCRE2.4	Spring Gap Creek-Cedar Creek	Cedar Creek at low bridge above Monacan living exhibit off of the Cedar Creek Trail. Station co-located with DEQ station ID 2-CEC004.60.	37.6307	-79.5481
ACB.CEDCRE2.4	Spring Gap Creek-Cedar Creek	Cedar Creek at low bridge above Monacan living exhibit off of the Cedar Creek Trail. Station co-located with DEQ station ID 2-CEC004.60.	37.6307	-79.5481
ACB.CGC01	Alone Mill Creek-Maury River	Cedar Grove Creek at confluence with Maury River	37.8828	-79.3859

Sample Data

The second set of columns are for data that identifies the sampling event itself. When the sample was taken, at what depth and a comment field for any additional information about that sampling event. As noted above, if replicate samples are taken there will be two rows of data where the Sample Date/Time would be the same for each row and the replicate number would be indicated in the Sample Comment column (i.e. Replicate 1).

The required data elements that are:

- **Sample Date/Time:** The date and time the sample was taken from the waterbody for analysis. Preferred format is yyyy-mm-dd hh:mm:ss (i.e. 2019-04-14 09:58:00) using a

24 hour clock. Measurement to the second a sample was taken is not necessary, just the hour and minute. Separate columns for the date and time are also acceptable.

- **Sample Depth:** The depth the sample was taken in the water column in meters. DEQ surface water samples are typically taken at 0.3 meters (1 foot). Monitoring in lakes or estuarine waters are often sampled at various depths. 0.3 meters is an acceptable estimate for samples taken near the surface for which an exact depth is not known.
- **Sample Comment:** This column is for comments about the entire sample, not just a single parameter (i.e. unusual water conditions under which a sample might have been taken). This column should also be used to indicate replicate samples. If replicate samples are collected there should be a row of data for each replicate. The values in the Station ID, Station Waterbody, Station Description, Latitude/Longitude, Sample Date/Time, and Sample Depth columns should be identical among replicates, and they should be differentiated with a replicate number in the Sample Comment Column (e.g. Replicate 1).

This data should be provided in this format:

Sample_DateTime	Sample_Depth	Sample_Comment
12/12/2019 11:30:00	0.3	Water level still low, but flow seems normal. Water is murkier than it has been since I started this.
11/5/2019 11:05:00	0.3	The water level is lower than before. Water is clear, and I can see the bottom well.
12/12/2019 11:07:00	0.3	I could see fish near rocks on the river bottom. The fish were about 6”” long and darker colored as seen from the top. Herring? This test was done in the afternoon of a hot day.
11/5/2019 12:10:00	0.3	Recent boat launches may account for high turbidity (decreased clarity) today. Canada goose and 4-5 goslings eating duck weed at the shoreline 4pprox. 7-8 meters from dock. Floating feces observed after water for culture obtained.
12/19/2019 13:30:00	0.3	A large amount of small-leafed plants floating on the water. Plants accumulated at the dock, and large patches were observed out on the river.
11/21/2019 13:30:00	0.3	No submerged aquatic vegetation but last year at this time there was considerable underwater vegetation, so the absence this year is worth noting.
11/19/2019 13:30:00	0.3	Very dry conditions for last two months.
12/10/2019 14:59:00	0.3	Banks are all overgrown and full of sand deposits left after high river levels this year.
12/4/2019 15:00:00	0.3	Septics are backing up into homes in the area. This may be a part of the high E coli count in the water.

Parameter Data

The next set(s) of columns are for data about the individual parameters that are monitored. For each parameter monitored there will be set of four columns as detailed below. It is important to note that there is no expectation that data will be entered for every row for the _Qualifer,

_Remark and _Level columns. Those columns should only be used when information is available, and otherwise left blank.

- **Parameter Value:** The numeric result for the parameter. If the parameter was a 'non-detect' this column should be left blank. If the result was a less than or greater than value, enter the numeric value and note the less/greater than in the qualifier field. Please also provide the units for the parameter in the column header.
- **Parameter Qualifier:** Information that qualifies the value entered into the Parameter Value column. For less than please use < and for greater than please use >. If the parameter was not detected in the analysis, please enter 'non-detect'.
- **Parameter Remark:** Any comments specific to the parameter being monitored. The comments can include methods used, equipment issues, etc.
- **Parameter Level:** The tier (Level I, II or III) at which the volunteer monitoring group believes the data should be used for assessment purposes. This will be confirmed by DEQ staff based on the Quality Assurance Project Plan for the volunteer monitoring group. If the volunteer monitoring group does not wish for the data to be used, please enter 'Not to be used for assessment purposes' in the column for the parameter.

Below is an example of what this data would look like in this format for two parameters, DO and Fecal Coliform:

DO_mg_l _Value	DO _Qualifier	DO_Remark	DO _Level	Fecal_Coliform count_Value	Fecal_Coliform _Qualifier	Fecal_Coliform _Remark	Fecal_Coliform _Level
9.8		Method DO.1, issue with probe during sampling	3	10	<	Method FC.1	2
6.8		Method DO.1, issue with probe during sampling	3	10	<	Method FC.1	2
5.6		Method DO.1	3	40		Method FC.1	2
4.2		Method DO.1	3	55		Method FC.1	2
5.4		Method DO.1	3	30		Method FC.1	2
6.6		Method DO.1	3	10	<	Method FC.1	2
6.8		Method DO.1	3	10		Method FC.1	2
5.4		Method DO.1	3	10		Method FC.1	2
4.5		Method DO.1	3	60		Method FC.1	2

When defining the column headers it is very important to indicate the exact parameter being reported. For instance, for a parameter such as nitrogen, please indicate if the parameter being monitored for is total nitrogen or dissolved nitrogen as that distinction may make a difference in the assessment of the data. Other field data parameters (pH, water temperature, specific conductance, secchi depth, etc.) should be reported in the same four-column format.

Other Data

Please feel free to include additional columns at the end of the spreadsheet which capture other information which could be helpful in the use of the data for assessment. Data such as air temperature, other weather conditions, stream flow gage data, qualitative assessments of stream flow, etc. can be very helpful to DEQ staff during the assessment process.

Questions?

Please direct any questions about the submittal of water quality monitoring data to citizenwater@deq.virginia.gov.

Appendix 5

Resources

Resources

General Volunteer Water Quality Monitoring Resources

Campbell, G. and S. Wildberger. 1992. *The Monitor's Handbook.* LaMotte Company, Chestertown, Md. 71 pp.

Center for Marine Conservation & U. S. EPA. V*olunteer Estuary Monitoring: A Methods Manual*, Second Edition. Web site: https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual

Hach. 1997. *Hach Water Analysis Handbook.* 3rd ed. Hach Company, Loveland CO.

Miller, J.K. 1995. *Program Organizing Guide.* River Watch Program of River Network. Montpelier, VT.

Mitchell, M., and W. Stapp. 1999 *Field Manual for Water Quality Monitoring.* 12th ed. Kendall/Hunt.

U. S. Environmental Protection Agency (USEPA). 1990. *Volunteer Water Monitoring: A Guide For State Managers.* EPA 440/4-90-010. August. Office of Water, Washington, DC. 78 pp. Web site: https://www.epa.gov/wetlands/volunteer-stream-monitoring-methods-manual

U. S. Environmental Protection Agency (USEPA), 1991. *Volunteer Lake Monitoring: A Methods Manual.* EPA 4400/4-91-002. Office of Water, Washington, DC. 121 pp. Web site: https://www.epa.gov/nps/nonpoint-source-volunteer-monitoring

U. S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA841-B-97-003. November. Office of Water, Washington, DC. 211 pp. Web site: https://www.epa.gov/nps/nonpoint-source-volunteer-monitoring

Web Sites

Chesapeake Bay Program: https://www.chesapeakebay.net/

Virginia Citizens for Water Quality: https://vcwq.wordpress.com/

National Oceanic & Atmospheric Administration (NOAA)

- National Sea Grant Program: https://seagrant.noaa.gov/
- Volunteering for the Coast: https://www.noaa.gov/work-with-us/volunteer-opportunities-citizen-scientists

U. S. Environmental Protection Agency (EPA)

- How's My Waterway?: https://mywaterway.epa.gov/
- Healthy Watersheds Protection: https://www.epa.gov/hwp

Volunteer Monitoring https://www.epa.gov/nps/nonpoint-source-volunteer-monitoring

Virginia Department of Environmental Quality (DEQ)
Volunteer Monitoring: https://www.deq.virginia.gov/our-programs/water/water-quality/monitoring/citizen-monitoring
DEQ Monitoring Data: https://apps.deq.virginia.gov/EDM/

Virginia Water Monitoring Council: https://vwmc.vwrrc.vt.edu/

Chapter 2: Quality Assurance Project Plans and Approved Methods

American Public Health Association (APHA), American Water Works Association, and Water Environment Federation. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th ed. L. S. Clesceri, A. E. Greenberg, A.D. Eaton (eds). Washington, DC.

Mattson, M. 1992. "The Basics of Quality Control." *The Volunteer Monitor* 4(2): 6-8.

U. S. Environmental Protection Agency (USEPA). 1996. *The Volunteer Monitor's Guide to Quality Assurance Project Plans.* EPA 841-B-96-003. September. Web site: https://www.epa.gov/quality/volunteer-monitors-guide-quality-assurance-project-plans

Chapter 4: Dissolved Oxygen

Green, L. 1997. "Common Questions About DO Testing." *The Volunteer Monitor* 9(1).

Green, L. 1998. "Let Us Go Down to the Sea-How Monitoring Changes from River to Estuary." *The Volunteer Monitor* 10(2): 1-3.

Chapter 6: Nutrients

Dates, G. 1994. "Monitoring for Phosphorus or How Come They Don't Tell You This Stuff in the Manual?" *The Volunteer Monitor* 6(1).

Katznelson, R. 1997. "Nutrient Test Kits: What Can We Expect?" *The Volunteer Monitor* 9(1).

Chapter 7: Benthic Macroinvertebrates

Engel, Sarah R. and J. Reese Voshell, Jr. 2002. "Volunteer Biological Monitoring: Can It Accurately Assess the Ecological Condition of Streams?" *American Entomologist 48 (3): 164-177.* Web site: https://vasos.org/about-water-pollution-and-va-sos/va-sos-research/

U. S. Environmental Protection Agency (USEPA). 1999. *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers; Periphyton, Benthic Macroinvertebrates and Fish,* second edition, EPA Publication 841-B-99-002. Web site: https://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-1164.pdf

Web Sites

Virginia Save Our Streams Program: https://vasos.org/

Chapter 8: Bacteria

Ely, E. 1998. "Bacteria Testing Part 1: Methods Primer." *The Volunteer Monitor* 10(2):8-9

Ely, E. 1998. "Bacteria Testing Part 2: What Methods Do Volunteer Group Use? *The Volunteer Monitor* 10(2): 10-13.

Ely, E. 1997 "Interpreting Fecal Coliform Data: Tracking Down the Right Sources." *The Volunteer Monitor* 9(2): 18-20

Miceli, G. 1998. "Bacteria Testing Q & A." *The Volunteer Monitor* 10(2): 13-15

Chapter 10: Submerged Aquatic Vegetation (SAV)

U. S. Environmental Protection Agency (USEPA). 2000. *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis.* August.

Bergstrom, P. 1998. "SAV Hunter's Guide (for Chesapeake Bay)." *The Volunteer Monitor* 10(2): 17.

Hurley, L. M. 1992. *Field Guide to the Submerged Aquatic Vegetation of the Chesapeake Bay.* U. S. Fish and Wildlife Service Chesapeake Bay Estuary Program. Annapolis, MD. 52PP. (NOTE: Out of print). Web site: https://www.chesapeakebay.net/documents/Field_Guide_to_the_Submerged_Aquatic_Vegetation_of_Chesapeake_Bay_1990.pdf

Meyers, D. 1999. "Volunteers Add 'Missing Piece': Monitoring Restoration." *The Volunteer Monitor* 11(1): 10-11.

Reshetiloff, K. 1998. "SAV Hunt: Citizens Keep Track of Bay Grasses." *The Volunteer Monitor*
10(2): 16

Web Sites

Alliance for the Chesapeake Bay: https://www.allianceforthebay.org/

Chesapeake Bay Foundation*:* https://www.cbf.org/
Chesapeake Bay Program: https://www.chesapeakebay.net/issues/whats-at-risk/underwater-grasses
U. S. Fish and Wildlife Service Chesapeake Bay Field Office:
https://www.fws.gov/chesapeakebay/
Virginia Institute of Marine Science:
https://www.vims.edu/research/units/programs/sav/index.php

Chapter 15: Stream Flow

Rantz, S.E., and others, 1982, Measurement and Computation of Streamflow: Volume 2. Computation of Discharge. U. S. Geological Survey Water-Supply Paper. 2175. Web site: https://pubs.er.usgs.gov/publication/wsp2175

Web Sites

U. S. Geological Survey (USGS): https://www.usgs.gov/centers/virginia-and-west-virginia-water-science-center

Chapter 16: Stream Walks

U. S. Department of Agriculture. 1998. *National Water and Climate Center Technical Note 99-1: S*tream *Visual Assessment Protocol.* December.

U. S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA841-B-97-003. November. Office of Water, Washington, DC. 211 pp. Web site https://www.epa.gov/nps/nonpoint-source-volunteer-monitoring

Chapter 17: Riparian Forests

Austin, Samuel H. 1999. *Riparian Forest Handbook 1,* Virginia Department of Forestry, December.

Appendix 6

Equipment Suppliers

Equipment Suppliers

This is a partial list of common equipment suppliers from which a volunteer monitoring program may obtain equipment for water quality monitoring. This list is intended to assist programs in locating equipment and does not imply endorsement by the Virginia Volunteer Water Quality Monitoring Program or any of its partners.

Carolina Biological Supply Company
https://www.carolina.com
Phone: 800-334-5551
Forceps, reagents, educational materials.

Cole Parmer Instruments, Inc.
https://www.coleparmer.com
Phone: 800-323-4340
Lab equipment, field water test equipment.

Earth Force
https://www.earthforce.org
E-mail: green@earthforce.org
Phone: 703-299-9485
Low-cost kits for schools.

Fisher Scientific Company
https://www.fishersci.com
Phone: 800-766-7000
Lab equipment, sample bottles, reagents, water test equipment, Whirl-paks.

Forestry Suppliers, Inc.
https://www.forestry-suppliers.com
Phone: 800-647-5368
Secchi disks, transparency tubes, equipment.

HACH Equipment Company
https://www.hach.com
Phone: 800-227-4224
Field and lab equipment, reagents.

HydroLab
https://www.hydrolab.com
Phone: 800-949-3766
Multi-parameter meters for water monitoring.

Idexx Laboratories
https://www.idexx.com/water
Phone: 800-321-0207
Colilert method for bacterial monitoring.

LaMotte
https://www.lamotte.com
Phone: 800-344-3100
Field and lab water testing equipment, Secchi disks, armored thermometers.

Micrology Laboratories
https://www.micrologylabs.com/
Phone: 888-EASYGEL
Coliscan Easygel method for bacterial monitoring.

Nichols Net and Twine, Inc.
Phone: 618-797-0222; 800-878-6387
Nets of all kinds (dip, kick, macroinvertebrates), seines, custom nets.

YSI Incorporated
https://www.ysi.com
Phone: 937-767-7241
Meters for water quality monitoring.

Appendix 7

Levels of Quality Assurance and Uses of Volunteer Water Quality Data by DEQ

Levels of Volunteer Collected Water Quality Data in Virginia

In Virginia, the Department of Environmental Quality (DEQ) has developed three levels of data quality for volunteer and other non-DEQ water quality monitoring data based upon both the level of data quality and the authorized uses of the data provided to the agency. In addition to agency needs, collected data may also be used to educate the community, to assist local governments in land use planning, to supplement data for university and professional studies, and to assist local soil and water conservation districts in prioritizing watershed work for best management practices.

Level	Appropriate Data Uses	QA/QC Protocols
III	• List or delist waters on the 303(d) Impaired waters list • Assess waters for 305(b) Report • Use with DEQ data for TMDL development • All uses listed in Levels I and II	• DEQ-approved Quality Assurance Project Plan (QAPP) and field or lab Standard Operating Procedures (SOP). • Field and/or laboratory audit required. • Group provides calibration and quality control associated information to DEQ when submitting data. This information must meet the specific criteria stated in the QAPP.
II	• Identify waters for DEQ follow up monitoring • Track performance of TMDL implementation • All uses listed in Level I	• DEQ-approved Quality Assurance Project Plan (QAPP) and field or lab Standard Operating Procedures (SOP). • There may be deviation from an approved method if it can be demonstrated that the method collects data of similar quality to an approved method.
I	• Education • Baseline Conditions • Notification of Possible Pollution Events • Local Land Use Decisions • Special Studies	• No Quality Assurance Project Plan (QAPP) or SOP required by DEQ. • Uniform methodology recommended. • QAPP, SOPs and/or lab methods do not meet DEQ quality assurance/quality control requirements. • There is no numeric Virginia Water Quality Standard for the parameter*.

* There is no numeric criteria in the Virginia Water Quality Standard regulations for the following commonly monitored parameters: nitrate (except for waterbodies used for drinking water purposes), nitrite, Total Kjeldahl Nitrogen (TKN), orthophosphate, suspended solids, total nitrogen, total phosphorus (except for lakes), water clarity (turbidity/Secchi depth). Information about Virginia Water Quality Standards is available here. Data on parameters for which there is no standard may be used as Level II if used for agency business that does not require a standard (e.g. tracking TMDL implementation performance).

Monitors are encouraged to adopt Level II or III methods (e.g., samples sent to an accredited laboratory for analysis or otherwise follow DEQ recognized methods) in the event Virginia adopts such standards so the data could be used in the future.

Data Use Authorization Form

Name of group or organization:		Date:	
Name of Submitter:		Role or title: (QA Officer, leader, etc.)	
Type(s) of monitoring conducted by organization	☐ **Chemical** (pH, dissolved oxygen nutrients, etc.)	☐ **Physical** (Temperature, stream flow, etc.)	☐ **Biological** (Macroinvertebrate, E. coli, etc.)
Type of Data Submittal:	☐ Via Chesapeake Monitoring Cooperative	☐ Via Virginia Data Explorer	☐ Direct to DEQ (Level I data only)
Organization type:	☐ Volunteer	☐ Federal Agency	☐ State Agency
	☐ Local Government Agency	☐ Business or Industry	☐ College or University
	☐ Other (Name):		

Information about each of the three levels of volunteer data is available in the RFA. You may select more than one.

☐ 1. ***(DEQ Level III)*** List and delist impaired waters on the 303(d) Impaired Waters List and assess water quality

Data recognized by DEQ as Level III can be used to list or delist water on the 303(d) impaired waters list. We understand that 303(d) listed waters do not meet minimum water quality standards in Virginia and a Total Maximum Daily Load (TMDL) may eventually be developed to improve water quality. Water quality data can be used to assess overall water quality as part of 305(b) water quality assessment report developed by DEQ every two years.

☐ 2. ***(DEQ Level III)*** Source identification for TMDL development for waters already listed as impaired

Level III data can be used in conjunction with DEQ monitored data to identify sources of pollution for 303(d) listed waters for TMDL development. We

understand that our data will not be used by itself, without water quality data collected by DEQ, wherever possible.

☐ 3. *(DEQ Level II or III)* Track progress of a TMDL Implementation Plan and other restoration
Level II or III data can be used to track the progress of restoration in a TMDL waterbody including installed Best Management Practices or to identify areas where other restoration efforts are taking place.

☐ 4. *(DEQ Level II or III)* Identify waters for future DEQ monitoring
Level II or III data can be used to identify a waterbody for follow-up monitoring by DEQ. We understand that DEQ may not be able to monitor at these locations and/or assess water quality for some period of time.

☐ 5. *(DEQ Level I, II, or III)* Provide education and information on water quality monitoring and water quality issues
All levels of data can be used to help in educating the community about water quality.

On behalf of the group identified above, we agree that the Virginia Department of Environmental Quality (DEQ) may use water quality monitoring data we generate per our selection(s), above. Our choice(s) will remain in effect unless, or until our organization submits changes in the future.

Signature:

_____

☐ By checking this box, and typing my name on the signature line, I authorize the use of the data as specified, and serves as my digital signature.

E-mail to: citizenwater@deq.virginia.gov

Download a fillable PDF of the data use form on the volunteer monitoring program webpage.

Appendix 8

Monitoring Plan Worksheets

Monitoring Plan Worksheets

(Chapter 1 will guide you with completing these worksheets)

Project Name:_____

Organization Name:_____

Contact Person for Project:_____

Phone Number for Contact:_____

Email Address for Contact: _____

Mailing Address for Contact: _____

Date Monitoring Plan Completed: _____

Step 1: Problem Definition/Background

1. What waterbody (ies) do you want to monitor?_____
   _____
2. What monitoring/studies have been conducted in your waterbody of interest?_____
   _____
   _____
   _____
   _____
3. Have you consulted the following sources to determine if monitoring data has been collected:

   a. DEQ Water Quality Monitoring Database at https://apps.deq.virginia.gov/EDM/ ☐
   b. Water Quality Data Portal https://www.waterqualitydata.us/ ☐
   c. USGS ☐
      Local governments ☐
      Local soil and water conservation district ☐
      College or universities ☐
      Others?_____ ☐

   Problem statement/issues affecting your watershed?_____
   _____
   _____
   _____
   _____
   _____

Step 2: Why Are You Monitoring?

A. Overall goals:

B. Questions and information needed to address issues

Questions/Issues to Address	**Information Needed**

Step 3: Intended Uses and Users of Data

List data users and intended use of data. Consult with data users to determine the quality of data they need. For example, if data will be used for screening purposes only, you may not need to use approved methods or follow rigorous quality assurance/quality control checks on the data.

Data User	**Data Use**	**Level of Data Quality Needed**

Step 4: Where Will You Monitor?

A. Are all sites in safe locations on public property or where landowner permission has been obtained?_____

B. Are all sites representative of the stream (in the main flow of the stream away from discharge pipes)?_____

C. At what depth will samples be collected?_____

Site #	**Brief Description of Site Location**	**DCR Small Watershed Code***	**Latitude**	**Longitude**	**Parameters to Monitor**

*****DCR Small Watershed Code can be obtained from local soil and water conservation district or DEQ Water Quality Data Liaison.

Steps 5 & 6: What Parameters/Conditions Will You Monitor?

Sampling Methods and Analytical Methods Requirements

Parameter	**Field or Lab Analysis**	**Sampling Method (specify lab analysis method number or manufacturer and model # of test kit, meter, or other instrument)**	**Why Do You Want to Monitor this Parameter?**
Bacteria - *E. coli*			
Bacteria – Fecal Coliform			
Benthic Macroinvertebrates			
Chlorophyll *a*			
Conductivity			
Dissolved Oxygen			
Flow			
Nitrogen (Identify species)			
pH			
Phosphorus (Identify species)			
Salinity			
Total Solids (specify form)			
Turbidity/ Transparency			
Water Temperature			
Other			
Other			
Other			
Other			
Other			

Step 8: When Will You Sample?

Parameter	**Frequency**	**Time of Year (season)**	**Time of Day**	**Special Weather Conditions**

Step 9: Data Management and Reports

A. What will happen to data sheets once they are completed?_____

B. What software program will used?_____

C. Who will enter the data?_____

D. Who will verify the accuracy of data entry?_____

E. How will data be analyzed? _____

F. How will data be communicated to others? _____

Step 10: Quality Assurance/Quality Control

A. Training Requirements/Certification

1. Who will train volunteers?_____
2. Describe initial training requirements._____
3. Describe refresher training requirements._____

B. Is a QAPP needed for intended use of data?_____

If so, these worksheets can be expanded into a formal QAPP (Chapter 2 and Appendix 12)

Appendix 9

Technical Resource: Excerpt from EPA *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*

In 1990, Congress enacted the Coastal Zone Act Reauthorization Amendments and included a new section titled 'Protecting coastal waters (Section 6217)'. The program is jointly administered by the National Oceanic & Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA). The purpose of the program is to develop and implement management measures for nonpoint sources of pollution to restore and protect coastal waters. A key element of the program is to work in coordination with other federal, state, and local entities. Each state program is required to develop a program under this section that will 'provide for the implementation, at a minimum, of management measures in conformity with the guidance published under subsection (g), to protect coastal waters.'

This appendix is intended to provide additional technical resource information to organizations and individuals that conduct water quality monitoring activities. The information has been excerpted from guidance developed by national work groups and released in 1993 by EPA. The full guidance document can be found at https://www.epa.gov/nps/guidance-specifying-management-measures-sources-nonpoint-pollution-coastal-waters.

II. Techniques for Assessing Water Quality and for Estimating Pollution Loads

Water quality monitoring is the most direct and defensible tool available to evaluate water quality and its response to management and other factors (Coffey and Smolen, 1990). This section describes monitoring methods that can be used to measure changes in pollutant loads and water quality. Due to the wide range of monitoring needs and environmental conditions throughout the coastal zone it is not possible to specify detailed monitoring plans that apply to all areas within the zone. The information in this section is intended merely to guide the development of monitoring efforts at the State and local levels.

This section begins with a brief discussion of the scope and nature of nonpoint source problems, followed by a discussion of monitoring objectives as they relate to section 6217. A lengthy discussion of monitoring approaches is next, with a focus on understanding the watershed to be studied, appropriate experimental designs, sample size and frequency, site locations, parameter selection, sampling methods, and quality assurance and quality control. The intent of this discussion is to provide the reader with basic information essential to the development of effective, tailored monitoring programs that will provide the necessary data for use in statistical tests that are appropriate for evaluating the success of management measures in reducing pollutant loads and improving water quality.

After a brief discussion of data needs, an overview of statistical considerations is presented. Variability and uncertainty are described first, followed by a lengthy overview of sampling and sampling designs. This discussion is at a greater level of detail than others in the section to emphasize the importance of adequate sampling within the framework of a sound experimental design. Hypothesis testing is described next, including some examples of hypotheses that may be appropriate for section 6217 monitoring efforts. An overview of data analysis techniques is given at the end of the section.

A. Nature and Scope of Nonpoint Source Problems

Nonpoint sources may generate both conventional and toxic pollutants, just as point sources do. Although nonpoint sources may contribute many of the same kinds of pollutants, these pollutants are generated in different volumes, combinations, and concentrations. Pollutants from nonpoint sources are mobilized primarily during storm events or snowmelt, but baseflow contributions can be the major source of nonpoint source contaminants in some systems. Thus, knowledge of the hydrology of a system is critical to the design of successful monitoring programs.

Nonpoint source problems are not just reflected in the chemistry of a water resource. Instead, nonpoint source problems are often more acutely manifested in the biology and habitat of the aquatic system. Such impacts include the destruction of spawning areas, impairments to the habitat for shellfish, changes to aquatic community structure, and fish mortality. Thus, any given nonpoint source monitoring program may have to include a combination of chemical, physical, and biological components to be effective.

B. Monitoring Objectives

Monitoring is usually performed in support of larger efforts such as nonpoint source pollution control programs within coastal watersheds. As such, monitoring objectives are generally established in a way that contributes toward achieving the broader program objectives. For example, program objectives may include restoring an impaired use or protecting or improving the ecological condition of a water resource. Supporting monitoring objectives, then, might include assessing trends in use support or in key biological parameters.

The following discussion identifies the overall monitoring objectives of section 6217 and gives some examples of specific objectives that may be developed at the State or local level in support of those overall objectives. Clearly, due to the prohibitive expense of monitoring the effectiveness of every management measure applied in the coastal zone, States will need to develop a strategy for using limited monitoring information to address the broad questions regarding the effectiveness of section 6217 implementation. A combination of watershed monitoring to track the cumulative benefits of systems of management measures and demonstrations of selected management measures of key importance in the State may be one way in which the overall section 6217 monitoring objectives can be met within the constraints imposed by limited State monitoring budgets.

1. Section 6217 Objectives

The overall management objective of section 6217 is to develop and implement management measures for nonpoint source pollution to restore and protect coastal waters. The principal monitoring objective under section 6217(g) is to assess over time the success of the management measures in reducing pollution loads and improving water quality. A careful reading of this monitoring objective reveals that there are two sub-objectives: (1) to assess changes in pollution loads over time and (2) to assess changes in water quality over time.

A pollutant load is determined by multiplying the total runoff volume times the average concentration of the pollutant in the runoff. Loads are typically estimated only for chemical and

some physical (e.g., total suspended solids) parameters. Water quality, however, is determined on the basis of the chemical, physical, and biological conditions of the water resource. Section 6217(g), therefore, calls for a description of pollutant load estimation techniques for chemical and physical parameters, plus a description of techniques to assess water quality on the basis of chemical, physical, and biological conditions. This section focuses on those needs.

2. Formulating Monitoring Objectives

A monitoring objective should be narrowly and clearly defined to address a specific problem at an appropriate level of detail (Coffey and Smolen, 1990). Ideally, the monitoring objective specifies the primary parameter(s), location of monitoring (and perhaps the timing), the degree of causality or other relationship, and the anticipated result of the management action. The magnitude of the change may also be expressed in the objective. Example monitoring objectives include:

- To determine the change in trends in the total nitrogen concentration in Beautiful Sound due to the implementation of nutrient management on cropland in all tributary watersheds.
- To determine the sediment removal efficiency of an urban detention basin in New City.
- To evaluate the effects of improved marina management on metals loadings from the repair and maintenance areas of Stellar Marina.
- To assess the change in weekly mean total suspended solids concentrations due to forestry harvest activities in Clean River.

C. Monitoring Approaches

1. General

a. Types of Monitoring

The monitoring program design is the framework for sampling, data analysis, and the interpretation of results (Coffey and Smolen, 1990). MacDonald (1991) identifies seven types of monitoring:

1. Trend monitoring;
2. Baseline monitoring;
3. Implementation monitoring;
4. Effectiveness monitoring;
5. Project monitoring;
6. Validation monitoring; and
7. Compliance monitoring.

Trend, baseline, implementation, effectiveness, and project monitoring all relate to the monitoring objectives of section 6217. These types of monitoring, in fact, are not mutually exclusive. The distinction between effectiveness monitoring and project monitoring, for example, is often simply one of scale, with effectiveness monitoring primarily directed at individual practices and project monitoring directed at entire sets of practices or activities

implemented over a larger area. Since one cannot evaluate the effectiveness of a project or management measure (i.e., achievement of the desired effect) without knowing the status of implementation, implementation monitoring is an essential element of both project and effectiveness monitoring. In addition, a test for trend is typically included in the evaluation of projects and management measures, and baseline monitoring is performed prior to the implementation of pollution controls.

Meals (1991a) discussed five major points to consider in developing a monitoring system that would provide a suitable data base for watershed trend detection: (1) understand the system you want to monitor, (2) design the monitoring system to meet objectives, (3) pay attention to details at the beginning, (4) monitor source activities, and (5) build in feedback loops. These five points apply equally to both load estimation and water quality assessment monitoring efforts.

b. Section 6217 Monitoring Needs

The basic monitoring objective for section 6217 is to assess over time the success of the measures in reducing pollution loads and improving water quality. This objective would seem to indicate a need for establishing cause-effect relationships between management measure implementation and water quality. Although desirable, monitoring to establish such cause-effect relationships is typically beyond the scope of affordable program monitoring activities.

Mosteller and Tukey (1977) identified four criteria that must be met to show cause and effect: association, consistency, responsiveness, and a mechanism.

- **Association** is shown by demonstrating a relationship between two parameters (e.g., a correlation between the extent of management measure implementation and the level of pollutant loading).
- **Consistency** can be confirmed by observation only and implies that the association holds in different populations (e.g., management measures were implemented in several areas and pollutant loading was reduced, depending on the effect of treatment, in each case).
- **Responsiveness** can be confirmed by an experiment and is shown when the dependent variable (e.g., pollutant loading) changes predictably in response to changes in the independent variable (e.g., extent of management measure implementation).
- **Mechanism** is a plausible step-by-step explanation of the statistical relationship. For example, conservation tillage reduced the edge-of-field losses of sediment, thereby removing a known fraction of pollutant source from the stream or lake. The result was decreased suspended sediment concentration in the water column.

Clearly, the cost of monitoring needed to establish cause-effect relationships throughout the coastal zone far exceeds available resources. It may be suitable, however, to document associations between management measure implementation and trends in pollutant loads or water quality and then account for such associations with a general description of the primary mechanisms that are believed to come into play.

c. Scale, Local Conditions, and Variability

There are several approaches that can be taken to assess the effectiveness of measures in reducing loads and improving water quality. There are also several levels of scale that could be selected: individual practices, individual measures, field scale, watershed scale, basin scale, regional scale, etc. With any given monitoring objective, the specific monitoring approach to use at any specific site is a function of the local conditions (e.g., geography, climate, water resource type) and the type of management measures implemented.

The detection and estimation of trends is complicated by problems associated with the characteristics of pollution data (Gilbert, 1987). Physical, chemical, and biological parameters in the receiving water may undergo extreme changes without the influence of human activity. Understanding and monitoring the factors responsible for variability in a local system are essential for detecting the improvements expected from the implementation of management measures.

Simple point estimates taken before and after treatment will not confirm an effect if the natural variability is typically greater than the changes due to treatment (Coffey and Smolen, 1990). Therefore, knowledge of the variability and the distribution of the parameter is important for statistical testing. Greater variability requires a larger change to imply that the observed change is not due solely to random events (Spooner et al., 1987b). Examination of a historical data set can help to identify the magnitude of natural variability and possible sources.

The impact of management actions may not be detectable as a change in a mean value but rather as a change in variability (Coffey and Smolen, 1990). Platts and Nelson (1988) found that a carefully designed study was required to isolate the large natural fluctuations in trout populations to distinguish the effects of land use management. They assumed that normal fluctuation patterns were similar between the control and the treatment area and that treatment-induced effect could be distinguished as a deviation from the historical pattern.

Meals (1991a) calls for the collection and evaluation of existing data as the first step in a monitoring effort, recognizing that additional background data may be needed to identify hot spots or fill information gaps. The results of such initial efforts should include established stage-discharge ratings and an understanding of patterns not associated with the pollution control effort.

2. Understanding the System to Be Monitored

a. The Water Resource

Options for tracking water quality vary with the type of water resource. For example, a monitoring program for ephemeral streams can be different from that for perennial streams or large rivers. Lakes, wetlands, riparian zones, estuaries, and near-shore coastal waters all present different monitoring considerations. Whereas upstream-downstream designs work on rivers and streams, they are generally less effective on natural lakes where linear flow is not so prevalent. Likewise, estuaries present difficulties in monitoring loads because of the shifting flows and changing salinity caused by the tides. A successful monitoring program recognizes the unique

features of the water resources involved and is structured to either adapt to those features or avoid them.

Streams. Freshwater streams can be classified on the basis of flow attributes as intermittent or perennial streams. Intermittent streams do not flow at all times and serve as conveyance systems for runoff. Perennial streams always flow and usually have significant inputs from ground water or interflow. For intermittent streams, seasonal variability is a very significant factor in determining pollutant loads and water quality. During some periods sampling may be impossible due to no flow. Seasonal flow variability in perennial streams can be caused by seasonal patterns in precipitation or snowmelt, reservoir discharges, or irrigation practices.

For many streams the greatest concentrations of suspended sediment and other pollutants occur during spring runoff or snowmelt periods. Concentrations of both particulate and soluble chemical parameters have been shown to vary throughout the course of a rainfall event in many studies across the Nation. This short-term variability should be considered in developing monitoring programs for flowing (lotic) waterbodies.

Spatial variability is largely lateral for both intermittent and perennial streams. Vertical variability does exist, however, and can be very important in both stream types (e.g., during runoff events, in tidal waters, and in deep, slow-moving streams). Intake depth is often a key factor in stream sampling. For example, slow-moving, larger streams may show considerable water quality variability with depth, particularly for parameters such as suspended solids, dissolved oxygen, and algal productivity. Suspended sediment samples must be taken with an understanding of the vertical distribution of both sediment concentration and flow velocity (Brakensiek et al., 1979). When sampling bed sediment or monitoring biological parameters, it is important to recognize the potential for significant lateral and vertical variation in the toxicity and contaminant levels of bed sediments (USEPA, 1987).

Lakes. Lakes can be categorized in several ways, but a useful grouping for monitoring guidance is related to the extent of vertical and lateral mixing of the waterbody. Therefore, lakes are considered to be either mixed or stratified for the purpose of this guidance. Mixed lakes are those lakes in which water quality (as determined by measurement of the parameters and attributes of interest) is homogenous throughout, and stratified lakes are considered to be those lakes which have lateral or vertical water quality differentials in the lake parameters and attributes of interest. Totally mixed lakes, if they exist, are certainly few in number, but it may be useful to perform monitoring in selected homogenous portions of stratified lakes to simplify data interpretation. Similarly, for lakes that exhibit significant seasonal mixing, it may be beneficial to monitor during a time period in which they are mixed. For some monitoring objectives, however, it may be best to monitor during periods of peak stratification.

Temporal variability concerns are similar for mixed and stratified lakes. Seasonal changes are often obvious, but should not be assumed to be similar for all lakes or even the same for different parts of any individual lake. Due to the importance of factors such as precipitation characteristics, climate, lake basin morphology, and hydraulic retention characteristics, seasonal variability should be at least qualitatively assessed before any lake monitoring program is initiated.

Short-term variability is also an inherent characteristic of most still (lentic) waterbodies. Parameters such as pH, dissolved oxygen, and temperature can vary considerably over the course of a day. Monitoring programs targeted toward biological parameters should be structured to account for this short-term variability. It is often the case that small lakes and reservoirs respond rapidly to runoff events. This factor can be very important in cases where lake water quality will be correlated to land treatment activities or stream water quality.

In stratified lakes spatial variability can be lateral or vertical. The classic stratified lake is one in which there is an epilimnion and a hypolimnion (Wetzel, 1975). Water quality can vary considerably between the two strata, so sampling depth is an important consideration when monitoring vertically stratified lakes.
Lateral variability is probably as common as vertical variability, particularly in lakes and ponds receiving inflow of varying quality. Figure 8-1 illustrates the types of factors that contribute to lateral variability in lake water quality. In reservoir systems, storm plumes can cause significant lateral variability.

Davenport and Kelly (1984) explained the lateral variability in chlorophyll a concentrations in an Illinois lake based on water depth and the time period that phytoplankters spend in the photic zone. A horizontal gradient of sediment, nutrient, and chlorophyll a concentrations in St. Albans Bay, Vermont, was related to mixing between Lake Champlain and the Bay (Clausen, 1985). It is important to note that there frequently exists significant lateral and vertical variation in the toxicity and contaminant levels of bed sediments (USEPA, 1987).

Despite the distinction made between mixed and stratified lakes, there is considerable gray area between these groups. For example, thermally stratified lakes may be assumed to be mixed during periods of overturn, and laterally stratified lakes can sometimes be treated as if the different lateral segments are sub-lakes. In any case, it is important that the monitoring team knows what parcel of water is being sampled when the program is implemented. It would be inappropriate, for example, to assign the attributes of a surface sample to the hypolimnion of a stratified lake due to the differences in temperature and other parameters between the upper and lower waters.

Estuaries. Estuaries can be very complex systems, particularly large ones such as the Chesapeake Bay. Estuaries exhibit temporal and spatial variability just as streams and lakes do. Physically, the major differences between estuaries and fresh waterbodies are related to the mixing of fresh water with salt water and the influence of tides. These factors increase the complexity of spatial and temporal variability within an estuary.

Short-term variability in estuaries is related directly to the tidal cycles, which can have an effect on both the mixing of the fresh and saline waters and the position of the freshwater-saltwater interface (USEPA, 1982a). The same considerations made for lakes regarding short-term variability of parameters such as temperature, dissolved oxygen, and pH should also be made for estuaries.
Temperature profiles such as those found in stratified lakes can also change with season in estuaries. The resulting circulation dynamics must be considered when developing monitoring

programs. The effects of season on the quantity of freshwater runoff to an estuary can be profound. In the Chesapeake Bay, for example, salinity is generally lower in the spring and higher in the fall due to the changes in freshwater runoff from such sources as snowmelt runoff and rainfall (USEPA, 1982a).

Spatial variability in estuaries has both significant vertical and lateral components. The vertical variability is related to both temperature and chemical differentials. In the Chesapeake Bay thermal stratification occurs during the summer, and chemical stratification occurs at all times, but in different areas at different times (USEPA, 1982a). Chemical stratification can be the result of the saltwater wedge flowing into and under the freshwater outflow or the accumulation or channeling of freshwater and saltwater flows to opposite shores of the estuary. The latter situation can be caused by a combination of tributary location, the earth's rotation, and the barometric pressure. In addition, lateral variability in salinity can be caused by different levels of mixing between saltwater and freshwater inputs. As noted for streams and lakes, the lateral and vertical variation in the toxicity and contaminant levels of bed sediments should be considered (EPA, 1987).

Coastal Waters. Researchers and government agencies are collectively devoid of significant experience in evaluating the effectiveness of nonpoint source pollution control efforts through the monitoring of near-shore and offshore coastal waters. Our understanding of the factors to consider when performing such monitoring is therefore very limited.

As for other waterbody types, it is important to understand the hydrology, chemistry, and biology of the system in order to develop an effective monitoring program. Of particular importance is the ability to identify discrete populations to sample from. For trend analysis it is essential that the researcher is able to track over time the conditions of a clearly identifiable segment or unit of coastal water. This may be accomplished by monitoring a semi-enclosed near-shore embayment or similar system. Knowledge of salinity and circulation patterns should be useful in identifying such areas.

Secondly, monitoring should be focused on those segments or units of coastal water for which there is a reasonable likelihood that changes in water quality will result from the implementation of management measures. Segment size, circulation patterns, and freshwater inflows should be considered when estimating the chances for such water quality improvements.

Near-shore coastal waters may exhibit salinity gradients similar to those of estuaries due to the mixing of fresh water with salt water. Currents and circulation patterns can create temperature gradients as well. Farther from shore, salinity gradients are less likely, but gradients in temperature may occur. In addition, vertical gradients in temperature and light may be significant. These and other biological, chemical, and physical factors should be considered in the development of monitoring programs for coastal waters.

3. Experimental Design

a. Types of Experimental Designs

EPA has prescribed monitoring designs for use in watershed projects funded under section 319 of the Clean Water Act (USEPA, 1991b). The objective in promoting these designs is to

document changes in water quality that can be related to the implementation of nonpoint source control measures in selected watersheds. The designs recommended by EPA are paired-watershed designs and upstream-downstream designs. Single downstream station designs are not recommended by EPA for section 319 watershed projects (USEPA, 1991b).

Monitoring before implementation is usually required to detect a trend or show causality (Coffey and Smolen, 1990). Two years of pre-implementation monitoring are typically needed to establish an adequate baseline. Less time may be needed for studies at the management measure or edge-of-field scale, when hydrologic variability is known to be less than that of typical agricultural systems, or when a paired-watershed design is used.

Paired-Watershed Design. In the paired-watershed design there is one watershed where the level of implementation (ideally) does not change (the control watershed) and a second watershed where implementation occurs (the study watershed). This design has been shown in agricultural nonpoint source studies to be the most powerful study design for demonstrating the effectiveness of nonpoint source control practice implementation (Spooner et al., 1985). Paired-watershed designs have a long history of application in forest hydrology studies. The paired-watershed design must be implemented properly, however, to generate useful data sets. Some of the considerations to be made in designing and implementing paired-watershed studies are described below.

In selecting watershed pairs, the watersheds should be as similar as possible in size, shape, aspect, slope, elevation, soil type, climate, and vegetative cover (Striffler, 1965). The general procedure for paired-watershed studies is to monitor the watersheds long enough to establish a statistical relationship between them. A correlation should be found between the values of the monitored parameters for the two watersheds. For example, the total nitrogen values in the control watershed should be correlated with the total nitrogen values in the study watershed. A pair of watersheds may be considered sufficiently calibrated when a parameter for the control watershed can be used to predict the corresponding value for the study watershed (or vice versa) within an acceptable margin of error.

It is important to note that the calibration period should cover all or the significant portion of the range of conditions for each of the major water quality determinants in the two watersheds. For example, the full range of hydrologic conditions should be covered (or nearly covered) during the calibration period. This may be problematic in areas where rainfall and snowmelt are highly variable from year to year or in areas subject to extended wet periods or drought. Calibration during a dry year is likely to not be adequate for establishing the relationship between the two watersheds, particularly if subsequent years include both wet and dry periods.
Similarly, some agricultural areas of the country use long-term, multiple-crop rotations. The calibration period should cover not only the range of hydrologic conditions but also the range of cropping patterns that can reasonably be expected to have an influence on the measured water quality parameters. This is not to say that the calibration period should take 5 to 10 years, but rather that States should use careful judgment in determining when the calibration period can be safely ended.

After calibration, the study watershed receives implementation of management measures, and monitoring is continued in both watersheds. The effects of the management measures are evaluated by testing for a change in the relationship between the monitored parameters (i.e., a change in the correlation). If treatment is working, then there should be a greater difference over time between the treated study watershed and the untreated (poorly managed) control watershed. Alternatively, the calibration period could be used to establish statistical relationships between a fully treated watershed (control watershed) and an untreated watershed (study watershed). After calibration under this approach, the study watershed would be treated and monitoring continued. The effects of the management measures would be evaluated, however, by testing for a change in the correlation that would indicate that the two watersheds are more similar than before treatment.

It is important to use small watersheds when performing paired-watershed studies since they are more easily managed and more likely to be uniform (Striffler, 1965). EPA recommends that paired watersheds be no larger than 5,000 acres (USEPA, 1991b).

Upstream-Downstream Studies. In the upstream-downstream design, there is one station at a point directly upstream from the area where implementation of management measures will occur and a second station directly downstream from that area. Upstream-downstream designs are generally more useful for documenting the magnitude of a nonpoint source than for documenting the effectiveness of nonpoint source control measures (Spooner et al., 1985), but they have been used successfully for the latter. This design provides for the opportunity to account for covariates (e.g., an upstream pollutant concentration that is correlated with a downstream concentration of same pollutant) in statistical analyses and is therefore the design that EPA recommends in cases where paired watersheds cannot be established (USEPA, 1991b).

Upstream-downstream designs are needed in cases where project areas are not located in headwaters or where upstream activities that are expected to confound the analysis of downstream data occur. For example, the effects of upstream point source discharges, uncontrolled nonpoint source discharges, and upstream flow regulation can be isolated with upstream-downstream designs.

Inflow-Outflow Design. Inflow-outflow, or process, designs are very similar to upstream-downstream designs. The major differences are scale and the significance of confounding activities. Process designs are generally applied in studies of individual management measures or practices. For example, sediment loading at the inflow and outflow of a detention basin may be measured to determine the pollutant removal efficiency of the basin. In general, no inputs other than the inflow are present, and the only factor affecting outflow is the management measure. As noted above (see The Management Measures to Be Implemented), process monitoring cannot generally be applied to studies of source-reduction management measures or measures that prevent direct impacts, but it can be applied successfully in the evaluation of delivery-reduction management measures.

b. Scale

Management Measure. Monitoring the inflow and outflow of a specific management measure should be the most sensitive scale since the effects of uncontrollable discharges and uncertainties in treatment mechanisms are minimized.

Edge of Field. Monitoring pollutant load from a single-field watershed should be the next most sensitive scale since the direct effects of implementation can be detected without pollutant trapping in a field border or stream channel (Coffey and Smolen, 1990).

Sub-watershed. Monitoring a sub-watershed can be useful to monitor the aggregate effect of implementation on a group of fields or smaller areas by taking samples close to the treatment (Coffey and Smolen, 1990). Sub-watershed monitoring networks measure the aggregate effects of treatment and nontreatment runoff as it enters an upgradient tributary or the receiving waterbody. Sub-watershed monitoring can also be used for targeting critical areas.

Watershed. Monitoring at the watershed scale is appropriate for assessing total project area pollutant load using a single station (Coffey and Smolen, 1990). Depending on station arrangement, both sub-watershed and watershed outlet studies are very useful for water and pollutant budget determinations. Monitoring at the watershed outlet is the least sensitive of the spatial scales for detecting treatment effect. Sensitivity of the monitoring program decreases with increased basin size and decreased treatment extent or both (Coffey and Smolen, 1990.

c. Reference Systems and Standards

EPA's rapid bioassessment protocols advocate an integrated assessment, comparing habitat and biological measures with empirically defined reference conditions (Plafkin et al., 1989). Reference conditions are established through systematic monitoring of actual sites that represent the natural range of variation in "least disturbed" water chemistry, habitat, and biological condition. Reference sites can be used in monitoring programs to establish reasonable expectations for biological, chemistry, and habitat conditions. An example application of this concept is the paired-watershed design (Coffey and Smolen, 1990).

EPA's ecoregional framework can be used to establish a logical basis for characterizing ranges of ecosystem conditions or quality that are realistically attainable (Omernik and Gallant, 1986). Ecoregions are defined by EPA to be regions of relative homogeneity in ecological systems or in relationships between organisms and their environments. Hughes et al. (1986) have used a relatively small number of minimally impacted regional reference sites to assess feasible but protective biological goals for an entire region.

Water quality standards can be used to identify criteria that serve as reference values for biological, chemical, or habitat parameters, depending on the content of the standard. The frequency distribution of observation values can be tracked against either a water quality standard criterion or a reference value as a method for measuring trends in water quality or loads (USEPA, 1991b).

4. Site Locations

Within any given budget, site location is a function of water resource type (see The Water Resource), monitoring objectives (see Monitoring Objectives), experimental design (see Types of Experimental Designs), the parameters to be monitored (see Parameter Selection), sampling techniques (see Sampling Techniques and Samples and Sampling), and data analysis plans (see Data Analysis). Additional considerations in site selection are accessibility and landowner cooperation.

It is recommended that monitoring stations be placed near established gauging stations whenever possible due to the extreme importance of obtaining accurate discharge measurements. Where gauging stations are not available but stream discharge measurements are needed, care should be taken to select a suitable site. Brakensiek et al. (1979) provide excellent guidance regarding runoff measurement, including the following selected recommendations regarding site selection:

- Field-calibrated gauging stations should be located in straight, uniform reaches of channel having smooth beds and banks of a permanent nature whenever possible.
- Gauging stations should be located away from sewage outfall, power stations, or other installations causing flow disturbances.
- Consider the geology and contributions of ground-water flow.
- Where ice is a potential problem, locate measuring devices in a protected area that receives sunlight most of the time.
- Daily current-meter measurements may be necessary where sand shifts occur.

5. Sampling Frequency and Interval
a. Sample Size and Frequency

It is important to estimate early in a monitoring effort the number and frequency of samples required to meet the monitoring objectives. Spooner et al. (1991) report that the sampling frequency required at a given monitoring station is a function of the following:

- Monitoring goals;
- Response of the water resource to changes in pollutant sources;
- Magnitude of the minimum amount of change for which detection with trend analyses is desired (i.e., minimum detectable change);
- System variability and accuracy of the sample estimate of reported statistical parameter (e.g., confidence interval width on a mean or trend estimate);
- Statistical power (i.e., probability of detecting a true trend);
- Autocorrelation (i.e., the extent to which data points taken over time are correlated);
- Monitoring record length;
- Number of monitoring stations; and
- Statistical methods used to analyze the data.

The minimum detectable change (MDC) is the minimum change in a water quality parameter over time that is considered statistically significant. Knowledge of the MDC can be very useful in the planning of an effective monitoring program (Coffey and Smolen, 1990). The MDC can be estimated from historical records to aid in determining the required sampling frequency and to evaluate monitoring feasibility (Spooner et al., 1987a). MacDonald (1991) discusses the same concept, referring to it as the minimum detectable effect.

The larger the MDC, the greater the change in water quality that is needed to ensure that the change was not just a random fluctuation. The MDC may be reduced by accounting for covariates, increasing the number of samples per year, and increasing the number of years of monitoring. Sherwani and Moreau (1975) stated that the desired frequency of sampling is a function of several considerations associated with the system to be studied, including:

- Response time of the system;
- Expected variability of the parameter;
- Half-life and response time of constituents;
- Seasonal fluctuation and random effects;
- Representativeness under different conditions of flow;
- Short-term pollution events;
- Magnitude of response; and
- Variability of the inputs.

Coastal waters, estuaries, ground water, and lakes will typically have longer response times than streams and rivers. Thus, sampling frequency will usually be greater for streams and rivers than for other water resource types. Some parameters such as total suspended solids and fecal coliform bacteria can be highly variable in stream systems dominated by nonpoint sources, while nitrate levels may be less volatile in systems driven by baseflow from ground water. The highly variable parameters would generally require more frequent sampling, but parameter variability should be evaluated on a site-specific basis rather than by rule of thumb.

In cases where pollution events are relatively brief, sampling periods may also be short. For example, to determine pollutant loads it may be necessary to sample frequently during a few major storm events and infrequently during baseflow conditions. Some parameters vary considerably with season, particularly in watersheds impacted primarily by nonpoint sources. Boating is typically a seasonal activity in northern climates, so intensive seasonal monitoring may be needed to evaluate the effectiveness of management measures for marinas.

The water quality response to implementation of management measures will vary considerably across the coastal zone. Pollutant loads from confined livestock operations may decline significantly in response to major improvements in runoff and nutrient management, while sediment delivery from logging areas may decline only a little if the level of pollution control prior to section 6217 implementation was already fairly good. Fewer samples will usually be needed to document water quality improvement in watersheds that are more responsive to pollution control efforts.

Sherwani and Moreau (1975) state that for a given confidence level and margin of error, the necessary sample size, and hence sampling frequency, is proportional to the variance. Since the variance of water quality parameters may differ considerably over time, the frequency requirements of a monitoring program may vary depending on the time of the year. Sampling frequency will need to be greater during periods of greater variance.

There are statistical methods for estimating the number of samples required to achieve a desired level of precision in random sampling (Cochran, 1963), stratified random sampling (Reckhow, 1979), cluster sampling (Cochran, 1977), multistage sampling (Gilbert, 1987), double sampling (Gilbert, 1987), and systematic sampling (Gilbert, 1987). For a more detailed discussion of sampling theory and statistics, see Samples and Sampling .

b. Sampling Interval

A method for estimating sampling interval is provided by Sherwani and Moreau (1975). They note that the least favorable sampling interval for parameters that exhibit a periodic structure is equal to the period or an integral multiple of the period. Such sampling would introduce statistical bias. Reckhow (1979) points out that, for both random and stratified random sampling, systematic sampling is acceptable only if "there is no bias introduced by incomplete design, and if there is no periodic variation in the characteristic measured." Gaugush (1986) states that monthly sampling is usually adequate to detect the annual pattern of changes with time.

c. Some Recommendations

It is generally recommended that the sampling of plankton, fish, and benthic organisms in estuaries should be seasonal, with the same season sampled in multiyear studies (USEPA, 1991a). The aerial coverage and bed density for submerged aquatic vegetation (SAV) vary from year to year due to catastrophic storms, exceptionally high precipitation and turbidity, and other poorly understood natural phenomena (USEPA, 1991a). For this reason, short-term SAV monitoring may be more reflective of infrequent impacts and may not be useful for trend assessment. In addition, incremental losses in wetland acreage are now within the margin of error for current detection limits. It is recommended that SAV and wetland sampling be conducted during the period of peak biomass (USEPA, 1991a).

The frequency of sediment sampling in estuaries should be related to the expected rate of change in sediment contaminant concentrations (USEPA, 1991a). Because tidal and seasonal variability in the distribution and magnitude of several water column physical characteristics in estuaries is typically observed, these influences should be accounted for in the development of sampling strategies (USEPA, 1991a).

For monitoring the state of biological variables, the length of the life cycle may determine the sampling interval (Coffey and Smolen, 1990). EPA (1991b) recommends a minimum of 20 evenly spaced (e.g., weekly) samples per year to document trends in chemical constituents in watershed studies lasting 5 to 10 years. The 20 samples should be taken during the time period (e.g., season) when the benefits of implemented pollution control measures are most likely to be

observed. For benthic macroinvertebrates and fish, EPA recommends at least one sample per year.

8. Sampling Techniques
a. Automated Sampling to Estimate Pollutant Loads

Typical methods for estimating pollutant loads include continuous flow measurements and some form of automated sampling that is either timed or triggered by some feature of the runoff hydrograph. For example, in the Santa Clara watershed of San Francisco Bay, flow was continuously monitored at hourly intervals, wet-weather monitoring included collection of flow-composite samples taken with automatic samplers, and dry-weather monitoring was conducted by obtaining quarterly grab samples (Mumley, 1991). Data were used to estimate annual, wet-weather, and dry-weather copper loads.

In St. Albans Bay, Vermont, continuous flow and composite samples were used to estimate nutrient loads for trend analysis (Vermont RCWP, 1984). In the Nationwide Urban Runoff Program (NURP) project in Bellevue, Washington, catchment area monitoring included continuous gauging and automatic sampling that occurred at a preset time interval (5 to 50 minutes) once the stage exceeded a preset threshold (USEPA, 1982b).

b. Grab Sampling for Pollutant Loads

Grab sampling with continuous discharge gauging can be used to estimate load in some cases. Grab sampling is usually much less expensive than automated sampling methods and is typically much simpler to manage. These significant factors of cost and ease make grab sampling an attractive alternative to automated sampling and therefore worthy of consideration even for monitoring programs with the objective of estimating pollutant loads.

Grab sampling should be carefully evaluated to determine its applicability for each monitoring situation (Coffey and Smolen, 1990). Nonpoint source pollutant concentrations generally increase with discharge. For a system with potentially lower variability in discharge, such as irrigation, grab sampling may be a suitable sampling method for estimating loads (Coffey and Smolen, 1990). Grab sampling may also be appropriate for systems in which the distribution of annual loading occurs over an extended period of several months, rather than a few events. In addition, grab sampling may be used to monitor low flows and background concentrations.

For systems exhibiting high variability in discharge or where the majority of the pollutant load is transported by a few events (such as snowmelt in some northern temperate regions), however, grab sampling is not recommended.

c. Habitat Sampling

EPA recommends a procedure for assessing habitat quality where all of the habitat parameters are related to overall aquatic life use support and are a potential source of limitation to the aquatic biota (Plafkin et al., 1989). In this procedure, EPA begins with a survey of physical

characteristics and water quality at the site. Such physical factors as land use, erosion, potential nonpoint sources, stream width, stream depth, stream velocity, channelization, and canopy cover are addressed. In addition, water quality parameters such as temperature, dissolved oxygen, pH, conductivity, stream type, odors, and turbidity are observed.
Then, EPA follows with the habitat assessment, which includes a range of parameters that are weighted to emphasize the most biologically significant parameters (Plafkin et al., 1989). The procedure includes three levels of habitat parameters. The primary parameters are those that characterize the stream "microscale" habitat and have the greatest direct influence on the structure of the indigenous communities. These parameters include characterization of the bottom substrate and available cover, estimation of embeddedness, and estimation of the flow or velocity and depth regime. Secondary parameters measure the "macroscale" and include such parameters as channel alteration, bottom scouring and deposition, and stream sinuosity. Tertiary parameters include bank stability, bank vegetation, and streamside cover.

MacDonald (1991) discusses a wide range of channel characteristics and riparian parameters that can be monitored to evaluate the effects of forestry activities on streams in the Pacific Northwest and Alaska. MacDonald states that "stream channel characteristics may be advantageous for monitoring because their temporal variability is relatively low, and direct links can be made between observed changes and some key designated uses such as coldwater fisheries." He notes, however, that "general recommendations are difficult because relatively few studies have used channel characteristics as the primary parameters for monitoring management impacts on streams."

On the other hand, MacDonald concludes that the documented effects of management activities on the stability and vegetation of riparian zones, and the established linkages between the riparian zone and various designated uses, provide the rationale for including the width of riparian canopy opening and riparian vegetation as recommended monitoring parameters. Riparian canopy opening is measured and tracked through a historical sequence of aerial photographs (MacDonald, 1991). Riparian vegetation is measured using a range of methods, including qualitative measures of vegetation type, visual estimations of vegetation cover, quantitative estimations of vegetation cover using point- or line-intercept methods, light intensity measurements to estimate forest cover density, stream shading estimates using a spherical densiometer, and estimates of vegetation density based on plot measurements.

Habitat variables to monitor grazing impacts include areas covered with vegetation and bare soil, stream width, stream channel and streambank stability, and width and area of the riparian zone (Platts et al., 1987). Ray and Megahan (1978) developed a procedure for measuring streambank morphology, erosion, and deposition. Detailed streambank inventories may be recorded and mapped to monitor present conditions or changes in morphology through time.

To assess the effect of land use changes on streambank stability, Platts et al. (1987) provide methods for evaluating and rating streambank soil alteration. Their rating system can be used to determine the conditions of streambank stability that could affect fish. Other measurements that could be important for fisheries habitat evaluations include streambank undercut, stream shore water depth, and stream channel bank angle.

d. Benthic Organism Sampling

Benthic communities in estuaries are sampled through field surveys, which are typically time-consuming and expensive (USEPA, 1991a). Sampling devices include trawls, dredges, grabs, and box corers. For more specific benthic sampling guidance, see Klemm et al. (1990).

e. Fish Sampling

For estuaries and coastal waters, a survey vessel manned by an experienced crew and specially equipped with gear to collect organisms is required (USEPA, 1991a). Several types of devices and methods can be used to collect fish samples, including traps and cages, passive nets, trawls (active nets), and photographic surveys. Since many of these devices selectively sample specific types of fish, it is not recommended that comparisons be made among data collected using different devices (USEPA, 1991a).

f. Shellfish Sampling

Pathobiological methods provide information concerning damage to organ systems of fish and shellfish through an evaluation of their altered structure, activity, and function (USEPA, 1991a). A field survey is required to collect target organisms, and numerous tissue samples may be required for pathobiological methods. In general, pathobiological methods are labor-intensive and expensive (USEPA, 1991a).

g. Plankton Sampling

Phytoplankton sampling in coastal waters is frequently accomplished with water bottles placed at a variety of depths throughout the water column, some above and some below the pycnocline (USEPA, 1991a). A minimum of four depths should be sampled. Zooplankton sampling methods vary depending on the size of the organisms. Devices used include water bottles, small mesh nets, and pumps (USEPA, 1991a).

h. Aquatic Vegetation Sampling

Attributes of emergent wetland vegetation can be monitored at regular intervals along a transect (USEPA, 1991a). Measurements include plant and mulch biomass, and foliar and basal cover. Losses of aquatic vegetation can be tracked through aerial photography and mapping.

i. Water Column Sampling

In estuaries and coastal waters, chemical samples are frequently collected using water bottles and should be taken at a minimum of four depths in the vertical profile (USEPA, 1991a). Caged organisms have also been used to monitor the bioaccumulation of toxic chemicals.

Physical sampling of the water column at selected depths in estuaries is done with bottles for temperature, salinity, and turbidity, or with probes for temperature and salinity (USEPA, 1991a). Current meters are used to characterize circulation patterns.

j. Sediment Sampling

Several types of devices can be used to collect sediment samples, including dredges, grabs, and box corers (USEPA, 1991a). Sampling depth may vary depending on the monitoring objective, but it is recommended that penetration be well below the desired sampling depth to prevent sample disturbance as the device closes (USEPA, 1991a). EPA also recommends the selection of sediment samplers that also sample benthic organisms to cut sampling costs and to permit better statistical analyses relating sediment quality to benthic organism parameters.

k. Bacterial and Viral Pathogen Sampling

For estuaries and coastal waters it is recommended that samples be taken of both the underlying waters and the thin microlayer on the surface of the water (USEPA, 1991a). This is recommended, despite the fact that standardized methods for sampling the microlayer have not been established, because research has shown bacterial levels several orders of magnitude greater in the microlayer. In no case should a composite sample be collected for bacteriological examination (USEPA, 1978).

Water samples for bacterial analyses are frequently collected using sterilized plastic bags or screw cap, wide-mouthed bottles (USEPA, 1991a). Several depths may be sampled during one cast, or replicate samples may be collected at a particular depth by using a Kemmerer or Niskin sampler (USEPA, 1978). Any device that collects water samples in unsterilized tubes should not be used for collecting bacteriological samples without first obtaining data that support its use (USEPA, 1991a). Pumps may be used to sample large volumes of the water column (USEPA, 1978).

9. Quality Assurance and Quality Control

Effective quality assurance and quality control (QA/QC) procedures and a clear delineation of QA/QC responsibilities are essential to ensure the utility of environmental monitoring data (Plafkin et al., 1989). Quality control refers to the routine application of procedures for obtaining prescribed standards of performance in the monitoring and measurement process. Quality assurance includes the quality control functions and involves a totally integrated program for ensuring the reliability of monitoring and measurement data.

EPA's QA/QC program requires that all EPA National Program Offices, EPA Regional Offices, and EPA laboratories participate in a centrally planned, directed, and coordinated Agency-wide QA/QC program (Brossman, 1988). This requirement also applies to efforts carried out by the States and interstate agencies that are supported by EPA through grants, contracts, or other formalized agreements. The EPA QA program is based on EPA order 5360.1, which describes the policy, objectives, and responsibilities of all EPA Program and Regional Offices (USEPA, 1984).

Each office or laboratory that generates data under EPA's QA/QC program must implement, at a minimum, the prescribed procedures to ensure that precision, accuracy, completeness,

comparability, and representativeness of data are known and documented. In addition, EPA QA/QC procedures apply throughout the study design, sample collection, sample custody, laboratory analysis, data review (including data editing and storage), and data analysis and reporting phases.

Specific guidance for QA/QC is provided for EPA's rapid bioassessment protocols (Plafkin et al., 1989) and for EPA's Ocean Data Evaluation System (USEPA, 1991a). Standardized procedures for field sampling and laboratory methods are an essential element of any monitoring program.

D. Data Needs

Data needs are a direct function of monitoring goals and objectives. Thus, data needs cannot be established until specific goals and objectives are defined. Furthermore, data analyses should be planned before data types and data collection protocols are agreed upon. In short, the scientific method, defined as "a method of research in which a problem is identified, relevant data gathered, an hypothesis formulated, and the hypothesis empirically tested" (Stein, 1980), should be applied to determine data needs. Types of data generally needed for nonpoint source monitoring programs will include chemical, physical, and biological water quality data; precipitation data; topographic and morphologic data; soils data; land use data; and land treatment data. The specific parameters should be determined based on site-specific needs and the monitoring objectives that are established.

Under EPA's quality assurance and quality control (QA/QC) program (see Quality Assurance and Quality Control), a full assessment of the data quality needed to meet the intended use must be made prior to specification of QA/QC controls (Brossman, 1988). The determination of data quality is accomplished through the development of data quality objectives (DQOs), which are qualitative and quantitative statements developed by data users to specify the quality of data needed to support specific decisions or regulatory actions. Establishment of DQOs involves interaction of decision makers and the technical staff. EPA has defined a process for developing DQOs (USEPA, 1986).

Appendix 10

Example Site Location Form

(Courtesy of Alliance for the Chesapeake Bay)

Office Use Only
Monitoring Coordinator:_____
Site Designation:_____
Tributary:_____
Date Site Information entered into database:_____

Instructions: Please fill in this form as fully and accurately as possible. The information you provide will be used to document monitoring site locations. Be as descriptive as you can. We need to have precise site documentation to enable the location of your site in the future. In each of the Sections, circle the option that applies.

ACB Citizen Monitoring Site Documentation

SITE NAME: _____
PRIMARY MONITOR'S NAME:_____
BACK-UP MONITOR'S NAME:_____
DATA COLLECTION START DATE: _____

I. Location Description: (Please Circle)

Tidal Nontidal Lake

Water body (What Creek, Stream, River, Lake the site is on)

_____

Other Location Details:_____

II. Collection Description: (Please Circle)

Shoreline Pier/Dock Bridge crossing
Boat Wading to Stream Center

III. Coordinates:

*A USGS 7-minute quadrangle map or a GPS Unit are the recommended methods for determining site coordinates. You can find all USGS quadrangle maps online for free by going to http://www.topozone.com. You may search by place name or by river name by choosing the link titled "Place Name Search" under "Get A Map". Once you have located your site, you may zoom in by clicking on the 1:25,000 button in the top left corner above the map. Use your mouse to click on the exact location- a red crosshair will appear over your site. Choose "DD.DDDD" (decimal degrees) as the coordinate type located beneath the map. The coordinates will then be listed in these units above the map. You can then either print the map, or email it to us. You can also find USGS maps for local areas at libraries, fishing and camping stores, and engineering and architectural supply stores. Cost is about $3.00 a map.

Please Put in Units in Decimal Degrees (DD.DDDD)

LATITUDE:_____ (Example: 37.1234) **LONGITUDE:_____** (Example: -77.1234)

☐ MAP- Please attach a map of your site to this form, with the site labeled.*

☐ PHOTO DOCUMENTATION- It is recommended that you visually document your site with photographs of the monitoring location looking upstream and downstream. Label the photos accordingly, and attach copies to this form.

(Updated 11/18/02)

Appendix 11

Handout from Virginia Water Monitoring Council's Quality Assurance/Quality Control Forum

Basic QA/QC Concepts

Modified from ***The Volunteer Monitor's Guide to Quality Assurance Project Plans***. EPA 841-B-96-003. September 1996. This guide is recommended for all volunteer monitoring organizations in Virginia interested in developing a quality assurance project plan.

Quality Assurance (QA)
Refers to a broad plan for maintaining quality in all aspects of a program, including all quality control measures, sample collection, sample analysis, data management, documentation, evaluation, *etc.* It is helpful to data users in determining the integrity (soundness) of data.

Quality Control (QC)
The steps, including measurements, calibrations, and standardization practices, taken to assure the quality of specific sampling and analytical procedures. QC is used to reduce error in the data collection and analysis. For example, the collection of two samples (QC samples) taken at the same time and location should yield the same (or very similar) results; data quality can be determined by evaluating the results of the QC samples and determining precision and accuracy. The decision to accept data, reject it, or accept only a portion of it should be made after analysis of the QC data.

Quality Assurance Project Plan (QAPP)
The formal written document describing the detailed quality assurance procedures and QC activities that will be used to assure data quality.

Precision
Degree of agreement among repeated measurements. Reproducible results are precise. Can be calculated using the standard deviation (a statistical way to measure variation around the data set's average value).

Accuracy
Measures how close your results are to a *true* value. The smaller the difference between the measurement and its "true" value, the more accurate the measurement. Found by analyzing a standard or reference sample (one with a known value).

Representativeness
The extent to which measurements actually depict the true condition being evaluated. For example, data collected just below a pipe outfall are not representative of the entire stream.

Completeness
The number of samples and documentation needed to meet the sampling objectives. Volunteers may not be able to collect as many samples as planned so try to take more samples than you expect to need.

Comparability
The extent to which data from one study can be directly compared to either past data obtained in the study or from data obtained in another study.

Detection Limit
In general, the lowest concentration of a given parameter your method or equipment can reliably detect and report as greater than zero. For example, if an instrument has a detection limit of 1 ppb (parts per billion) and a sample contains 0.5 ppb of lead, the sample will be "below the detection limit." Note, this does not mean the sample is free of lead (0 ppb), simply that the amount of lead is less than the instrument can detect.

Metadata
Metadata is data about the data. It describes the data information presented in a given dataset and quality criteria associated with their generation. Metadata is all other data collected that is not the actual value of the parameter measured. Metadata provides information on the procedures used, quality control measures, site locations, sample collectors, quality of the data, etc.

Standard Operating Procedures (SOPs)
Written instructions, which describe the step-by-step procedures for a process. For example, the procedures for collecting a water sample are referred to as field SOPs while the procedures for analyzing the sample in a lab are referred to as the lab SOPs.

Information provided by the **Virginia Water Monitoring Council (VWMC)**. To join the VWMC, contact **Jane Walker** at **540-231-4159** or **vwmc@vt.edu**. A special thank you to DEQ for assistance with this handout.

Appendix 12

Quality Assurance Project Plan Template and Directions

Virginia Department of Environmental Quality
Water Monitoring Quality Assurance Project Plan (QAPP) Template

Remove this page before submitting

Purpose and Background: This template has been developed by the Virginia Department of Environmental Quality (DEQ) to aid in the development of QAPPs as part of the volunteer water monitoring program.

This template is based on EPA QA/G-5 and QA/R-5 guidance for the development of QAPPs. The language provided is generalized and based on common features of monitoring projects. The specificity and information required in a QAPP is highly project dependent, and as such, this document should be tailored to meet the needs of the individual user/monitoring project.

Use: The text highlighted in yellow and in italics are for the purpose of guiding the user and provide context and examples of the requirements for each section. This text should be removed and replaced with text specific to the user's monitoring project. Examples throughout the QAPP template do not reflect an actual project and are used for general information only.

Before submitting this document for review, please be sure to remove and/or replace all highlighted and italicized text, update the table of contents, and ensure the header information is correct.

DEQ
VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Insert Project Name
Quality Assurance Project Plan

Date

Insert Organization Information

Insert contact information for project manager

PROJECT MANAGEMENT

Title of Plan and Approval

Quality Assurance Project Plan

Enter Title of Project

This Quality Assurance Project Plan (QAPP) documents the procedures, roles, and responsibilities associated with this project or special study.

Title	Name	Approval Signature	Date
Insert QAPP applicant project manager title			
Insert QAPP applicant quality assurance officer title			
Additional QAPP applicant signatory title remove if not used			
Insert DEQ project manager title			
Additional DEQ signatory title remove if not used			
DEQ Quality Assurance Officer			

Insert Name of Organization

Log of changes

Revised by:	Date:	Revision number:	Summary of changes:

Updates made to references, typos, and adding clarifications to the language can be described as ‘No major changes’.

1.1 Table of Contents

1.2 Distribution List

This section is used to list the major data users, significant staff such as the project manager and QA officer, and major project partners covered by this QAPP.

Position Title	Name	Address	Phone/E-mail

1.3 Project/Task Organization

This section is used to identify major participants of the study including the signatories found on page 1. Add additional lines as necessary.

Name	Project Job Title	Responsibility/Duties

1.4 Problem Definition/Background

Problem Statement

In this section, describe the reason why the group is doing this project. This includes stating the issue of concern, where it is located, and potential sources or areas the study will address.

For example:

Previous monitoring in Bob's Creek in Nelson County has shown high levels of E. coli bacteria. Based on looking at aerial photography maps, we suspect the bacteria is entering the water from nearby farm runoff and failing septic systems. By setting up additional sampling stations along the creek, we will be able to identify significant E. coli bacteria sources.

Intended Usage of Data

This section covers how the results from the study will be used as well as who will receive the results.

For example:

We intend to use the data to identify possible pollution sources in Bobs Creek. We will share our findings with the local government, soil and water conservation district, DEQ, and local residents. This data will be

useful to target areas for cost share implementation for local farms and provide justification to implement a regular septic pump out and maintenance program.

1.5 Problem/Task Description and Schedule

General Overview of Project

This section helps give a brief overview of the project. It is important to include such items as the water quality parameters the group is testing for and the methods to collect samples. In addition, it is good to identify which tests are the most critical and which are of secondary importance.

For example:

The project will focus on collecting E. coli bacteria grab samples starting in January 2016. Sampling will consist of monthly sampling at 3 locations with sampling ending by December 2016. Monitoring will include secondary field observations such as the appearance and odor of the water being sampled and the amount of rainfall during the previous 48 hours before sampling. These secondary sampling parameters will be used with the bacteria results to gauge when conditions are likely to generate high bacteria levels in the water. Sites are located at bridge crossings or areas where stream access is provided by landowner permission.

Project Timeline/Work Schedule

This template uses a table to define specific tasks and division of work for the project. It is highly recommended this is supported with a narrative explanation to define these tasks for each key position.

For example:

Task 1- The project manager develops the QAPP. The QAPP must describe the whole project in detail and have it approved before the project begins. See page 1 for approval initials.

Task 2- The project manager establishes stations and determines sample collection logistics including shipping samples to the laboratory and receiving results.

Task 3- The quality assurance officer conducts and oversees new or refresher training of field team members and reviews monthly data.

Task 4- Field team leader oversees the field collection staff on collecting field data, and shipping samples to the laboratory for analysis. The sampling procedures are presented in section 2.2.

Task 5- The laboratory QA officer will oversee the laboratory analysis of water samples. The laboratory method and laboratory requirements are described in section 2.4.

Task 6- The quality assurance officer will validate the laboratory analytical results by assessing for bias, completeness, representativeness, and acceptable levels of precision and accuracy as outlined in section 2.5.

Task 7- The project manager will submit the final report when the data have all been collected, validated, approved, analyzed, to the distribution contacts listed in section 1.3.

Task	Activity	Projected Start Date	Anticipated Date of Completion
1	*Develop QAPP*	*November 2024*	*December 2024*
2	*Review and approval of sample sites*	*November 2024*	*December 2024*
3	*Provide monitor training/certification*	*December 2024*	*January 2025*
4	*Collect samples*	*January 2025*	*December 2025*
5	*Oversee analysis*	*January 2025*	*December 2025*
6	*Review results*	*January 2025*	*December 2025*
7	*Generate report and submit data*	*February 2026*	*February 2026*

1.6 Quality Objectives and Criteria for Measurement Data

This section is to summarize how the study will collect quality data that will be used to address the study goals stated in section 1.5.2.

For example:

Data produced by this survey are used for evaluating the environmental condition of State waters or identifying other water quality problems. Data generated in this survey may be used to make decisions on the sources of the contaminants in the sampled water. Both field and laboratory personnel will work to achieve the highest possible level of confidence in the quality of study results by using established procedures to ensure the accuracy, precision, representativeness, comparability, and completeness of the data.

Data Precision, Accuracy, Measurement Range

For DEQ to approve a QAPP the group must use EPA and/or DEQ recognized methods. The website www.nemi.gov offers free downloads of EPA approved methods and list other recognized methods. Groups can also contact local laboratories, college science departments, or the DEQ QA officer for more information.

Matrix	Parameter/Method	Measurement Range	Accuracy
Water	*E. coli: EPA 1103.1*	*<1 to >2,000 CFU/100 ml*	*≤0.6 Log transformed difference in duplicate samples*

Data Representativeness

It is important that this study produces data representative to actual conditions. In this section, the group should note such items as:

- number of sample sites
- how sites were selected
- specific timeframe samples are collected
- and any reasons why samples are collected under specific conditions.

For example:

Due to the heavily wooded nature of the watershed, sample sites were selected based on accessibility and safety considerations. Sites will include road crossings and sites adjacent to fields where landowner permission was obtained. Sampling will occur between 10 am to 2 pm to ensure samples arrive in time for analysis by the laboratory. During the study, two targeted samples will occur within 1 hour of the start of a significant rainfall event (estimated >0.1 inches). These samples will compare bacteria levels due to runoff sources and will be marked as targeted samples in the data results so they can be separated from the routine baseline testing results.

Data Comparability

In this section, state the methods for testing samples. Include a brief summary of how samples are collected, transported (if going to a laboratory or another location for analysis), methods are used to analyze samples, and significant differences to cited protocols. It is recommended groups include an attachment of their sampling and test methods (known as Standard Operating Procedures or SOP).

For example:

The bacteria sampling will use standard collection and analytical methods as outlined in EPA method 1103.1. Samples are kept on ice during transport and storage. Due to the delay in shipping samples to a laboratory for processing, samples are processed within 24 hours of collection which is longer than the standard 6 hour holding time stated for the method. Based on a bacteria survivability study done by Virginia DEQ, the delay in processing will have insignificant impact on recovery of E. coli results compared to the method listed six hour holding time.

Appendix 1 of this document contains the sampling and testing procedure for E. coli bacteria. Sampling consists of collecting water using standard bacteria sampling techniques and sterile sample bottles. Samples are processed using standard sterile technique. An overview of the method is available at the National Environmental methods Index (NEMI) at https://www.nemi.gov/methods/method_summary/5581.

Data Completeness

This section is used to determine how much data is needed to represent actual conditions. For most sampling programs, samples should cover a full range of flow conditions. For bacteria and general water column testing (nutrients, dissolved oxygen, pH, etc.), the minimum recommended frequency of sampling is usually monthly. Benthic macroinvertebrate, sediment sampling, or advanced water chemistry (PCB, dissolved metals, etc.) is usually once or twice a year at a site but can be more frequent depending on the study.

Groups should plan to collect extra samples or have enough time set aside during the collection season to reschedule sampling in the event of bad weather or a sample is lost before analysis. Therefore, groups should develop a sample completeness percentage goal. Depending on the sample size, most groups set a goal of 80 to 95% completeness. The monitoring group QA officer and the DEQ QA officer can help set this goal based on the needs of the project. If the sample completeness goal is not met, the final report should note this to inform data users that the study was not complete so results may not represent actual conditions.

Use the table below to define this section.

Parameter	Number of Samples Planned	Minimum Percent Goal
E. coli	*3 stations x 14 samples = 42*	*>90%*

1.7 Special Training Requirements/Certification

Training Logical Arrangements

List the training activities of the group and related staff (e.g. laboratory staff)

Type of Training	Frequency of Training/Certification
New/refresher water quality sampler training	*January of every year during the project phase.*
Laboratory technician proficiency testing	*June of every year or when a new technician is hired.*

Description of Training and Trainer Qualifications

Field samplers and laboratory staff should receive regular training or recertification to ensure they follow EPA or DEQ recognized methods. Normally, this is accomplished by an annual training or recertification event or individual training of new monitoring or lab staff. Include a summary of what is involved in the training event and who will conduct/oversee the event. This section can refer to a more complete version of training and certification as an appendix but should be summarized in this section.

For example:

Every year, monitors meet to receive training and recertification. The quality assurance officer verifies sample team collection bottles and equipment distributed to monitors are clean and in good condition. Training is done by sample team members performing a sample collection for the QA officer to review. If necessary, monitors are retrained and scheduled for a follow up field audit to ensure they are performing correct sampling procedures as outlined in field sampling SOP manual found in Appendix 1.

Laboratory personnel performing E. coli testing, have their methods evaluated on an annual basis by the laboratory QA officer. This review consists of performing 10 replicate samples to verify E. coli results are within an acceptable range of difference.

1.8 Documentation and Records

This section deals with how the group will record and store data. This section is broken up into four subsections based on the type of data or forms. Groups can delete any subsections which do not apply with their study.

Please note the amount of time that the group will hold onto the data (usually 3 or more years) and who is responsible for maintaining the data. In addition, include a blank copy of any calibration, field sheets, and related data forms as an attachment to the QAPP.

For example:

Field and laboratory results are to be submitted to DEQ via the Virginia Data Explorer. In addition, the QAPP and any final reports or conclusions will be provided to each organization representative listed in section 1.3. The below subsections identify the documents and reports to be generated throughout the survey and the information to be included in these documents and reports.

Field Documentation

Required subsection for nearly every project as samples are collected in a field setting.

For example:

The QA officer will receive and enter all the data collected in the field into the database once laboratory results are received. Usually this is within three days of sample submission. In summary, the QA Officer will be responsible for maintaining the following documents:

(1) Field Data Sheet
(2) Quality Control Checks for pre- and post-calibration checks of field equipment.
(3) Sample container labels
(4) *Any other paperwork necessary for shipping or delivering to the laboratory*

Laboratory Documentation

Applies for projects using a laboratory to perform analysis.

For example:

Laboratory documentation will include producing and submitting the following information:

(1) Electronic data submittal of final certified data to project manager
(2) Printed copies of Certificates of Analysis when specifically requested to do so
(3) Any other data associated with the measurement process when specifically requested to do so.

Audit Reports

The group or laboratory QA officer, or when needed, the DEQ QA officer, will conduct an audit of field collection and/or laboratory audit to ensure samples are being collected and analyzed based on the protocols outlined in the QAPP.

For example:

Technical system audits will be conducted as needed by the QA officer during field activities by auditing a random field sampler every six months or a specific sampler if problems are suspected. The laboratory QA officer will audit technician performance if problems are identified in the laboratory quality control tests. The auditing procedures are outlined in more detail in Section 3 of this QAPP. The auditors will prepare a report that summarizes the observations and findings of each of these audits. As needed, the audit reports will be supplemented by a corrective action plan, to be implemented as soon as feasible, to correct each observation or finding of erroneous procedures.

Data Validation Reports

This subsection is very important when working with parameters that require laboratory analysis or involve complex field sampling protocols such as using field probes. This section summarizes how potentially faulty data is identified and segregated from the rest of the dataset.

For example:

Only valid and certified data will be transferred to the monitoring group from the laboratory. Data validation flags will be applied to those sample results that fall outside of specific limits and include a description of why the data was flagged. Field data that was collected due to using faulty equipment such as equipment that failed calibration checks will be flagged with a description of why the data was flagged.

Periodically, the laboratory QA officer, at the request of monitoring group, will identify biases inherent in the data, including assessment of laboratory performance, and overall precision, accuracy, representativeness and completeness. The data validation report will address whether the quality of the flagged data affects the ability to use the data as intended. As needed, the data validation reports will be supplemented by a corrective action plan, to be implemented as soon as feasible, to correct each observation or finding of erroneous procedures.

Section 4 of this QAPP provides more detail on how the data validation process is conducted.

DATA GENERATION AND ACQUISITION

A Standard Operating Procedure for each parameter/method that will be collected must be included as an attachment in the appendix unless this QAPP provides thorough step by step procedures for each parameter/method in the following sub-sections.

Sampling Design

Rational for Selection of Sampling Sites

The group uses this subsection to identify sampling locations and explain why the sites were selected. The group should summarize any safety or other considerations for selecting the sample site and refer to the sample collection SOP manual which should be included as an attachment to this QAPP.

For example:

Water quality monitoring to identify bacteria sources will be conducted at 3 stations on Bob's Creek. The goal of this study is to collect monthly E. coli water quality samples for the year. Sampling sites are located at bridges or areas where landowner permission was obtained and are above confluences with nearby major tributaries. All samples will be analyzed by a contacted laboratory. Stations are listed in section 2.1.2.

1.8.1 Sample Design Logistics

The table below is an example and groups can modify or develop a similar table and include it as an attachment to the QAPP. The table must provide a clear description of sample sites using terms that anyone not familiar with the project can locate using Google Maps or similar applications. Good examples use names or route numbers of road crossings or approximate distance from a major tributary or dominant landmark/feature. Latitude and longitude must be in decimal degrees to at least five decimal places using NAD 1983 geographic coordinate system.

Citizen Monitoring Grant recipients can use the monitoring plan developed for their proposal to satisfy the requirements of this section (please attach as an appendix). Coordination grantees must ensure that station lists include the collecting organization, and that those sub-organizations are consistent with the list in section 1.3.

The Environmental Data Mapper is a useful online map application that provide coordinates for sites is available at https://apps.deq.virginia.gov/EDM/ .

Waterbody Name	Station ID	Description	Latitude	Longitude	Parameter and Frequency
Bobs Creek	*BC1*	*At Wilson Road bridge*	*37.68142*	*-78.86203*	*E. coli 1/month*
Bobs Creek	*BC2*	*50 feet above outfall of Nelson Lake*	*37.69391*	*-78.88147*	*E. coli 1/month*
Bobs Creek	*BC3*	*At private farm access road ~2800 stream feet upstream of railroad crossing*	*37.69907*	*-78.89150*	*E. coli 1/month*

Sampling Methods

In the table below, list all water quality parameters, equipment, and sampling methods used. Such equipment may be as simple as collecting a sample using a sample bottle dipped directly in the water to the complex such as an automated sampler collecting samples at specific times at the site. Sampling methods are usually either grab (sampled directly at the stream at a specific time), or composite (multiple samples obtained during the day at the site and combined into one large container for analysis. Include holding times and sample preservation as specified in the parameter method.

Parameter	Sampling Equipment	Sampling Method	Preservation	Holding Time
E. coli	*Sample bottle*	*Grab sample*	*Ice- $\leq 4\ ^oC$*	*$\leq$ 24 hours*

Sampling Handling and Custody

This section applies to projects where samples are taken to another location for testing such as a laboratory. Projects where samples are tested at the sample site will have very little if any sample handling or custody requirements.

For projects where samples are shipped to another location for testing, this section lists what the group will do to ensure the samples arrive to the location that have not been contaminated due to improper handling or storage during transport. NOTE: laboratories which process samples for a group usually have a Chain of Custody (COC) form that should be included as an attachment to the QAPP (see section 1.9.1). At the

end of this document is a generic COC form in the event one is needed and not provided by the laboratory. Users can modify this to best suit their needs.

For example:

Sample bottles are labeled with the station id, date/time of collection, and sampler initials after collection using provided tags. Samples are preserved on ice and transported as described in the SOP manual found in Appendix 1 of this QAPP. Samples are shipped in a sealed cooler to the laboratory using UPS. As samples are shipped in a sealed container, the COC form lists the person who packed the samples in the cooler with the COC form attached to the inner lid of the cooler in a Ziploc bag. Upon reaching the laboratory, the laboratory staff who received the cooler signs the COC form and the sample is handled in accordance with the laboratory sample handling procedures.

Analytical Methods

This section goes into more detail than what was provided in subsection 1.7.3. This section provides information on the methods used to analyze the samples. This should include the test methods (EPA 1600 for example) and the equipment used to conduct the study (membrane filter apparatus for example). Organizations can go to www.nemi.gov to find approved methods for most environmental sampling methods. Laboratories performing analysis should be able to provide the methods and equipment used for samples they process. NOTE that some laboratories may not wish to share their actual methods/procedures due to fear of reveling proprietary information. In such cases, have the laboratory provide a contact if there are questions on procedures.

For example:

E. coli sample analyses will be conducted using EPA method 1103.1, membrane filtration of E. coli using modified mTEC agar. The analytical procedures and standard test methods used by the laboratory are included in Appendix 2 of this document. Questions on specific laboratory procedures can be directed to the laboratory QA officer using the contact information found in section 1.3.

Quality Control

This section is very important to any QAPP as it defines the steps project staff will follow to ensure data generated in the study is scientifically valid. Refer to https://www.epa.gov/quality/volunteer-monitors-guide-quality-assurance-project-plans for a basic overview of various quality assurance and quality control terminology and methods to ensure proper sampling technique and performance.

1.8.2 Field Measurement/Analysis Quality Control Checks

Under this subsection, the group must describe the methods used to test and/or collect field samples. This can refer to an SOP submitted as an appendix with the QAPP. This subsection should include what type and frequency quality control checks are done on field samples such as: taking multiple measurements at the site to check equipment performance, field blanks to check for contamination of equipment, and split samples to check the variability due to sampling methods. A good quality control frequency is 10% for small studies (<100 sample events) or 5% for large studies (>100 sample events).

For example:

All field and field quality control sampling will be collected in accordance with the SOP manual found in Appendix 1. Equipment blanks and field splits are collected at frequency of at least 10 percent. All quality control samples will be entered into the database and flagged as quality control samples. Any deficiencies observed and corrective action taken will be reported is covered in Section 3 of this document.

1.8.3 Laboratory Analysis Quality Control Checks

This subsection applies for any laboratory testing performed during the study. Usually, the laboratory will provide a summary of their checks such as laboratory duplicate, matrix spike, laboratory blank, and related quality control samples as part of the laboratory report.

For example:

All laboratory samples will be analyzed in accordance with established standard laboratory methods, procedures and QA procedures outlined in Appendix 2 of this document. Periodically the laboratory QA officer will generate a report evaluating the accuracy, precision, representativeness and comparability to identify deficiencies in analysis. Any deficiencies observed will be reported and corrective action taken is covered in section 3 of this document.

1.8.4 Data Analysis Quality Control Checks

This section mainly applies for projects where data is provided from multiple sources or from other organizations to ensure that the data was checked. Usually this is done by the group's project manager or QA officer and may involve simple procedures such as looking for discrepancies in results such as high blank readings coupled with very low or non-detect sample readings (usually due to a field staff member mislabeling the bottles).

For example:

The group QA officer reviews the submitted laboratory data to verify sample results reflect suspected conditions such as high bacteria levels usually associated with recent rain events. The officer also verifies simple errors in results such as if a blank sample shows very high E. coli levels while the accompanying sample showed no E. coli which likely indicates the sample bottles were mislabeled in the field. Any deficiencies observed and corrective action taken is covered in section 3 of this document.

Instrument/Equipment Testing, Inspection, and Maintenance

This section details the steps the group and laboratory staff undertake to ensure equipment used is properly cleaned and maintained to avoid faulty data. These checks can include something as simple as a visual inspection of sample equipment to make sure it is free of dirt to more complex steps such as calibrating laboratory equipment.

For example:

The field staff will be responsible for the maintenance of equipment used to collect and transport samples following procedures outlined in the sample collection SOP found in Appendix 1 of this document. Checks include ensuring sample bottles appear clean and sterile seals are intact. Coolers are routinely inspected and cleaned to prevent mold or other contaminates interfering with samples.

Laboratory staff performs regular inspections of equipment and growth media to confirm no contamination occurs in the analyzed samples. Details are found in the table below, and Appendix 2 of this document.

Equipment Type	Inspection Frequency	Type of Inspection	Maintenance Procedure
Sample bottles	*Before use*	*Visual check to ensure bottles are clean and sterile seals are intact*	*Replace broken/unsealed bottles*
Incubator	*Before use*	*Visual check to confirm temperature is properly set*	*Adjust temperature setting as needed*
Filtering equipment and glassware	*Monthly*	*Confirm equipment is sterile and not interfering with analysis by performing a positive and negative bacteria control check*	*Clean and sterilize equipment as outlined in laboratory SOP. Replace equipment with deep scratches or chips.*
Autoclave	*Monthly*	*Perform pressure and temperature check and visually check for deposits.*	*Adjust valves and settings as necessary flush out debris.*

Instrument/Equipment Calibration and Frequency

This section covers the need to calibrate field, laboratory, or other equipment used to obtain readings. This can include morning and end of day calibration checks using known standards or checking thermometers against an certified reference thermometer. The table below is a good example that can address this section. A narrative description can also be used.

For example:

The field staff is responsible for the maintenance of equipment used to measure all the requested water quality parameters in accordance with the SOP manual listed in Appendix 1. As there is no monitoring equipment except using the sample collection bottles, no calibration is necessary.

Laboratory staff performs an annual verification of incubator thermometers using a NIST certified thermometer in a water bath heated to 35.0 °C which reflects the incubation temperature for the bacteria test. Incubator thermometers that are within +/-0.1 °C of this NIST reference is accepted and used in the incubators. The autoclave max temp thermometer is verified at 121.0 °C using a NIST reference and must be within +/- 0.5 °C of the NIST value. Thermometers failing this validation are disposed and replacement certified thermometers are used. Additional details are available in Appendix 2.

Equipment Type	Calibration Frequency	Standard or Calibration Instrument Used	Acceptance Criteria	Corrective Action
Incubator thermometer	*Annually*	*NIST validation at 35.0 °C*	*+/- 0.1 °C*	*Replace thermometer with NIST certified thermometer*
Autoclave check thermometer	*Annually*	*NIST validation at 121.0 °C*	*+/- 0.5 °C*	*Replace thermometer with NIST certified thermometer*

Inspection/Acceptance Requirements for Supplies and Consumables

This section covers procedures used to check all equipment, regents, and related consumable supplies are of good quality.

For example:

The field staff and QA officer are responsible for inspecting incoming equipment and supplies to be used in the special study before placing them in service. Any defective equipment such as sample bottles with broken or missing sterile seals are discarded as outlined in section 2.6 of this document.

Laboratory staff inspect all reagents and consumables to ensure they are sterile and within expiration dates. In addition, a positive and negative bacteria control test is performed monthly or whenever a new batch of growth media, membrane filters, and new de-ionized (DI) water cartridges are used.

Non-direct Measurements

This section outlines all sources of data not associated with actual monitoring by the project team members. Some examples include obtaining rainfall or stream flow data from a weather service or USGS stream gauge website. In addition, this section is used to reference any sources of information used or included on this project and how it is managed. Note that items referred to in this section should be referenced in section 5 of this QAPP template.

For example.

Part of the study is to determine the amount of fecal bacteria is present due to runoff from nearby fields, septic drain fields, and wildlife sources. As fecal bacteria is usually the highest at the beginning phase of a heavy rain event, the study will use weather forecasts and local weather station data to determine the ideal time to sample and record actual rainfall totals. This will be obtained through the National Weather Service Weather Prediction Center (https://www.wpc.ncep.noaa.gov/). Actual rainfall totals at time of sample collection will be obtained from the meteorological website Weather Underground (www.wunderground.com).

Stream flow data from the nearest and most representative USGS stream gauge located at Piney River at gauge 02027500 (http://waterdata.usgs.gov/va/nwis/nwisman/?site_no=02027500). The Piney River station was selected due to relatively close proximity to the study area so that rain events are reasonably assumed to be the same. However, the Piney River discharges nearly 10 times the area of Bobs Creek (49 mi^2 vs. 4.85 mi^2). Extrapolating a direct discharge rating curve will be limited to a best estimate due to the significant differences in size. However, the resulting rating curve should provide a reasonable estimate of hydrological conditions required for bacteria levels to exceed state recreational standards.

Data Management

In this section, applicants will describe how data from the project are handled and kept for future reference. section 4 will cover this in greater detail.

For example:

Project data will include computer and handwritten entries. Field observations, measurements, and records such as sample collection and shipping information will be recorded on hardcopy forms, and in a Microsoft 2010 Access database. Hardcopy records are kept for a minimum of six years. Electronic data is stored indefinitely and includes data backup to a secure offsite database.

Data analyzed in the laboratory is entered into the Laboratory Information Management System (LIMS) by the responsible laboratory personnel. Following validation and approval, data is shipped electronically to the group project manager where it is uploaded into the access database.

ASSESSMENT AND OVERSIGHT

Technical System Audits (TSAs)

In any well-developed study, it is important to do regular Technical System Audits (TSA) of staff and procedures to ensure results are not influenced due to poor technique. This usually involves the QA officer or senior field team leader performing random audits of field or laboratory staff or checking performance using a standard reference (proficiency sample) unknown to the testing group. Results of this audit are then reported to the project manager and any corrective actions implemented.

For example:

Field personnel are audited annually. Audits can occur sooner if an issue is suspected with how a staff member is collecting a sample. This audit is performed by the field team leader or QA officer due to their extensive experience and knowledge of the sampling method. Field TSAs focus on availability and proper use of field equipment; ability to follow and document sample collection, identification, handling, and transport of samples and proper collection and handling of field blank and duplicate samples. If problems are discovered during the field TSA, the field staff is retrained and noted deficiencies are recorded in a field audit form for future reference. If the error is severe enough to question the validity of previously collected data, the suspected data will be flagged based on a review by the QA officer and communicated to the project manager.

TSAs of laboratory operations will be performed by the laboratory QA officer on an ongoing basis. Laboratory TSAs include reviews of sample handling procedures, internal sample tracking, following SOPs, analytical data documentation, QA/QC protocols, and data reporting. If errors or deficiencies are discovered, appropriate laboratory staff undergoes retraining. If the error is severe that may affect the quality of previously submitted data, this is communicated to the project manager and QA officer along with recommendations using a corrective action form found in Appendix 2.

1.9 Reports and Management

This section covers all reports made to the project manager to inform of corrective actions or modifications that need to be made. In addition, this section covers reports provided by a contracted laboratory as the project manager usually handles or oversees laboratory data being entered along with any field data collected by the group.

For example:

The QA officer and laboratory QA officer will provide all correction action reports related to the project and corrective actions taken to the project manager. Laboratory data is submitted electronically to the data manager who oversees the results are correctly entered with data collected by field staff.

2 DATA VALIDATION AND USABILITY

2.1 Data Review, Verification, and Validation

The purpose of this section is to describe the process for documenting the degree to which the project objectives were met, individually and collectively, and to estimate the effect of any QA/QC procedural deviations on the ability to use the data.
Each of following areas will be reviewed:

- Sample collection procedures
- Sample handling
- Analytical procedures
- Quality control verification of equipment blanks (EB) and field splits (S1 & S2).

For example:

Each month, the QA officer will review the data collected by the field staff is correct and keyed in values match field sheet entries. If questions arise, the QA officer will speak with the field sampler and/or laboratory manager. Sample runs where an equipment blank or spilt sample was collected and failed to meet quality control requirements outlined in subsection 1.7.1 of this document will be flagged as suspect due to contaminated equipment or improper collection technique.

If data is in need of correction or is suspect, the QA officer will flag and document the data for additional review. Decisions to reject data not meeting quality assurance will be done through agreement of the QA officer, project manager, and sample team leader. Rejected data will be notated in the database as to the reason why it were flagged and rejected.

2.2 Verification and Validation Methods

The previous step of the QAPP dealt with who will be responsible for reviewing the data. This step covers the methods that the person will review and validate the data. Such examples include:

- Use of sample spikes and other QC steps
- Confirming computer-entered data with actual field sheets
- Ensuring proper filling out of chain of custody forms
- Equipment calibration frequency

Also, include a section discussing if the person finds errors in the data, how they plan to correct the errors.

For example:

The QA officer will verify all equipment blank and sample duplicate samples are within tolerances as outlined in section 1.7.1.

The QA officer will review laboratory submitted data to ensure the laboratory performed the necessary quality assurance checks and the results are within acceptable margins. This includes checking that laboratory based blanks, matrix spikes, and duplicates are complete and of good quality.

If issues are found or biases in analysis is suspected, the QA officer will confer with the laboratory QA officer and project manager to identify if a problem exists and if so, if the problem is severe enough to affect

reported results. If a result is identified as being likely biased, it is rejected and noted in the database as to the reason why the results were flagged and rejected.

Reconciliation with User Requirements

The group should describe how to determine if the data generated by the project will meet the objectives of the project (section 1.7). To determine this, the project manager should compare and analyze the project data for completeness, accuracy, precision, representativeness, and comparability.

In the event the data does not meet with the planned goals, describe how the group would approach to address and correct the problem. Discarding of some data, revising the project scope, or setting limits on how unusable data is acceptable in these situations. Please also state who will receive any data corrections.

For example:

At the completion of the monitoring phase and all data has been received and entered, the project manager and QA officer will review the results to ensure it meet the goals outlined in section 1.7.

If the project failed to meet the minimal sample goal or if deficiencies in sampling or analysis are discovered during this review, limits will be placed on the dataset. Such limits can include not using the results to identify bacteria sources or use the results as a baseline dataset for Total Maximum Daily Load modeling. Such limitations will be predominately highlighted and explained in the final report to ensure readers of the report do not use the data or report improperly.

3 REFERENCES

This section is to cite all reference material used or in this document. When available, include website addresses for material available online. The below format is an acceptable scientific bibliographic format.

1. US EPA (March 2000). *Method 1103.1- Improved Enumeration Methods for the Recreational Water Quality Indicators: Enterococci and Escherichia coli*, EPA/821/R-97/004 www.nemi.gov/methods/method_pdf/5575/
2. USGS (March 2014) How Streamflow is Measured http://water.usgs.gov/edu/measureflow.html
3. USGS Piney River Stream Gauge 02027500 http://waterdata.usgs.gov/va/nwis/nwisman/?site_no=02027500
4. NOAA Weather Prediction Center http://www.hpc.ncep.noaa.gov/qpf/qpf2.shtml
5. Weather Underground Arrington Weather Station https://www.wunderground.com/?cm_ven=cgi

APPENDIX

An appendix should be added for each supporting document affiliated with the QAPP. This includes field and laboratory data sheets, SOPs, and any other documents referenced within the QAPP.

Appendix 13

Expiration Date of Some Commonly Used Reagents

(Courtesy of Alliance for the Chesapeake Bay)

Expiration Date of Some Commonly Used Reagents

This Appendix is used by the Alliance for the Chesapeake Bay to determine the expiration date of the reagents used by organizations using the Alliance's protocols for dissolved oxygen and pH measurement.

Assuming that chemicals have been stored properly (cool, dark place- not exposed to long periods of sunlight or heat), the chemicals, even once opened should be good for as long as the shelf life indicated on the bottles. Table 1 lists the maximum shelf life for chemicals used in the LaMotte Dissolved Oxygen and pH test kits).

Table 1

Chemicals	Shelf Life (years)
Dissolved Oxygen (LaMotte Winkler Test Kit)	
Alkaline Azide	3
Manganese Sulfate	3
Sodium Thiosulfate	18 months
Starch	18 months
Sulfuric Acid (and powder)	2
pH (Various LaMotte Test Kits)	
Bromcresol	2
Bromthymol Blue	2
Chlorophenol Red	2
Cresol Red	2
Lamotte Yellow	2
Phenol Red	2
Thymol Blue	2
Wide Range Test Kit	2

Appendix 14

Dissolved Oxygen Saturation Concentrations

How to Calculate Theoretical Dissolved Oxygen Values

Proper calibration of Dissolved Oxygen (DO) probes is important to collect accurate data. An easy way to see if a probe is calibrated correctly is to compare the probe's results against a theoretical DO value. This value is what the DO level should be based on temperature and barometric pressure.

DO Level based on temperature

The top table on the attached chart allows users to find the DO level based on temperature. The top and side axis of the table corresponds to the temperature that the probe is reporting. The intersection of the two axes displays the DO reading. Write this number down to start calculating the theoretical DO level.

Correction factor for barometric pressure

Barometric pressure is a way to tell how much atmosphere is pressing down on a surface. Weather systems and elevation above (or below) sea level can change this value. The bottom table of the attached chart will help compensate for these changes in pressure. Dissolved oxygen probes normally show pressure in millimeters of mercury (**mmHg**) or millibars (**mBar**).

Having a barometer on hand is a good way to get pressure data. A weather station can also provide pressure data. Websites such as www.wunderground.com are useful to find local weather stations. Please note that most barometers and weather stations report pressure in inches of mercury (**inHg**).

Note about using weather station pressure readings

Weather stations compensate pressure readings to make it appear as if the station is at sea level. To account for this, subtract the barometric pressure by 1.01 inHg per 1,000 feet in elevation of the weather station. This final value is known as **absolute barometric pressure**.

Example: Find the absolute barometric pressure of a station located 222 feet above sea level that reported 30.12 inHg.

$$30.12 \text{ inHg} - \frac{1.01 \text{ inHg}}{1000/\ 222 \text{ feet}} \rightarrow 30.12 - \frac{1.01}{4.50} \rightarrow 30.12 - 0.22 == 29.90 \text{ inHg absolute barometric pressure}$$

Once finding the absolute pressure, use the bottom table found on the attached chart to find the proper correction factor to use. The formulas at the bottom of the chart will help in converting inHg barometric pressure readings into **millibars** (mBar) or **millimeters of mercury** (mmHg) that are commonly used to calibrate a dissolved oxygen probe. Use this value to find the correction factor to use in the final calculation.

Example: A barometric pressure of 970 millibars you would use a correction factor of 0.96 (second column, bottom row).

Theoretical DO Calculation

To find the theoretical DO value, use the following formula.

Theoretical DO = (DO level based on temperature) x (barometric pressure correction factor)

Example: If a probe had a temperature of 18.4 C and the barometric pressure was 970 mBar, the theoretical DO value would be 9.00 mg/L (9.37mg/L x 0.96 correction factor).

Dissolved Oxygen Saturation

Directions- To determine theoretical DO saturation, multiply the O2 concentration value (found in the top chart) by the barometric pressure correction factor (bottom chart).

Example: Find the DO saturation for at a temperature of **18.4 C** at **730 mmHg** pressure: 9.37 x 0.96= **9.00 mg/L**

Temp in ^{O}C	**O_2 concentrations in mg/L**									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
5	12.75	12.71	12.68	12.65	12.61	12.58	12.55	12.52	12.48	12.45
6	12.42	12.39	12.36	12.32	12.29	12.26	12.23	12.2	12.17	12.14
7	12.11	12.08	12.05	12.02	11.99	11.96	11.93	11.9	11.87	11.84
8	11.81	11.78	11.758	11.72	11.69	11.67	11.64	11.61	11.58	11.55
9	11.53	11.5	11.47	11.44	11.42	11.39	11.36	11.33	11.31	11.28
10	11.25	11.23	11.2	11.18	11.15	11.12	11.1	11.07	11.05	11.02
11	10.99	10.97	10.94	10.92	10.89	10.87	10.84	10.82	10.79	10.77
12	10.75	10.72	10.7	10.67	10.65	10.63	10.6	10.58	10.55	10.53
13	10.51	10.48	10.46	10.44	10.41	10.39	10.37	10.35	10.32	10.3
14	10.28	10.26	10.23	10.21	10.19	10.17	10.15	10.12	10.1	10.08
15	10.06	10.04	10.02	9.99	9.97	9.95	9.93	9.91	9.89	9.87
16	9.85	9.83	9.81	9.79	9.76	9.74	9.72	9.7	9.68	9.66
17	9.64	9.62	9.6	9.58	9.56	9.54	9.53	9.51	9.49	9.47
18	9.45	9.43	9.41	9.39	**9.37**	9.35	9.33	9.31	9.3	9.28
19	9.26	9.24	9.22	9.2	9.19	9.17	9.15	9.13	9.11	9.09
20	9.08	9.06	9.04	9.02	9.01	8.99	8.97	8.95	8.94	8.92
21	8.9	8.88	8.87	8.85	8.83	8.82	8.8	8.78	8.76	8.75
22	8.73	8.71	8.7	8.68	8.66	8.65	8.63	8.62	8.6	8.58
23	8.57	8.55	8.53	8.52	8.5	8.49	8.47	8.46	8.44	8.42
24	8.41	8.39	8.38	8.36	8.35	8.33	8.32	8.3	8.28	8.27
25	8.25	8.24	8.22	8.21	8.19	8.18	8.16	8.15	8.14	8.12
26	8.11	8.09	8.08	8.06	8.05	8.03	8.02	8	7.99	7.98
27	7.96	7.95	7.93	7.92	7.9	7.89	7.88	7.86	7.85	7.83
28	7.82	7.81	7.79	7.78	7.77	7.75	7.74	7.73	7.71	7.7
29	7.69	7.67	7.66	7.65	7.63	7.62	7.61	7.59	7.58	7.57
30	7.55	7.54	7.53	7.51	7.5	7.49	7.48	7.46	7.45	7.44

Barometric Pressure Correction factor:

mmHg (mBar)	**Corr. Factor**	**mmHg (mBar)**	**Corr. Factor**	**mmHg (mBar)**	**Corr. Factor**	**mmHg (mBar)**	**Corr. Factor**
775-771 (1033-1028)	**1.02**	**750-746 (1000-995)**	**0.987**	**725-721 (967-961)**	**0.953**	**700-696 (934-928)**	**0.92**
770-766 (1027-1021)	**1.014**	**745-741 (994-988)**	**0.98**	**720-716 (960-955)**	**0.947**	**695-691 (927-921)**	**0.914**
765-761 (1020-1014)	**1.007**	**740-736 (987-981)**	**0.973**	**715-711 (954-948)**	**0.94**	**690-686 (920-915)**	**0.907**
760-756 (1013-1008)	**1**	**735-731 (980-975)**	**0.967**	**710-706 (947-941)**	**0.934**	**685-681 (914-908)**	**0.9**
755-751 (1007-1001)	**0.993**	**730-726 (974-968)**	**0.96**	**705-701 (940-935)**	**0.927**	**680-676 (907-901)**	**0.893**

Appendix 15

Commonly Used Formulas for Water Quality Monitoring

Metric Units

1 **kilo**(grams, meters, etc.)= 1,000 (grams, meters, etc)	1 (gram, meter, etc.) = 0.001 **kilo**(gram, meter, etc.)
1(gram, meter, etc.) = 1,000 **milli**(gram, meter, etc.)	1 **milli**(gram, meter, etc.)= 0.001 (gram, meter, etc.)
1 **kilo**(gram, meter, etc.) = 1,000,000 **milli**(gram, meter, etc)	1 **milli**(gram, meter, etc.) = 0.000001 **kilo**(gram, meter, etc.)

Weight

1 pound = 453.59 grams	1 gram = 0.002205 pounds
1 kilogram = 2.205 pounds	1 pound = 0.4535 kilograms

Volume

1 cubic foot (ft^3)= 7.48 gallons	1 gallon = 0.1337 cubic foot (ft^3)

Length

1 mile = 5,280 feet	1 foot = 0.0001894 mile
1 meter = 3.28084 feet	1 foot = 0.3048 meter
1 mile = 1.609 kilometers	1 kilometer = 0.6214 mile

Specific Characteristics of Water

1 gallon = 8.34 pounds	1 pound = 0.12 gallon
1 gallon = 3.783 liters	1 liter = 0.26417 gallon
1 liter = 1 kilogram	1 kilogram = 1 Liter
1 gallon = 3.783 kilograms	1 kilogram = 0.26417 gallon
1 liter = 2.205 pounds	1 pound = 0.4535 liters

Barometric Pressure

1 inHg = 25.4 mmHg	1 inHg = 33.8 millibars (mBar)

Temperature

$Celsius = \frac{5}{9} \times (Temp\ ^oF - 32)$	$Fahrenheit = (\frac{9}{5} \times Temp\ ^oC) + 32$

Basic Geometry

a. Circumference	C = 3.1416 x Diameter
b. Perimeter	P = (2 x Length) + (2 x Width)
c. Area	
Rectangle	Area = Length x Width
Circle	Area= 0.785 x Diameter x Diameter
Triangle	Area= ½ x Base x Height
d. Volume	
Rectangle	Volume= Length x Width x Depth
Cylinder	Volume= 0.785 x Diameter x Diameter x Depth
Cone	Volume = 0.262 x Diameter x Diameter x Height
Sphere	Volume= 0.524 x Diameter x Diameter x Diameter

Calculating Flow

a. Million Gallons per Day (MGD) to Gallons Per Day (GPD)	Flow, GPD = FLOW, MGD x 1,000,000 gallons / MG
b. MGD to Gallons per Minute (GPM)	$\textbf{Flow, GPM} = \frac{\textbf{Flow, MGD x 1,000,000 gallons / MG}}{\textbf{1,440 minute / Day}}$
c. MGD to Cubic Feet per Second (CFS)	Flow, CFS = Flow, MGD x 1.55 CFS / MGD
d. CFS to MGD	Flow, MGD = Flow, CFS x 0.645 MGD / CFS
e. Flow (Velocity), CFS	Using a float: Flow = ALC / T Using a flow meter: Flow = AMC Where: A = Area of stream (average stream depth x stream width) L = Distance covered by float run M= Measured flow rate based on average flow meter readings C = 0.9 if the streambed is smooth (silt, sand, or bedrock) 0.8 if the streambed is rough (rubble, stones, gravel) T = Average time of float run

Laboratory Equations

Convert mg/L Results	
a. mg/L to Pounds/Day	Pounds/Day = Result, mg/L x Flow, (MGD) x 8.34 lbs (MG/mg/L)
b. mg/L to Kilograms/Day	Kilograms/Day = Result, mg/L x Flow, (MGD) x 3.785 lbs (MG/mg/L)

Quality Assurance	
a. Relative Percent Difference (duplicate samples)	$RPD\% = \frac{\text{AbsoluteValue}(\text{Sample1} - \text{Sample2})}{\text{Average}(\text{Sample1} + \text{Sample2})} \times 100\%$
b. Probe Slope	Slope (millivolt change) = Standard value 2 – Standard value 1

Dissolved Oxygen	
Winkler Titration	$DO, mg/L = \frac{\text{Titrant, mL x Normality(N) x 8,000}}{\text{Equivalent Sample Volume, mL}}$ If N = 0.0250 & Sample Volume = 200 mL then : mL Titrant Used = DO, mg/L

Bacteria (E. coli, Enterococcus, etc.)	
a. Multiple Tube, Colilert, etc.	$MPN / 100\ mL = MPN_{chart} \times \frac{Sample\ Volume\ In\ First\ Dilution_{chart}}{Sample\ Volume\ in\ First\ Dilution_{sample}}$
b. Membrane Filtration, Coliscan, etc.	$Colonies / 100\ mL = \frac{Colonies\ Counted}{Sample\ Volume, mL} \times 100\ mL$
Geometric Mean (if collecting more than one sample per month)	$GeometricMean = \sqrt[n]{Test_1 \times Test_2 \times Test_3 ... \times Test_n}$