Volunteer Estuary Monitoring
A Methods Manual

Second Edition

The Ocean Conservancy

EPA

Volunteer Estuary Monitoring
A Methods Manual

Second Edition

The Ocean Conservancy

EPA

Volunteer Estuary Monitoring
A Methods Manual

Second Edition

Ronald L. Ohrel, Jr.
The Ocean Conservancy

Kathleen M. Register
Clean Virginia Waterways
and Longwood University

The Ocean Conservancy

The Ocean Conservancy
2029 K Street, NW
Suite 500
Washington, DC 20006
Phone: 202-429-5609
Fax: 202-972-0619
Web: www.oceanconservancy.org

EPA

U.S. Environmental Protection Agency
Office of Wetlands, Oceans, and Watersheds
Volunteer Monitoring (4504T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Phone: 202-566-1200
Fax: 202-566-1336
E-mail: OW-General@epamail.epa.gov

This document was prepared under Cooperative Agreement #CX825019-01-3 from the U.S. Environmental Protection Agency (EPA), Office of Wetlands, Oceans and Watersheds to The Ocean Conservancy.
Second Reprint 2006, ©2002 The Ocean Conservancy.

NOTICE:
This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

♻ Printed on recycled paper using soy-based inks.

COVER PHOTOS:
Top row (l to r): The Ocean Conservancy, K. Register, The Ocean Conservancy, R. Ohrel
Row 2 (l to r): K. Register, S. Schultz, Weeks Bay Watershed Project, K. Register
Row 3 (l to r): L. Monk, The Ocean Conservancy, S. Schultz, E. Ely
Row 4 (l to r): T. Monk, The Ocean Conservancy, The Ocean Conservancy, R. Ohrel

Acknowledgements

U.S. Environmental Protection Agency Project Officer: Joseph N. Hall, II
The Ocean Conservancy Project Director: Seba B. Sheavly
Editors and Primary Contributors:
Ronald L. Ohrel, Jr., The Ocean Conservancy
Kathleen M. Register, Clean Virginia Waterways and Longwood College
Proofreader: Elaine Hruska
Document Design and Graphics (except where indicated): Critical Stages

The author of the first edition of this document in 1993 was Nina A. Fisher.

The Ocean Conservancy is the nation's leading nonprofit organization dedicated solely to protecting ocean environments and marine life in all its abundance and diversity. As part of a cooperative agreement with the U.S. Environmental Protection Agency (EPA), The Ocean Conservancy conducted a series of train-the-trainer workshops on monitoring estuary environments. Workshop attendees provided valuable comments on the first edition of this manual, which helped guide the revision. We thank them for their time and input.

In addition, the following estuary monitoring experts and volunteer monitoring program coordinators contributed significantly to this project by submitting case studies and other information:

Charles Barr, The Ocean Conservancy; **Peter Bergstrom**, U.S. Fish and Wildlife Service (Chesapeake Bay Field Office); **Eve Brantley**, Weeks Bay Watershed Project; **Amber Cornell**, Adopt A Beach; **Carol Elliott**, Alliance for a Living Ocean; **Eleanor Ely**, *The Volunteer Monitor*; **Jon Graves**, Portland State University; **Holly Greening**, Tampa Bay Estuary Program; **Kerry Griffin**, Tillamook Bay National Estuary Project; **Linda Hanson**, Washington State Department of Health; **Paul Heimowitz**, Oregon State University Extension Sea Grant; **Philip L. Hoffman**, Tampa BayWatch, Inc.; **Harold G. Marshall**, **Ph.D.**, Old Dominion University; **Lisa Monk**, The Ocean Conservancy; **Stacey Moulds**, Alliance for the Chesapeake Bay; **Bob Murphy**, Alliance for the Chesapeake Bay; **Seba B. Sheavly**, The Ocean Conservancy; and **Esperanza Stancioff**, University of Maine Cooperative Extension. Portions of this document were excerpted and adapted from other authors, which are referenced in each chapter.

The editors also wish to thank the reviewers who offered valuable comments on this document:

Cathy Barnette, Dauphin Island Sea Lab/Alabama Department of Economic and Community Affairs; **Charles Barr**, The Ocean Conservancy; **Peter Bergstrom**, U.S. Fish and Wildlife Service (Chesapeake Bay Field Office); **Beth Biermann**, The Ocean Conservancy; **Eleanor Bochenek, Ph.D.**, New Jersey Sea Grant; **Eve Brantley**, Weeks Bay Watershed Project; **David Buckalew, Ph.D.**, Longwood College; **Barry Burgan**, EPA; **Diane Calesso**, EPA Region 2; **Kim Donahue**, Chesapeake Bay Foundation; **Carol Elliott**, Alliance for a Living Ocean; **Eleanor Ely**, *The Volunteer Monitor*; **Joe Farrell**, Delaware Sea Grant; **Iraida Garcia**, Jobos Bay National Estuarine Research Reserve; **Holly Greening**, Tampa Bay Estuary Program; **Dominic Gregorio**, California State Water Resources Control Board; **Kerry Griffin**, Tillamook Bay National Estuary Project; **Joseph N. Hall**, **II**, EPA; **Paul Heimowitz**, Oregon State University Extension Sea Grant; **Mark Kutnink**, EPA Region 9; **George Loeb**, EPA; **Harold G. Marshall**, **Ph.D.**, Old Dominion

Acknowledgements *continued*

University; **Alice Mayio**, EPA; **Gerri Miceli**, Gordon Research Conferences; **Clara Mojica, Ph.D.**, Jobos Bay National Estuarine Research Reserve; **Lisa Monk**, The Ocean Conservancy; **Bob Murphy**, Alliance for the Chesapeake Bay; **Paul Pan**, EPA; **Jonathan Phinney, Ph.D.**, American Society of Limnology and Oceanography; **Dominic Roques**, California State Water Resources Control Board; **Tamara Saltman**, EPA; **Kathleen Sayce**, ShoreBank Pacific; **Donald Schulz**, Surfrider Foundation (Huntington/Seal Beach Chapter); **Seba B. Sheavly**, The Ocean Conservancy; **Linda Sheehan**, The Ocean Conservancy; **Frederick Short, Ph.D.**, University of New Hampshire; **Esperanza Stancioff**, University of Maine Cooperative Extension; **Edward Stets**, EPA; **Terry Tamminen**, Environment Now; **Marie-Francoise Walk**, Massachusetts Water Watch Partnership; **Robert Warren**, Columbia River Estuary Study Taskforce (CREST); and **Karen Font Williams**, Oregon Department of Environmental Quality.

Finally, we would like to thank those individuals and organizations who provided photographs for inclusion in this document:

Peter Bergstrom, Gerrit Carver, Eleanor Ely, Maine Department of Marine Resources, Lisa Monk, Tim Monk, Bob Murphy, The Ocean Conservancy, PhotoDisc, Ronald Ohrel, M. Redpath, Kathleen Register, Sheila Schultz, Tillamook Bay National Estuary Project and Battelle Marine Science Lab, U.S. Environmental Protection Agency, University of Maine Cooperative Extension, and Weeks Bay Watershed Project.

Table of Contents

Unit Three: *Biological Measures*

Appendices

Executive Summary

This manual focuses on volunteer estuary monitoring. As concern over the well-being of the environment has increased during the past couple of decades, volunteer monitoring has become an integral part of the effort to assess the health of our nation's waters. Government agencies, often strapped by financial limitations, have found that volunteer programs can provide high-quality, reliable data to supplement their own water quality monitoring programs.

It may seem obvious, but should nonetheless be stated: **without individual volunteers who commit their time and energy to the effort, there would be no volunteer monitoring programs**. As people learn more about how an estuary functions and come to recognize its signs of distress, their concern for its future is increased. So too is their commitment to its protection.

Thus, volunteer monitoring of estuaries has grown significantly from the early programs that monitored only a few simple parameters. As these monitoring programs have developed, so has the interest of the Environmental Protection Agency (EPA), which has supported volunteer monitoring since 1987. The EPA sponsors national symposia on volunteer monitoring, publishes a newsletter for volunteers, has developed guidance manuals and a directory of volunteer organizations, and provides technical support to volunteer programs. Through these efforts, the EPA hopes to foster the interest and support of state and other agencies in these programs.

The EPA developed this manual as a companion to three other documents:

- *Volunteer Water Monitoring: A Guide for State Managers;*
- *Volunteer Lake Monitoring: A Methods Manual;* and
- *Volunteer Stream Monitoring: A Methods Manual.*

This document presents information and methodologies specific to estuarine water quality. Both the organizers of volunteer programs and the volunteers themselves should find it of use.

The first eight chapters of the manual deal with typical issues that a new or established volunteer estuary monitoring program might face:

- understanding estuaries, what makes them unique, the problems they face, and the role of humans in solving the problems;
- establishing and maintaining a volunteer monitoring program;
- working with volunteers and making certain that they are well-positioned to collect water quality data safely and effectively;
- ensuring that the program consistently produces data of high quality; and
- managing the data and making it available to data users.

The remaining chapters focus on several water quality parameters that are important in determining the health of an estuary. These chapters are divided into three units, which characterize the parameters as measures of the chemical, physical, or biological environment of the estuary.

The significance of each parameter and specific methods to monitor it are detailed in a step-by-step fashion. The manual stresses proper quality assurance and quality control techniques to ensure that the data are useful to state agencies and any other data users.

References are listed at the end of each chapter. Appendices containing additional resources are also supplied. These references should prove a valuable source of detailed information to anyone interested in establishing a new volunteer program or a background resource to those with already established programs.

Chapter 1

Introduction

The inspiration for this manual comes from the people who are dedicated to monitoring estuaries and the environment around them. The people who create volunteer monitoring programs and the people who serve as volunteer monitors care deeply about their estuaries, are concerned about their watersheds, and want the opportunity for more community involvement.

Photos (l to r): S. Schultz, T. Monk, S. Schultz

Where Would Estuaries Be Without Volunteer Monitors?

The inspiration for this manual comes from the people who are dedicated to monitoring estuaries and the environment around them. The people who create volunteer monitoring programs and the people who serve as volunteer monitors care deeply about their estuaries, are concerned about their watersheds, and want the opportunity for more community involvement.

Estuary volunteer monitoring programs give men, women, and children a priceless opportunity to intimately know the many spectacular riches of the estuarine environment. As people learn more about how an estuary functions and come to recognize its signs of distress, their concern for its future is increased. So too is their commitment to its protection. The fact is, we will take care of something when we value it.

Volunteer estuary monitoring programs can create citizen leaders who work to reduce pollution, increase education, and better manage our coastal areas, all with the purpose of protecting some very special places.

Estuaries are homes for wildlife, food suppliers, gateways of commerce, and cultural mainstays. They are also imperiled. Volunteer monitors help preserve our estuarine resources (photo by S. Schultz).

By donating their time and talents to a monitoring program, volunteers offer a priceless, enduring legacy to the future. We are collectively responsible for the preservation our natural world for the future generations of people, animals and plants that call an estuary "home." ■

About the Manual

Volunteer Estuary Monitoring: A Methods Manual is a companion document to *Volunteer Water Monitoring: A Guide for State Managers*, published in 1990 by the U.S. Environmental Protection Agency (EPA). The guide describes the role of volunteer monitoring in state programs and details how managers can best organize and administer these monitoring programs. This manual focuses on the concepts and plans developed by the EPA guide and places them in a nuts-and-bolts context specifically for volunteer estuary monitoring programs.

Two other EPA documents are also closely allied with this manual: *Volunteer Lake Monitoring: A Methods Manual* (1991) and *Volunteer Stream Monitoring: A Methods Manual* (1997). Together, these manuals provide guidance on volunteer water quality monitoring in much of our nation's watersheds.

Estuaries support a vast array of wildlife. Some make estuaries their lifelong homes, while others can be seen only during certain times of the year or during particular periods of their lives (photo by S. Schultz).

This is the second edition of *Volunteer Estuary Monitoring: A Methods Manual.* It updates information and adds new topics that have emerged since the first manual was introduced in 1993. ■

Purpose of the Manual

The overriding purpose of *Volunteer Estuary Monitoring: A Methods Manual* is to serve as a tool for volunteer leaders who want to launch a new estuary monitoring program or enhance an existing program. In the process, the manual shows how volunteer groups can collect meaningful data to assess estuarine health.

The manual is not intended to mandate new methods or override those currently being used by volunteer monitoring groups. Instead, it presents methods that have been adapted from those used successfully by existing volunteer estuary monitoring programs throughout the United States. The manual describes methodologies and techniques for monitoring water quality parameters, starting and maintaining a volunteer estuary monitoring program, working with volunteers, ensuring high quality data, and analyzing and presenting the data following collection. ■

Organization of the Manual

This manual is organized into 19 chapters. Chapters 1-8 provide information about estuaries, volunteers and volunteer monitoring programs, and ensuring and managing data of high quality. Chapters 9-19 address specific water quality variables that volunteer monitoring programs may elect to measure. These chapters are grouped into chemical, physical, and biological units. Finally, appendices supply additional information.

A summary of the manual's contents is provided here.

Chapter 1: Introduction

The introduction outlines the purpose of this manual and its relationship to other documents published by the EPA. It also provides information about how and by whom the manual should be used and explains plans for making updated materials available in the future. Finally, the introduction summarizes the contents of the manual.

Chapter 2: Understanding Our Troubled Estuaries

This chapter introduces the concept of an estuary and summarizes the major problems plaguing our nation's estuarine waters. It also discusses the reasons for monitoring estuarine water quality and how monitoring data can ultimately help provide solutions to these diverse problems.

Chapter 3: Planning and Maintaining a Volunteer Estuary Monitoring Program

This chapter covers the basics of planning, implementing, and maintaining a volunteer monitoring program so that it yields credible data that will identify problems and assess trends. Included in this chapter are discussions on establishing goals, liability and other risk management issues, and obtaining financial support. This chapter also presents guidance on developing a user-friendly data form and working with the media to promote your program activities.

Chapter 4: Recruiting, Training, and Retaining Volunteers

This chapter discusses how to recruit, train, and retain top-notch volunteers. It summarizes potential sources of volunteers and provides detailed information for volunteer coordinators on training techniques that are proven to produce knowledgeable and enthusiastic volunteers.

Chapter 5: Quality Assurance Project Planning

This chapter addresses one of the most difficult issues facing volunteer monitoring programs: data credibility. It details the importance of developing a quality assurance project plan (QAPP) and summarizes the steps involved.

Chapter 6: Sampling Considerations

This chapter reviews four critical questions that a volunteer program must address before taking a single water sample: (1) What parameters will the program monitor? (2) How will the selected paratmeters be monitored? (3) Where will the parameters be monitored? (4) When will they be monitored?

Chapter 7: In the Field

This chapter addresses what happens when volunteers leave their homes for the monitoring sites. It makes points about safety, the right use of equipment, finding the monitoring sites, making general observations about the site, collecting data, and completing the data form.

Chapter 8: Data Management, Interpretation, and Presentation

This chapter discusses the elements of a volunteer program that take place after volunteers collect their data. It introduces data management tools, discusses data interpretation, and gives suggestions for maximizing the distribution of your data.

Unit One: Chemical Measures

This unit describes several water quality parameters that may be included in volunteer monitoring programs. Water quality variables highlighted include oxygen (Chapter 9), nutrients (Chapter 10), pH and alkalinity (Chapter 11), and toxins (Chapter 12). The chapters supply information on sampling considerations and guidance on monitoring.

Unit Two: Physical Measures

This unit provides monitoring guidance for water quality variables that represent measures of the estuary's physical environment. Temperature (Chapter 13), salinity (Chapter 14), turbidity and total solids (Chapter 15), and marine debris (Chapter 16) are included.

Unit Three: Biological Measures

Living organisms can be useful indicators of estuarine health. This unit includes information about monitoring bacteria as indicators of potential pathogens (Chapter 17), submerged aquatic vegetation (Chapter 18), and other biological parameters, including macroinvertebrates, plankton, and non-indigenous species (Chapter 19).

Appendices

Several appendices, referred to throughout the manual, are also included. These sections provide sample data forms (Appendix A), additional resources not listed in the chapters (Appendix B), and information on equipment suppliers (Appendix C). A glossary and acronyms section as well as an index are also included. ■

How to Use the Manual

Intended Audience

This manual is intended to be a resource for leaders of volunteer estuary monitoring programs. Such programs may be managed by environmental groups, educational institutions, or government agencies.

Individual volunteers will also find this manual to be a valuable resource, although some components may not apply to them. Volunteer leaders may elect to photocopy and distribute portions of the manual to volunteers as educational supplements, training reinforcement, or background materials.

Is the Manual the Answer to All Estuarine Monitoring Needs?

Certainly not! It would be impossible to provide monitoring methods that are uniformly applicable to all estuaries or all volunteer programs throughout the United States. Factors such as geographic region, program goals and objectives, and program resources will all influence the specific methods used by each group. This manual, therefore, urges volunteer program coordinators to work hand-in-hand with state and local water quality professionals or other potential data users in developing and operating a volunteer monitoring program.

This manual is only one resource for volunteer programs. Many other resources are available from government agencies and volunteer monitoring programs. Some are listed at the end of individual chapters and in Appendix B.

A Lot of Help from Our Friends

Some portions of this manual draw heavily from other resources. The editors wish to give these sources their due recognition and have listed them at the end of each applicable chapter, separate from other references.

Updates to the Manual

This manual is available in hard copy and on the Internet. It is anticipated that periodic updates will be made. While the updates will be included in future print versions, they will also be made available for downloading from the Internet. By making updates available on the Internet, it is anticipated that volunteer groups can access new information sooner than having to wait for a new print version of the manual. ■

References and Further Reading

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.

U.S. Environmental Protection Agency (USEPA). 1991. *Volunteer Lake Monitoring: A Methods Manual*. EPA 440/4-91-002. Office of Water, Washington, DC. 121 pp.

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Chapter 2

Understanding Our Troubled Estuaries

To say that estuaries are valuable resources is a gross understatement. They are among the most productive natural environments in the world and among the most sought-after places for people to live. Estuaries support major fisheries, shipping, and tourism. They sustain organisms in many of their life stages, serve as migration routes, and are havens for threatened and endangered species. Associated wetlands filter pollutants, dissipate floodwaters, and prevent land erosion.

Photos (l to r): U.S. Environmental Protection Agency, R. Ohrel, Weeks Bay Watershed Project, R. Ohrel

Overview

To say that estuaries are valuable resources is a gross understatement. They are among the most productive natural environments in the world and among the most sought-after places for people to live. Estuaries support major fisheries, shipping, and tourism. They sustain organisms in many of their life stages, serve as migration routes, and are havens for threatened and endangered species. Associated wetlands filter pollutants, dissipate floodwaters, and prevent land erosion.

Yet, despite their value, estuaries are in trouble.

Nearly half of the U.S. population lives in coastal areas, which include the shores of estuaries. Unfortunately, this increasing concentration of people is upsetting the natural balance of estuarine ecosystems and threatening their integrity. Pollution, habitat destruction, overfishing, wetland loss, and the introduction of non-indigenous species are among the consequences of many human activities.

As concern over the well-being of the environment has risen during the past several decades, so has the interest in gathering information about the status of estuaries. Government agencies have limited funds for monitoring. As a result, volunteer monitoring has become an integral part of the effort to assess the health of our nation's waters. Designed properly, volunteer programs can provide high-quality reliable data to supplement government agencies' water quality monitoring programs.

This chapter discusses our troubled estuaries. The estuarine environment is described and several problems relating human activities to estuarine degradation are investigated. Finally, the role of volunteer monitoring in identifying, fixing, or preventing problems is examined.

The Science

What Is an Estuary?

Unlike many features of the landscape that are easily described, estuaries are transitional zones that encompass a wide variety of environments. Loosely categorized as the zone where fresh and salt water meet and mix, the estuarine environment is a complex blend of continuously changing habitats. To qualify as an estuary, a waterbody must fit the following description:

"a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage"

(Pritchard, 1967).

The estuary itself is a rather well-defined body of water, bounded at its mouth by the ocean and at its head by the upper limit of the tides. It drains a much larger area, however, and pollutant-producing activities near or in tributaries even hundreds of miles away may still adversely affect the estuary's water quality.

While some of the water in an estuary flows from the tributaries that feed it, the remainder moves in from the sea. When fresh and salt water meet, the two do not readily mix. Fresh water flowing in from tributaries is relatively light and overrides the wedge of more dense salt water moving in from the ocean. This density differential often causes layering or stratification of the water, which significantly affects both circulation and the chemical profile of an estuary.

Scientists often classify estuaries into three types according to the particular pattern of water circulation (Figure 2-1):

- Highly Stratified Estuary

  The layering between fresh water from the tributaries and salt water from the ocean is most distinct in this type of estuary, although some seawater still mixes with the surface freshwater layer. To compensate for this "loss" of seawater, there is a slow but continual up-estuary movement of the salty water on the bottom.

- Moderately Stratified Estuary

  In this intermediate estuary type, mixing of fresh and salt water occurs at all depths. With this vertical mixing, salinity levels generally increase toward the estuary mouth, although the lower layer is always saltier than the upper layer.

- Vertically Mixed Estuary

  In this type of estuary, powerful mixing by tides tends to eliminate layering altogether. Salinity in these estuaries is a function of the tidal stage. This tidal dominance is usually observed only in very small estuaries.

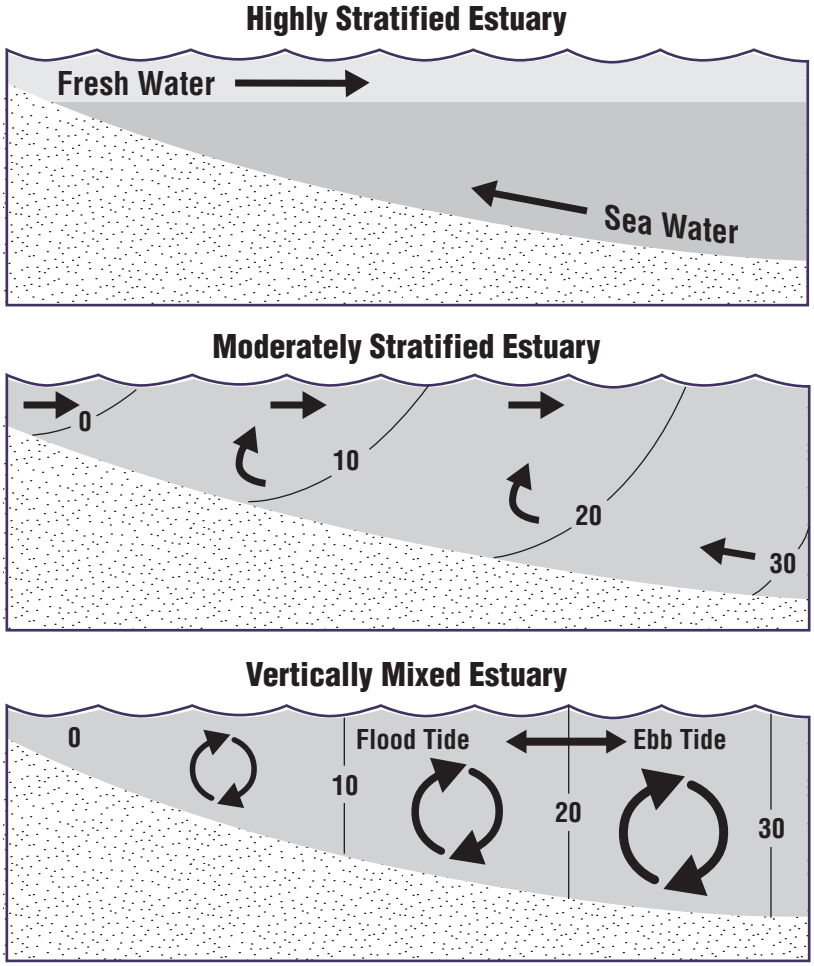


Figure 2-1. Three types of estuaries: highly stratified, moderately stratified, and vertically mixed *(adapted from Levinton, 1982)*. Numbers refer to salinity in parts per thousand.

Rivers flow in a single direction, flushing out sediments and pollutants. In estuaries, however, there is a constant balancing act between the up-estuary saltwater movement and down-estuary freshwater flow. Rather than quickly flushing water and pollutants through its system, an estuary often has a lengthy retention period. Consequently, waterborne pollutants, along with contaminated sediment, may remain in the estuary for a long time, magnifying their potential to adversely affect the estuary's plants and animals.

Other factors also play a role in the hydrology of an estuary. Basin shape, mouth width, depth, area, tidal range, surrounding topography, and regional climate combine to make each estuary unique.

Why Are Estuaries Important?

Estuaries are critical for the survival of many species. Tens of thousands of birds, mammals, fish, and other wildlife depend on estuarine habitats as places to live, feed, and reproduce. They provide ideal spots for migratory birds to rest and refuel during their journeys. Many species of fish and shellfish rely on the sheltered waters of estuaries as protected places to spawn, giving estuaries the nickname "nurseries of the sea." Hundreds of marine organisms, including most commercially valuable fish species, depend on estuaries at some point during their development.

Besides serving as an important habitat for wildlife, the wetlands that fringe many estuaries perform other valuable services. Water draining from upland areas carries sediments, nutrients, and other pollutants. But as the water flows through wetlands, much of the sediments and pollutants are filtered out. This filtration process creates cleaner and clearer water, which benefits both people and marine life. Wetland plants and soils also act as natural buffers between the land and ocean, absorbing floodwaters and dissipating storm surges. This protects upland organisms as well as valuable real estate from storm and flood damage. Salt marsh grasses, mangrove trees, and other estuarine plants also prevent erosion and stabilize the shoreline.

Among the cultural benefits of estuaries are recreation, scientific knowledge, education, and aesthetic value. Boating, fishing, swimming, surfing, and bird watching are just a few of the numerous recreational activities people enjoy in estuaries. They are often the cultural centers of coastal communities—focal points for commerce, recreation, history, customs, and traditions. As transition zones between land and ocean, estuaries are invaluable laboratories for scientists and students, providing countless lessons in biology, geology, chemistry, physics, history, and social issues. Estuaries also provide a great deal of aesthetic enjoyment for the people who live, work, or recreate in and around them.

Wetlands, like this one in Virginia, provide many valuable services. They remove pollutants, absorb floodwaters, dissipate storm surges, stabilize shorelines, and serve as habitat for many organisms (photo by R. Ohrel).

Commercial and recreational activities in estuaries generate billions of dollars for local economies (photo by USEPA).

Finally, the tangible and direct economic benefits of estuaries should not be overlooked. Tourism, fisheries, and other commercial activities thrive on the wealth of natural resources that estuaries supply. Protected estuarine waters also support important public infrastructure, serving as harbors and ports vital for shipping, transportation, and industry. Some attempts have been made to measure certain aspects of the economic activity that depends on America's estuaries and other coastal waters. For example:

- Estuaries provide habitat for more than 75 percent of America's commercial fish catch and for 80-90 percent of the recreational fish catch (National Safety Council's Environmental Center, 1998). Commercial and recreational fishing contribute about $4.3 billion annually to the U.S. economy, while related marine industries add another $3 billion annually (ANEP, 1998).

Importance of Estuaries

HABITAT: Tens of thousands of birds, mammals, fish, and other wildlife depend on estuaries.

NURSERY: Many marine organisms, most commercially valuable fish species included, depend on estuaries at some point during their development.

PRODUCTIVITY: A healthy, undisturbed estuary produces from four to ten times the weight of organic matter produced by a cultivated cornfield of the same size.

WATER FILTRATION: Water draining off upland areas carries a load of sediments and nutrients. As the water flows through salt marsh peat and the dense mesh of marsh grass blades, much of the sediment and nutrient load is filtered out. This filtration process creates cleaner and clearer water.

FLOOD CONTROL: Porous, resilient salt marsh soils and grasses absorb floodwaters and dissipate storm surges. Salt marsh-dominated estuaries provide natural buffers between the land and the ocean. They protect upland organisms as well as billions of dollars of human real estate.

ECONOMY: Estuary-dependant activities—recreation, shipping, fishing, and tourism—generate billions of dollars each year.

CULTURE: Native Americans and early settlers depended on productive estuaries for survival. Sheltered ports were essential for the transfer of goods and information from other continents. Today, estuaries support a way of life valued by many.

(Excerpted from NERRS Web site: http://inlet.geol.sc.edu/nerrsintro.html.)

- Nationwide, commercial and recreational fishing, boating, tourism, and other coastal industries provide more than 28 million jobs. Commercial shipping alone employed more than 50,000 people as of January 1997 (National Safety Council's Environmental Center, 1998).
- There are 25,500 recreational facilities along the U.S. coasts—almost 44,000 square miles of outdoor public recreation areas (NOAA, 1990). The average American spends 10 recreational days on the coast each year. In 1993, more than 180 million Americans visited ocean and bay beaches—nearly 70 percent of the U.S. population. Coastal recreation and tourism generate $8 to $12 billion annually (National Safety Council's Environmental Center, 1998).

In short, estuaries provide us with a whole suite of resources, benefits, and services. Some of these can be measured in dollars and cents; others cannot. Estuaries are irreplaceable natural resources that must be managed carefully for the mutual benefit of all who enjoy and depend on them.

Where Land Meets Ocean

You may have heard the saying, "We all live downstream." This is a rather simple statement intended to bring attention to complex, intertwined processes affecting water quality. Estuaries are the intermediary between oceans and land (Figure 2-2); consequently, these two factors influence their physical, chemical, and biological properties.

Estuaries are part of a larger collection of geographic features that make up a watershed, an area that drains surface bodies of water.

Watersheds generally include lakes, rivers, wetlands, streams, groundwater recharge areas, and the surrounding landscape, in addition to estuaries.

Tributaries flow downstream through the watershed for up to hundreds of miles. In their journey, they pick up materials that wash off the land or are discharged directly into the water by land-based activities. Eventually, the materials that the tributaries accumulate are delivered to estuaries.

The types of materials that eventually enter an estuary largely depend on how the land is used. Undisturbed forests, for example, will discharge considerably fewer pollutants than an urban center or cleared agricultural field. Surrounding land uses and land use decisions, then, can have significant effects on an estuary's overall health. ■

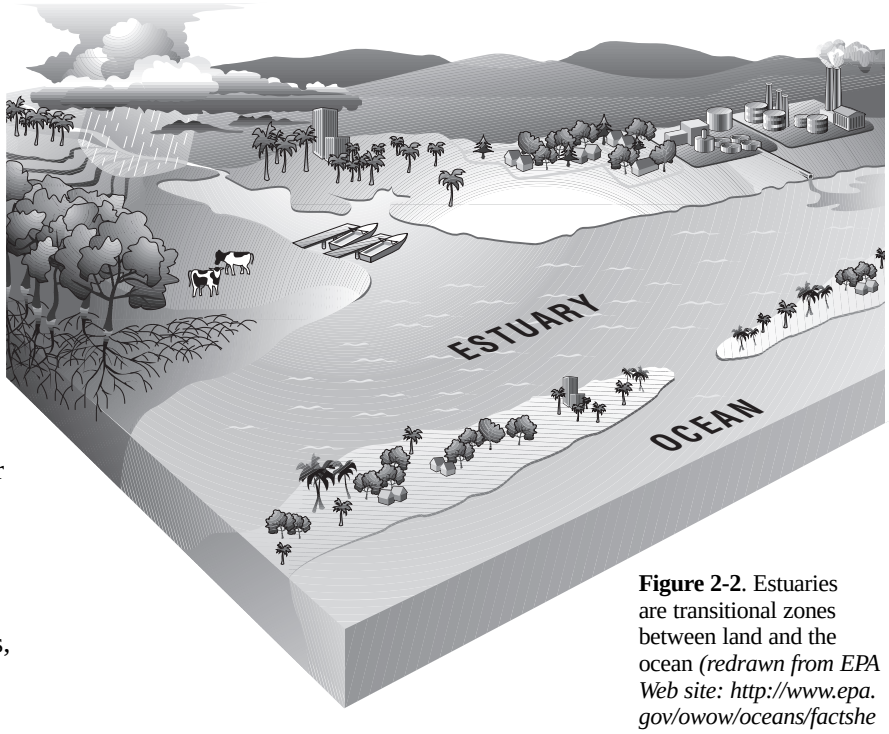


Figure 2-2. Estuaries are transitional zones between land and the ocean *(redrawn from EPA Web site: http://www.epa.gov/owow/oceans/factsheets/fact5.html).*

The Problems

Changes to the coastal landscape have had serious implications for estuarine health. Estuaries are bombarded by several pollutant sources, and their impacts can be severe.

Pollutant Sources

Wherever there is human activity, there is usually a potential source of pollutants. Table 2-1 and Figure 2-3 summarize some common estuarine pollutants and their potential sources.

Estuarine pollution is generally classified as either **point source pollution** or nonpoint source pollution. Point source pollution describes pollution that comes from a discernible source, such as an industrial discharge or wastewater treatment plant. Point source pollution is usually identified as coming from a pipe, channel, or other obvious discharge point. Laws regulate point sources, with limits placed on the types and quantities of discharges to estuaries and other waterways.

Nonpoint source pollution (NPS), on the other hand, comes from a variety of diffuse sources that do not have a single discharge point. Examples include stormwater runoff from urban areas, marina operations, farming, forestry, and construction activities; faulty or leaking septic systems; and atmospheric deposition originating from industrial operations or vehicles. NPS pollution, which is often hard to identify and quantify, is generally more difficult and expensive to regulate and control than point source pollution.

Point sources deliver pollutants to estuaries through a pipe or other discharge point. Here, the pipe is located under a pier (photo by R. Ohrel).

Pollutant Impacts

Many of our nation's more than 100 estuaries are also under siege. Historically, estuaries and other waterbodies have been the receptacles for society's wastes. Human sewage, industrial byproducts, and runoff

Table 2-1. Common pollutants and impacts associated with selected coastal land uses *(adapted from USEPA, 1997; Maine DEP, 1996; USEPA, 1993).*

Source	Common Pollutants	Possible Impacts
Cropland	Sediments, nutrients, pesticides	Reduced water clarity, smothered benthic habitat, toxicity to organisms, excessive algal growth, reduced dissolved oxygen, water temperature changes
Grazing land	Fecal bateria, sediments, nutrients	Possible introduction of pathogens, reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen, water tempterature changes
Forestry	Sediments	Reduced water clarity, smothered benthic habitat, water temperature changes
Mining	Acid discharge, sediments	Reduced water clarity, smothered benthic habitat, impacts on pH and alkalinity
Industrial/commercial discharge	Sediments, toxins	Reduced water clarity, smothered benthic habitat, impacts on pH and alkalinity, toxicity to organisms
Sewage treatment plants	Nutrients, suspended solids, fecal bacteria	Reduced water clarity, excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, water temperature and pH changes, possible introuction of pathogens
Construction	Sediments, toxins, nutrients	Reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen, water temperature changes, toxicity to organisms
Urban runoff	Sediments, nutrients, metals, petroleum hydrocarbons, bacteria	Reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, water temperature changes, toxicity to organisms, possible introduction of pathogens
Lawns/golf courses	Toxins, nutrients, sediments	Reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, toxicity to organisms
Septic systems	Fecal bacteria, nutrients	Excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, water temperature changes, possible introduction of pathogens
Marinas/boat usage	Toxins, nutrients, bacteria	Excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, toxicity to organisms, possible introduction of pathogens

Improperly managed construction sites can clog estuaries with tons of sediments (photo by R. Ohrel).

from farming operations disappeared as they mixed with receiving waters and washed into the nation's fragile estuaries.

Over the past several decades, however, the signs of estuarine decline have become increasingly apparent. Many fish and shellfish populations hover near collapse. Although we have recognized the problems and have generally reduced the pollutants entering our waters, the sheer numbers of people living near the coasts continue to stress our estuaries, lagoons, and other coastal waters.

No coastal areas, estuaries included, are immune to the threat of pollution; they all share common problems. Many are often subject to seasonal depletion of dissolved oxygen, particularly in their deeper waters. Accelerated **eutrophication**—a condition in which high nutrient concentrations stimulate excessive algal blooms, which then deplete dissolved oxygen as they decompose—often threatens the character of the natural system.

Across the country, estuaries are vulnerable to assault from a wide variety of toxic substances, which menace the health of humans and wildlife. While sources of these substances may be relatively scarce in the more pristine areas surrounding an estuary, industrialized areas often lead to "hot spots" in the adjacent estuary, with toxins concentrating in the water, sediment, and local aquatic plants and animals. Stormwater runoff from urban and rural areas can also deliver toxic materials to estuaries. Metals, pesticides, and automotive fluids are frequently washed from lawns, agricultural fields, parking lots, marinas, and a myriad of other sources to estuarine waters.

Bacterial contamination is yet another

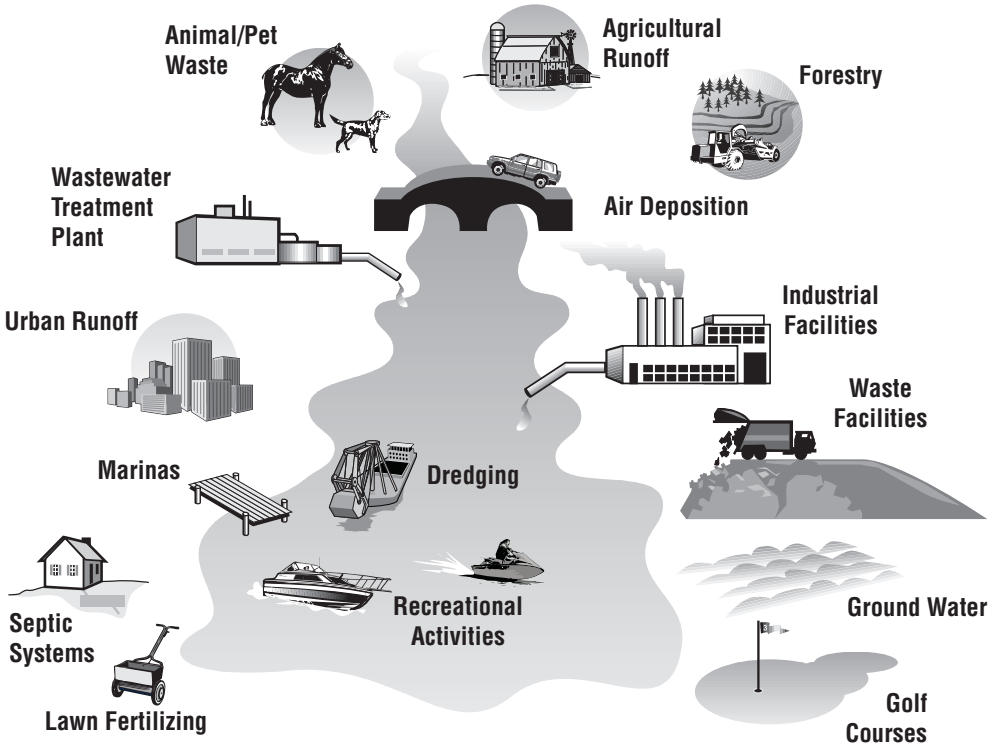


Figure 2-3. Potential sources of estuarine pollution.

problem prevalent in many estuaries. Inadequately treated sewage released to the estuary threatens recreational water users and contaminates local shellfish. States often monitor shellfish or the waters overlying shellfish beds for bacterial contamination, occasionally shutting down contaminated areas to recreational and commercial fishermen until bacteria numbers drop to safe levels.

Sediments from construction sites, agricultural activities, forestry operations, and dredging activities, among other sources, can be another concern. Sediments washing into estuaries or resuspended from dredging can carry a host of additional environmental problems with them. These sediments cover critical **benthic**, or bottom, habitat for numerous species and smother plants and animals. They cloud waters, preventing sunlight from reaching submerged plants. Metals and other toxic materials are frequently attached to sediments, and it is often through this affiliation that toxic materials are delivered to the estuary. Attached to sediments, they make their way to the benthic zone, where they accumulate within organisms and become introduced to the food web. Under certain environmental conditions, toxins may also be released from sediments into the water column.

Other areas suffer from large quantities of marine debris. Storm sewers, combined sewer overflows, and carelessly dropped litter are among the sources of these eyesores. Marine debris found on estuarine shorelines and underwater pose a health hazard to marine animals and humans.

Whether the problems are unique to one estuary or common to many, several have worsened over recent decades. Simultaneously, however, the interest of a few concerned citizens has grown into a nationwide awareness that the environment is a necessary national priority.

Along with this growing recognition, the means to assess the health and status of our nation's waters has also evolved. While scientists provided many early clues to the deterioration of estuarine water quality, citizens have become important contributors in the long-term effort to identify and address water quality problems. ■

Examples of Water Quality Degradation

- The Petaluma River, a tributary to San Francisco Bay, has experienced seasonal algal blooms, low oxygen levels, and fish kills resulting from municipal waste discharges.
- Low dissolved oxygen levels are problematic in Corpus Christi Bay and Galveston Bay in Texas and in Mobile Bay, Alabama. Low oxygen levels are especially prevalent where wastewater discharges and surface runoff go to areas that are poorly flushed or have little circulation.
- In 1990, nitrogen levels in Sarasota Bay, Florida, were estimated to be three times greater than predevelopment levels.
- Pollution from surface runoff has been implicated in nearly 30 percent reduction in seagrass coverage that occurred in the Indian River Lagoon, Florida, between 1970 and 1990. If no action is taken, it is estimated that pollution from surface runoff will increase by more than 30 percent by the year 2010 due to increasing human population.
- Runoff from the land contributes more than 50 percent of nitrogen loadings to Maryland's coastal bays, with 50 percent of these loadings coming from agricultural feeding operations (primarily poultry), which make up less than one percent of the watershed.
- A citizen-based water quality sampling effort in Buzzards Bay, Massachusetts, reports that nine of the Bay's 30 embayments experience poor water quality (primarily from nutrient over-enrichment) during the summer months. Another eight embayments are in transition from good to poor water quality. At least 50 percent of all the embayments have shown a slight to moderate decline in water quality during four years of monitoring.
- From mid-July through September each year, up to half of Long Island Sound in New York experiences dissolved oxygen levels insufficient to support healthy populations of marine life. Nitrogen loads are estimated to be more than twice those of pre-colonial times with 57 percent of the nitrogen entering the Sound each year attributable to human activities.

(Source: ANEP, 1998.)

The Solutions

Clarifying and characterizing the problems unique to an estuary help clear the path toward potential solutions. The first step in solving each problem is defining it. One should ask:

- Is there a problem?
- If so, how serious is it?
- Does the problem affect only a portion of the estuary, or the entire body of water?
- Does the problem occur sporadically, seasonally, or year-round?
- Is the problem a naturally occurring phenomenon, or is it caused by human activities?

The Importance of Monitoring

A systematic and well-planned monitoring program can identify water quality problems and help answer the questions critical to their solutions. Useful monitoring data will accurately portray the current chemical, physical, and biological status of the estuary. This type of information, collected systematically over time, can establish a record of water quality conditions in an estuary.

If reliable historical data exist for comparison, current monitoring data can also document changes in the estuary from the past to the present. These data may serve as a

warning flag, alerting managers to the development of a water quality problem. Or, on the positive side, data comparisons may indicate improvements in estuarine water quality.

Thus, monitoring programs can perform a variety of functions. The most effective monitoring program, however, resolves the use of the data early on so that the program design best addresses the defined problems. Most citizen monitoring programs serve to:

- supplement federal, state, and local monitoring efforts;
- educate the public;
- obtain data from remote areas;
- obtain data during storms or other unique events;
- bring a problem area to light; and/or
- document the illegal discharge of waste.

Citizen monitoring data, collected accurately and systematically, can be an important supplement to data collected by professionals. Accurate data often have far-reaching uses that the organizers may not have anticipated at the outset of their program. Indeed, these data have the potential to influence management actions taken to protect the waterbody. Further uses of the data include:

- providing a scientific basis for specific management decisions and strategies;
- contributing to the broad base of scientific information on estuary functions and the effects of estuary pollution;
- determining multiyear water quality trends;
- documenting the effect of nonpoint and point source pollutants on water quality;
- indicating to government officials that citizens care about their local waterways;
- documenting the impacts of pollution control measures; and
- providing data needed to determine permit compliance.

Assessing water quality should not be conducted purely for the sake of monitoring itself. Ultimately, the protection and restoration of an estuary's wildlife, natural functions, and compatible human uses is of greatest concern. To restore an estuary, we must ensure that water quality conditions remain within the optimal range for the health and vitality of native species. As scientists discover the ideal habitat conditions for each species, monitoring data will be instrumental in judging how often conditions are suitable for the survival and propagation of these species.

Measures of Environmental Health and Degradation

Estuaries are complex systems with a large assortment of habitats, animal and plant species, and physical and chemical conditions. As a result, there are dozens—perhaps hundreds—of monitoring parameters being used to evaluate the health of estuaries. Several parameters describe the basic chemical, physical, and biological properties of an estuary. These traits determine the estuary's fundamental nature. They form, in essence, the ABCs of estuarine water quality and set the stage for selecting the environmental parameters that will indicate estuarine health.

Warning: It's All Connected!

Simply measuring a chemical concentration or locating a particular organism does not necessarily tell the full story of an estuary's health. Several factors may interact to influence your data.

To facilitate discussion of different monitoring parameters, this Methods Manual *addresses monitoring topics according to chemical, physical, or biological properties. However, it is important to recognize that one environmental parameter may influence another (Figure 2-4). Temperature, for example, largely governs the rate of chemical reaction and biological activity. The pH affects the solubility of certain chemicals in the water. Nutrient concentrations influence algal growth, which ultimately affects dissolved oxygen concentrations. Turbidity controls the amount of sunlight that can reach underwater plants.*

Chapter 7 describes several environmental factors that could influence your monitoring results.

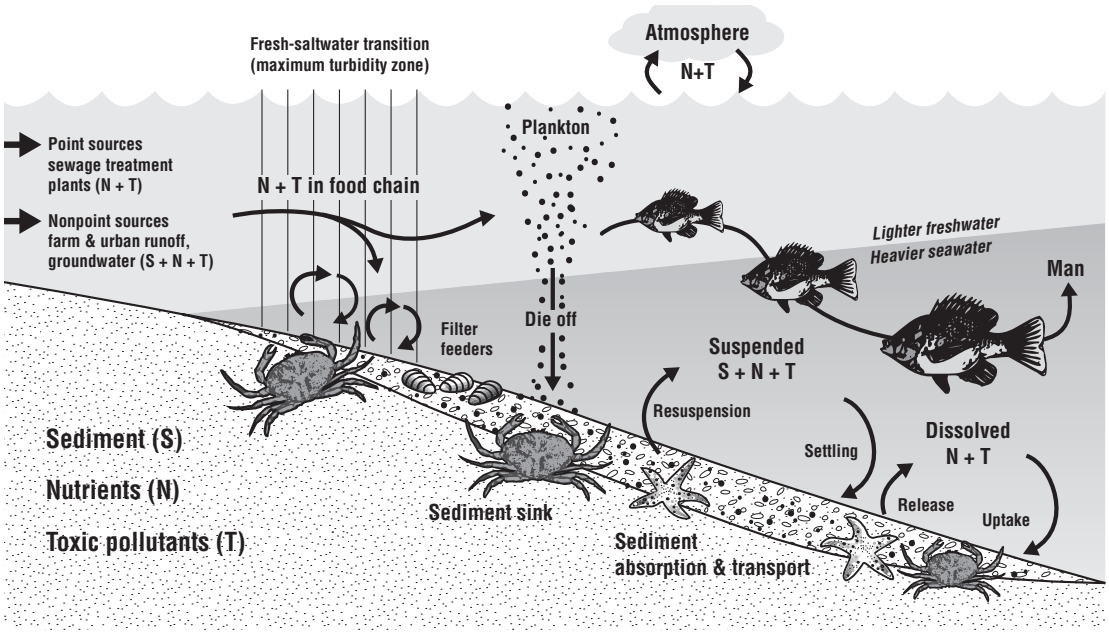


Figure 2-4. Schematic diagram of physical, chemical, and biological processes interacting in estuaries *(redrawn from USEPA, 1987).*

Chemical Measures

Chemical parameters are the main focus of many volunteer estuary monitoring programs, which concentrate on pollutants that arrive in the estuary from point and nonpoint sources (e.g., nutrients, toxins). Other chemical measurements serve as indicators of problems. Low dissolved oxygen concentrations, for example, can be disastrous for many estuarine organisms.

Unit 1 highlights some of the common estuarine chemical monitoring parameters and techniques.

Physical Measures

Some parameters are neither biological nor chemical in nature; they represent measures of the physical environment. Sediment and marine debris are examples of natural and manmade materials, respectively, that can affect estuarine organisms' living environment and health.

Unit 2 discusses some measures of the physical environment employed by many volunteer estuary monitoring programs.

Biological Measures

Living organisms can reveal a great deal about an estuary's health. In some cases, their presence can be a good sign. For example, the widespread distribution of submerged aquatic vegetation (SAV) can suggest that turbidity or excessive nutrients may not be problems in the area. Other organisms, however, can be causes of concern. High bacteria levels can indicate the presence of pathogens in the water—a potential human health risk. The presence of non-indigenous species can threaten native organisms and disrupt a delicate ecological balance.

Biological monitoring is discussed in greater detail in Unit 3.

Peculiarities of Volunteer Estuary Monitoring

You may be thinking, "I know how to monitor streams, so I know how to monitor estuaries." In many respects, you are correct. Basic monitoring techniques are similar for streams, lakes, rivers, and estuaries. However, estuaries have several, often unique,

properties that must be considered when conducting monitoring efforts. As one volunteer leader wrote, "Estuary monitoring can be characterized as a mixture of river and lake monitoring techniques—liberally salted" (Green, 1998).

Two main influences that make estuary monitoring unique are tides and salinity. Volunteers are strongly recommended to learn proper techniques for monitoring in an estuarine environment.

Tides

Estuaries differ from streams and lakes in several respects. First and foremost, they are subject to tides and the accompanying mixing of salt and fresh water. Any successful estuary monitoring program must take into account the tidal stage when scheduling training sessions and sampling times. Tidal stages can mean the difference between using a boat and trudging across mudflats to get to a sampling spot.

The fact that high tide occurs at different times in different parts of the estuary undeniably complicates scheduling. Some monitoring groups schedule sample collection for low and high tides at each station on each monitoring date—which translates into different sampling times for each location!

Estuaries are complex, with a wide variety of environments that are constantly changing. When the tide is rising, incoming salt water does not mix uniformly with fresh water. Fresh water is lighter (less dense) than salt water and tends to stay nearer the surface. The result is layering, or **stratification**, which may necessitate sampling at several depths—particularly for dissolved oxygen, nutrients, plankton, and salinity. On the other hand, tides of sufficient magnitude are effective mixers of estuarine waters and may break down stratification.

Tide charts are readily available and should be a standard part of any program coordinator's tool kit. Programs studying highly stratified estuaries or estuaries with tidal ranges over a few feet may want to measure tidal stage. Even if tidal stage data are not included at the beginning of the sampling effort, the National Oceanic and Atmospheric Administration (NOAA) publishes tide tables for most of the U.S. This information can be obtained and applied after the fact, if the monitoring station is reasonably close to one of the published tide table sites.

Barnegat Bay in New Jersey (photo by S. Schultz).

Salinity

Salinity, the concentration of salts in water, isn't usually monitored in streams, rivers, or lakes, unless there is a connection with salt water or concerns about excessive winter season road salting. Salinity changes with the tides and the amount of fresh water flowing into the estuary. It is often the major determinant of what lives where.

Salinity is often a factor in monitoring many key water quality variables. For example:

- To properly calibrate most dissolved oxygen meters, knowledge of salinity concentration is necessary.
- If you are interested in converting the dissolved oxygen concentration to **percent saturation** (the amount of oxygen in the water compared to the maximum it could hold at that temperature), you must take salinity into account. As salinity increases, the amount of oxygen that the water can hold decreases.
- If you use a meter to measure pH, the techniques are the same whether you are testing salt or fresh water. However, if you use a colorimeter, you must use a correction factor (available from the manufacturer) to compensate for the effects of salinity.
- Although **macroinvertebrates** (e.g., insects, worms, shellfish, and other animals that lack a spinal column) live in estuaries, using them as indicators of ecosystem health is more problematic than in streams. Estuaries support

Various land uses, including agricultural, residential/urban, forestry, mining, and marinas, can be sources of estuarine pollution (photo by Weeks Bay Watershed Project).

different invertebrate communities than freshwater systems, and many of the key freshwater indicators are not present in estuaries. In addition, collection is more difficult, given the tidal fluctuations and the muddy bottom. Finally, data analysis tools for relating macroinvertebrate communities to ecosystem health have not been as well developed for estuaries as for streams.

The Human Element

As mentioned previously, a number of estuary health problems can be traced to human activities. Humans also hold the key to finding their solutions. Many organizations and individuals are working to restore and protect estuaries, and volunteer monitoring is one essential aspect of the effort.

Each player has a different role in volunteer monitoring efforts, but all must work together to ensure efficient use of time, resources, and data.

The Role of Government Organizations

On the federal, state, and local levels, a myriad of government agencies are involved in volunteer estuary monitoring. Each government level has a different degree of involvement, summarized below:

- Federal
  Several federal agencies and programs are involved to some degree in volunteer estuary monitoring. The **U.S. Environmental Protection Agency (EPA)**, for example, has supported volunteer monitoring since 1987. The EPA has sponsored national symposia on volunteer monitoring, publishes a newsletter for volunteers, developed guidance manuals and a directory of volunteer organizations, and provides technical support to the volunteer programs (see Appendix B for resources).

  The EPA also administers the **National Estuary Program (NEP)**. Unlike traditional regulatory approaches to environmental protection, the NEP targets a broad range of issues and engages local communities in the process.

  The NEP encourages local communities to responsibly manage their estuaries. Each NEP is made up of representatives from federal, state, and local government agencies, as well as members of the community—citizens, business leaders, educators, and researchers. These stakeholders work together to identify problems in the estuary, develop specific actions to address those problems, and create and implement a formal management plan to restore and protect the estuary.

  To help in their tasks, NEPs work with volunteer groups and federal, state, and local agencies to gather critical data about their estuary. Many NEPs host informational workshops for volunteer monitors.

  Another federal program interested in volunteer data is the **National Estuarine Research Reserve System (NERRS)**, which is administered by the National Oceanic and Atmospheric Administration (NOAA). NERRS sites monitor the effects of natural and human activities on estuaries to help identify methods to manage and protect coastal areas. Volunteer groups are often engaged to help collect valuable data about estuarine health.

- State
  Depending on the state, several agencies may be involved with volunteer estuary monitoring. Agencies responsible for water quality, coastal and/or environmental management, fish and wildlife, public health, and other areas have shown interest in supplementing the data they regularly collect with information gathered by volunteers. State agencies play a major role in volunteer efforts. Many offer training opportunities, provide sampling equipment, and compile and distribute volunteer data. Occasionally, state laboratories may offer their services to process samples.

Some states are reluctant to fully use volunteer data, which can be a sore point with volunteer groups. To remedy such conflicts, many states establish quality assurance/quality control (QA/QC) requirements (see Chapter 5) to ensure that volunteer data can be used. They may also train volunteer groups on setting up a quality assurance project plan (QAPP). States can also work with volunteer groups to identify data needs, key sampling sites, and formats for submitting data. Such cooperation maximizes monitoring efficiency and data usefulness.

- Local

  Local agencies can get involved with volunteer monitoring in a number of ways. When considering development plans, they can use volunteer data to assess baseline water quality conditions and follow estuarine health as the development proceeds. Data can also be used to identify especially sensitive areas, which can then be designated for special protection.

  Volunteer data can also be helpful for locating local pollutant sources. For example, local governments are primarily responsible for septic system permitting, inspections, maintenance, and enforcement. Particularly in rural areas where septic systems are common, local agencies may not have enough staff to sample for bacteria and other indicators of failing systems. By working with volunteer groups, local agencies are tapping into a valuable resource.

The Role of Non-Government Organizations

With few exceptions, non-government organizations do the bulk of hands-on volunteer monitoring program planning and implementation. Such organizations can include environmental, school, community, and civic groups. Their membership is comprised largely of local citizens.

A major responsibility of non-government groups is to work with government agencies and other non-government organizations. Collaboration is important to coordinate monitoring activities and identify priority areas in the estuary. By coordinating with other organizations, volunteer monitors can also improve the likelihood that groups other than their own will utilize their data. For example, by working together with state agencies to develop a QAPP and determine which data the agencies are most interested in, volunteer organizations can become a valuable partner in estuary monitoring efforts.

Of course, the volunteer organization may elect to gather other data that may not be high on government agencies' priority lists. This information still has value! It can be used to guide local management decisions, educate the public, establish a baseline, and serve as an early warning of potential water quality problems.

Besides working with government agencies, non-government organizations do grassroots work. Among other things, they:

- recruit, train, and motivate volunteers;
- supervise monitoring activities;
- procure monitoring equipment;
- raise funds to support monitoring efforts; and
- work with local media to inform the public of their activities and findings.

A volunteer takes a Secchi disk reading from Puget Sound (photo by E. Ely).

The Role of Individuals

It may seem obvious, but should nonetheless be stated: **Without individual volunteers who commit their time and energy to the effort, there would be no volunteer monitoring programs.**

Besides actually monitoring the estuary, volunteers are valuable resources for other reasons. They generally monitor close to their homes and are familiar with the area. Because of their knowledge of local land uses, environmental issues, and history of the monitoring area, volunteers can provide valuable anecdotal information that can help explain data.

Individual volunteers can also assist with other non-monitoring activities, such as fundraising, writing press releases, educating the public, and helping with administrative work.

Chapter 4 goes into greater detail about the role of volunteers in monitoring programs. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

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

National Estuarine Research Reserve System (NERRS)
Web site: http://inlet.geol.sc.edu/ nerrsintro.html

National Estuary Program (NEP) Web site: http://www.epa.gov/owow/estuaries/about1.htm

Other references:

Association of National Estuary Programs (ANEP). 1998. Preserving Our Heritage, Securing Our Future: *A Report to the Citizens of the Nation.* Washington, DC. 49 pp.

Levinton, J. S. 1982. *Marine Ecology*. Prentice-Hall, Englewood Cliffs, NJ. 526 pp.

Maine Department of Environmental Protection (DEP). 1996. *A Citizen's Guide to Coastal Watershed Surveys*. 78 pp.

National Oceanic and Atmospheric Administration (NOAA). 1990. *Estuaries of the United States: Vital Statistics of a Natural Resource Base*. U.S. Department of Commerce, National Ocean Service.

National Safety Council's Environmental Center. 1998. *Coastal Challenges: A Guide to Coastal and Marine Issues*. Prepared in conjunction with Coastal America.
Web site: http://www.nsc.org/ehc/guidebooks/coasttoc.htm

Pritchard, D. W. 1967. "What Is an Estuary: A Physical Viewpoint." In: *Estuaries*. G. H. Lauff (ed.). American Association for the Advancement of Science. Publication No. 83. Washington, DC. 757 pp.

Stancioff, E. 1994. "Changing Tides: Special Challenges of Estuary Monitoring." *The Volunteer Monitor* 6(2).

U.S. Environmental Protection Agency (USEPA). 1987. *The State of the Chesapeake Bay, Second Annual Monitoring Report*. Chesapeake Bay Program, Annapolis, MD.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA 840-B-92-002. January. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Web site:

Restore America's Estuaries: http://www.estuaries.org/estuarywhat.html

Chapter 3

Planning and Maintaining a Volunteer Estuary Monitoring Program

Establishing goals, objectives, timelines, and strategies are important steps in creating an estuary monitoring program. People starting a monitoring program must also face questions about liability and other risk management issues. Another important component to a successful program is ongoing financial support. Finally, the program should be promoted regularly throughout the community.

Photos (l to r): G. Carver, K. Register, PhotoDisc, K. Register

Overview

Volunteer data contributes in many important ways to our understanding of the magnitude and extent of estuarine impairment. Therefore, it is important to ensure that a volunteer monitoring program is effectively and efficiently designed. Planning, implementing, and maintaining a volunteer monitoring program requires organization, time, resources, and dedication. However, the payoffs can be great. A well-organized, properly maintained volunteer monitoring program can yield credible water quality data that will enhance capabilities to identify problems, assess trends, and find solutions to water quality problems. The basic ingredients for success are outlined in this chapter.

Establishing goals, objectives, timelines, and strategies are important steps in creating an estuary monitoring program. People starting a monitoring program must also face questions about liability and other risk management issues. Another important component to a successful program is ongoing financial support. Finally, the program should be promoted regularly throughout the community. All of these topics are reviewed in this chapter.

Establishing Goals and Objectives

No step is more critical in the planning process than establishing the goal or goals of your estuary monitoring program. Every phase that follows will depend upon this initial decision. These all-important goals are best determined by the people who will be using the volunteer data. Once the program is established, volunteers can also help shape future goals. So, the first step is to identify the people and organizations that will use your data.

Identifying Data Uses and Users

The best-designed volunteer monitoring programs always begin with a clear understanding of how the data will be used (see Chapter 5 for more information). Potential data users should be identified and asked to serve on the project's planning committee. This committee will develop and articulate a clear purpose for the use of the data. The committee should include members of the scientific research community, local and regional officials who will play a part in resource policymaking, representatives of other monitoring groups, and citizen leaders who are potential volunteer monitors or who represent groups from which volunteers will be recruited.

Determining Goals and Planning for Quality

In addition to understanding who will use the volunteer data, the broad overall goals for the program should be determined. Is the primary goal to collect data that will supplement government monitoring? Or is the main goal of the program to educate the public? For a list of common program goals, see page 3-5.

Determining the goals of the program goes hand-in-hand with creating a plan that can deliver the level of data needed. As you will see in Chapter 5, many of these early decisions will play a critical role in developing a quality assurance project plan (QAPP). This plan contains details on all the methods you expect your volunteers to use. Careful planning ensures that your data will be consistent and of the desired level of quality.

The perception that amateurs cannot collect good quality data is the most common reason professional water quality managers decline to take advantage of volunteers as a resource. However, by preparing a QAPP and adhering to its elements, your volunteers will produce "data of known quality" that meet the stated data quality objectives of your program.

After establishing primary goals, the planning committee should go on to answer, in detail, the following questions:

- *What are the major problems and priorities in the specific estuary or sampling area?*

Planning an effective monitoring project

Benefits of Partnering

Partnering with data users when planning a monitoring project has several benefits. Examples are provided below:

- Their input on sampling parameters and methodologies will improve the likelihood that they will accept and use your data.
- The participation of regulatory agencies in the process will better ensure that they will be responsive to potential problems identified by the data.
- They can guide data management practices to maximize their access to the data (e.g., using compatible databases, reporting methods, etc.).
- They can help interpret the data.

Prospective Users of Volunteer Data:

- state environmental protection or management agencies
- state conservation and recreation agencies
- state and local health departments
- water quality analysts
- land use planners
- fisheries biologists
- environmental engineers
- educational institutions, including elementary, middle, and high schools
- state, regional, and local park staff
- local government planning and zoning agencies
- university researchers
- environmental groups
- soil and water conservation districts
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- U.S. Environmental Protection Agency
- National Oceanic and Atmospheric Administration
- Soil Conservation Service

requires that you learn everything you can about potential monitoring sites by contacting programs and agencies that might already monitor in your area. As you identify the most critical problems of the estuary, include the perceptions and values of community leaders, residents, and community organizations. Selection of priorities will help you determine what water quality parameters you need to monitor.

- *What sampling parameters or conditions will you monitor to characterize the status of the estuary? What methods or protocols will you use for collecting and analyzing samples? How will you pick your sampling sites, and how will you identify them over time?*

An important part of developing a monitoring program is selecting monitoring sites, parameters to be monitored, and a monitoring schedule. Also, there are sometimes several different methods or protocols that can be used to monitor each parameter. Considerations on selecting the "what, how, where, and when" to monitor can be found in Chapter 6.

- *How large a monitoring program should be attempted?*

What is the capacity of the planning committee to raise funds and organize a program? Do you have the skills, staff time, financial resources, and community support needed to reach your program's goals? If not, the planning committee may need to improve its organizational capacity by creating or strengthening relationships with community leaders, environmental interest groups, and community agencies such as local conservation districts and colleges.

Alternatively, your organization may need to revisit its goals to set something more realistic. Always keep in mind that small programs done well are far better than larger efforts done poorly. Small programs that are well-run can grow over time.

- *How will volunteers be recruited and trained, and how often will they receive refresher courses?*

As you develop your new estuary monitoring program, you will need to determine who will recruit and train the volunteers. The initial training of the volunteers is a crucial part of developing a water quality monitoring program. Without such training, usable, high-quality data cannot be obtained, and volunteers will soon grow frustrated. In addition to initial training, refresher courses for volunteers should be planned. Some practical considerations on successfully recruiting, training, and retaining volunteers can be found in Chapter 4.

- *How will you manage your data and ensure that your data are credible? How will the results of the program be presented?*

Understanding how the data will be used will lead you to answers about how the data will be managed and how reports will be generated to best fit users' needs. Choosing a data management approach early on in program development is critical if the hard work of the volunteers is to be meaningful. To take information from data sheets and convert it to something that makes sense to your audience requires several elements, which are summarized in Chapter 8.

Not only is it important to manage and present data according to users' needs, but every volunteer monitoring group should also address early in the planning process how the data analysis will be communicated back to the volunteers, who should see the tangible benefits of their work. This requires planning, since the data may need to be summarized and some general conclusions prepared for a non-technical audience. Chapter 5 provides more information on this topic.

- *How should the program be evaluated? What outcomes will you measure to determine if your program is "successful"?*

Success, especially at the beginning of a project, can be measured in many ways. The first time your volunteers take to the field and collect samples can rightfully be considered a success. Proving that it can be done is an extremely important step. Later, success may be measured by whether your data is used in local land use decisions or leads to actions that improve the health of the estuary.

Ongoing evaluation of the program is critical. The planning committee should meet periodically to evaluate the program, update objectives, and refine the monitoring process. You may decide to improve on sampling techniques, site selection, lab procedures, or any of the other elements of your monitoring project design. These periodic reviews should help ensure that the volunteer monitoring program will continue to produce high quality and useful data for those who require information concerning the estuary.

Be sure to document the important contributions of the monitoring group to community leaders, legislative bodies, and the community. This may help establish program credibility with funders and aid volunteer recruitment efforts. ■

Common Goals of Citizen Monitoring Programs:

- To supplement water quality data collected by professional staff in water quality agencies and scientific institutions.
- To educate the public about water quality issues.
- To build a constituency of citizens to practice sound water quality management at a local level and build public support of water quality protection.
- To obtain data from remote areas during storms or during unique events in the watershed.
- To increase awareness about a problem in the estuary, such as the documentation of illegal discharges into the water.
- To establish baseline conditions where no prior information exists.
- To determine water quality changes through time.
- To identify current and emerging problems, such as pollution sources, habitat loss, or the presence of non-indigenous species.

Designing a Data Collection Form

Most monitoring data, including those collected by volunteer programs, are stored and managed by computer. Data users and the database manager should be involved in the development of the data collection form to be sure that it clearly identifies the information to be collected and that the information can be easily and accurately entered into the database. Consideration should also be given to the ease with which the form can be filled out and understood by the volunteers.

Several suggestions for consideration when developing a data collection form are as follows:

- Print the form on waterproof paper, if possible.
- Keep it simple for volunteers to fill out.
- If many of your volunteers are over 40 years of age, consider using larger type sizes (12 point and larger).
- If possible, keep your data form to one side of an 8 1/2" x 11" piece of paper so that it can fit on a clipboard.
- Ask your volunteers for input on how the form can be improved.
- Remind volunteers that pencils are best when filling out the forms.
- Always include the full address and contact phone numbers of your program.
- On the back of the form, include:
  - emergency phone number and notes about safety;
  - a chart showing the expected ranges for each parameter that is tested (this can help volunteers verify that they are using the monitoring equipment correctly or determine whether their chemicals need to be examined for accuracy);
  - steps to remember for collecting the sample or data; and
  - an identification key of organisms (e.g., phytoplankton, SAV or macroinvertebrates).
- Specify on the form what units should be reported with the data. For example, if Secchi depth is measured in centimeters, then put "cm" on the line where volunteers write their Secchi depth data.
- Include on the data form any equations needed to convert measurements. This will minimize the chance of error.
- Put a reminder that a value of zero should not be reported. Remind volunteers to report the value as less than the lowest value that can be read with the equipment (Miller, 1995). For example, if the range of a test is 0-1 mg/l, the smallest increment is 0.01 mg/l, and the test result is zero, report the value as "less than 0.01 mg/l" or "<0.01 mg/l."

Appendix A contains several examples of data forms.

Insurance, Safety, and Liability—Risk Management

Questions of insurance, safety, and liability are always important considerations when starting any program that will place volunteers in the field. Insurance issues are rarely the favorite topic of volunteer monitoring programs. In fact, many programs may not be fully aware of what their insurance policies cover. Some may not even have liability insurance.

If people are confused about issues of insurance, safety, and liability (collectively termed **risk management**), there is good reason; this whole field is a tangle. To make matters worse, laws differ dramatically from state to state. For example, the interpretation and validity of waivers depends to a large degree on what state you are in. Workers' compensation is another case in point: some states allow volunteers to be covered while others do not.

So, what is a volunteer monitoring organization to do? The following sections offer answers to some of the most common questions. This is basic information; volunteer groups are encouraged to seek legal advice regarding any risk management issues.

Liability Insurance

Liability insurance protects you if you are sued. The most common type is "general liability," which covers most bodily injury and property damage claims. A liability policy covering an organization does not necessarily cover its volunteers in case they are sued personally. You can get your organization's liability coverage extended to your volunteers, but beware: once volunteers are added to the list of insured, they are excluded from collecting medical benefits under the policy if they are injured. A general liability contract protects the organization against claims brought by a third party, and once a volunteer is listed as an "insured" he or she is no longer a third party. In other words, you cannot sue yourself for damages.

Individual volunteers can also get liability coverage under their own homeowners' policies. It is especially important for each of your organization's board of directors to do this, since by law they can be held personally liable for damages caused by the organization. Note, however, that most homeowners' policies do not provide protection if someone sues you for a purely financial loss.

Injuries to Volunteers

How can you protect your volunteers in case they are injured "on the job"? In some states, volunteers can be covered by workers' compensation; call your state Department of Employment for information about applicable laws and the cost of covering volunteers. If workers' compensation is unavailable or very expensive, your organization may want to buy a separate accident and injury policy for volunteers. For a "supplemental" policy (one that takes effect only after the individual's own medical coverage is exhausted), the cost is usually only a few dollars per year per volunteer. Another option is to include volunteers in the medical payments portion of your general liability policy; however, the dollar amount of medical coverage in such policies is usually fairly limited.

Insurance Through Partnering

Teaming up with a partner who has good coverage is popular among volunteer monitoring groups. In some cases, volunteers sign a partner's form, after which they are covered by workers' compensation. This is easier and less expensive to do in some states.

For programs associated with a university, participants may be considered university volunteers and covered by the university's insurance policy. Student monitors may also be organized under a larger umbrella organization that affords coverage. The Boy Scouts of America, for example, has a division known as Explorer Posts, which allow boys and girls to participate. Each Post

focuses on a specific activity (in this case, the water monitoring project). The group must abide by all Explorer Post regulations, and participants are eligible for low-cost insurance coverage through the Boy Scouts.

Waivers

A carefully worded waiver can protect you if you are sued for negligent (unintentional) acts. Waivers are best suited for adults; those signed by minors (persons under 18) usually do not hold up in court.

It is important to make sure your waiver clearly spells out all the risks involved in an activity. Because states interpret waivers differently, it is impossible to design a standard form that can be used in all jurisdictions. Consult a lawyer for the best wording to use in your state.

Risk Reduction

Prevention, as always, is the best medicine. Volunteers should be trained to look for and avoid hazards at sampling sites, to use the buddy system, and to take appropriate precautions when handling chemical reagents. Above all, monitoring groups should stress that volunteer safety is always more important than the data and that volunteers should never put themselves at risk to obtain a measurement. See Chapter 7 for a discussion of volunteer safety.

Equipment Insurance

Volunteer groups may also wish to consider insuring their monitoring equipment for damage. This is especially true for expensive gear. ■

Paying for the Program—The Financial Side

Volunteer monitoring is cost-effective, but not free. Depending on the equipment and monitoring methods you choose, outfitting a team of monitors can cost several hundreds or thousands of dollars. Paying a salary (either part- or full-time) to one or more volunteer coordinators is also a critical component to many water quality monitoring programs. Dedicated staff members are needed to ensure program continuity, train volunteers, manage data, and ensure that data quality goals are being met. The following sections offer guidelines for finding the funds that will help your program to grow and flourish.

Funding Sources

Fundraising is an important component of running a successful volunteer monitoring program. Without funding to cover program costs, a program simply could not exist. The principal sources of funding for volunteer monitoring programs are government funds and private contributions.

Government Funds and Support

Federal grants are sometimes available to public or nonprofit non-governmental organizations to initiate and maintain citizen monitoring programs. Usually, these funds are distributed through grants given by the state. National Estuary Programs are eligible for combined federal and state funds to support research and public participation projects that can include volunteer monitoring. Some federal funding for volunteer monitoring programs is also routed to state universities from the National Oceanic and Atmospheric Administration (NOAA) Sea Grant Program and the Coastal Zone Management Program.

State and local funding sources may also exist to implement and maintain volunteer monitoring programs. Some state funding is distributed only to state agencies, while other programs provide funding to private organizations. Call your state and local agencies that are responsible for water quality, coastal, and/or environmental management to learn

about resources and support they offer to volunteer monitoring programs.

States vary in the amount of support they offer to volunteer monitoring programs. For example, in Oregon, interested citizens are trained in water quality monitoring techniques by the Oregon Department of Environmental Quality and supplied with all necessary equipment. Alabama has an extensive statewide monitoring effort that offers training, equipment, and quality assurance procedures through Alabama Water Watch, which is supported by state and federal funds. Other states may not provide equipment, but offer valuable assistance in developing quality assurance project plans and in selecting monitoring sites.

Private Funds and Support

Private contributions to fund your program can come from corporate sponsorships, foundation grants, individual contributions, fundraising events, civic organizations, board members, and even the program volunteers.

Foundations

Grants from foundations are very important for volunteer monitoring programs throughout the United States, and many resources list sources of foundation grants.

A great way to begin your funding search is by visiting Web sites. One site run by The Foundation Center (http://fdncenter.org/) compiles information on more than 37,500 active U.S. private foundations and corporate giving programs. This resource, and others like it, can help you identify appropriate funders. Ask your local library or university if they have directories of foundations that you can review. Be sure to read the description of each foundation carefully to learn if their funding goals are a good match for your program.

Check also to see if your state has a nonprofit statewide organization devoted to water quality or environmental issues. Many of these organizations provide research grants and offer funding that is available only within the state.

What's in a Budget?

Budgets for volunteer water quality monitoring programs include some or all of the following:

- staff salaries and fringe benefits;
- equipment and refilling chemical supplies;
- laboratory analysis;
- office overhead (phone, postage, duplicating, etc.);
- data management (software program, data entry, storage and retrieval);
- data analysis (including cost of a statistical software package);
- travel expenses (to train volunteers, perform quality assurance checks, attend local and regional conferences, and promote the program);
- printing costs for annual reports and newsletters; and
- other expenses (conferences, Web site maintenance, etc.).

(Adapted from USEPA, 1990.)

Local Sponsors

To find the initial funding that is needed to start a volunteer monitoring project, many groups also seek local supporters to underwrite postage, printing, and equipment purchases. The first step in this process is to identify potential donors through research. Talk to the leaders of other local nonprofits and ask them about their supporters. While some nonprofits may not want to let you know where they get their funding, others will be willing to give you helpful sources. Make a list of all the people, local businesses, and other organizations that share an interest in the water quality of the estuary.

Prepare a brief, focused statement outlining what the volunteer estuary monitoring program hopes to accomplish. Make appointments to meet with prospective supporters, and let them know how their support will benefit the community. Ask for a specific amount of funding. Corporations have to be convinced that part of their advertising budget should be spent on your program, so be sure to let them know how you will acknowledge their support.

Keep in mind that local sponsors may fund what is important to them and their employees. If their employees can and want to participate in the project, the employer is more likely to help fund the project.

Special Events

Another fundraising strategy is to plan a special event. In addition to raising funds, this approach can generate publicity about your volunteer monitoring program, help educate the citizens in the estuary watershed, and recruit new volunteers. In fact, many events may focus less on fundraising than on gathering new supporters.

Special events can take a great deal of effort to plan, so be sure this goal is achievable. Some special event ideas include: a concert on a beach, a festival or fair, a dinner with a guest speaker, or an auction of donated items. Local businesses, newspapers, and radio stations are important partners to line up early in the planning process. The publicity offered by local media will help ensure good attendance for your event (see "Promoting the Program—Working with the Media" in this chapter for more information). Also consider "tagging" your fundraising event onto an established community event. For example, if your community has an annual festival, your group could plan one aspect of the festival and keep the proceeds.

Board Members

In addition to contributing time, professional knowledge, and expertise, the board members of some volunteer organizations are also responsible for giving and getting financial support. If your program decides to have a board and if fundraising is to be one of the board responsibilities, prospective board members need to understand this expectation.

Membership Support

There are pros and cons to having a dues-paying membership as part of your monitoring program. On one hand, the people who live near the estuary and in its watershed are often interested in the water quality data that will be generated; as a result, they may be willing to help financially support your volunteer monitoring program. But maintaining membership records will take time and effort on the part of program staff. All donors must be thanked promptly, and records must be kept so that members can be billed when their memberships have expired. Members will also expect to be kept informed of program accomplishments, which might require the development of a newsletter or Web site.

In-Kind Donations

Many people and companies cannot contribute cash to your program, but would be willing and able to lend their support with in-kind gifts. In-kind donations of goods and services can offer tremendous support to a volunteer monitoring program. A graphic designer can donate time and expertise to develop a

Fundraising Is About Relationships

To develop funding, develop relationships. Fundraising is a long-term process; you need to build a relationship that benefits all involved. Establishing relationships with multiple funders will help you to ensure that you are not too dependent on one funding source.

After identifying funding sources, make personal contact with them. Call the contact person at a funding organization and ask a few questions about how your proposal can be targeted to the organization's funding goals. Your best chance to receive funding will be from organizations whose philanthropic philosophies match your program goals. For example, if potential funders are mainly interested in education, then highlight the educational aspects of your water quality monitoring project.

In order to survive as an economic entity, integrate fundraising into everything you do as an organization. Your program volunteers can also be valuable fundraising assets, as they can promote the program with others in the community.

brochure. A local printer or truck company can donate printing or hauling services. Individual volunteers can also assist with other non-monitoring activities, such as fundraising, writing press releases, educating the public, and doing administrative work.

Other volunteer monitoring programs can be another source of valuable support. Several non-government organizations around the U.S. conduct volunteer estuary monitoring (see Ely and Hamingson, 1998), and have gained knowledge and skills that they can share with newer programs. Conversations with these other environmental, school, community, and civic groups can greatly shorten your learning curve.

Writing a Successful Proposal

When writing a funding proposal, make your project sound exciting and focus the project description so that it appeals to the funder. Written proposals are sometimes the only opportunity you will have to present your program to funders. It is your chance to show them that your organization is credible, has a strong structure, and will be a valuable asset. Funders need to be convinced that your program will be successful and worth the investment. They want to feel as if they will be part of a successful project that will lead to tangible results.

Make sure that the proposal is professional and complete, and that it "sells" the importance of the project. A successful proposal should contain the following:

- cover letter (brief summary of the project, amount of funding requested, signature of top staffer, and contact person's name and phone number);
- introduction (description of organization, mission, population served, why your organization is best suited to do the project);
- project goal (and how it fits in with your mission);
- project objectives (specific measurable steps to meet the goal);
- request (specific dollar amount requested); and
- expected results.

When presenting a funding proposal:

- read the foundation's or grant's guidelines carefully and follow them exactly;
- ask for the right amount (know the foundation's limits);
- be succinct;
- do not misrepresent a "partnership" or exaggerate any aspect of your goals; and

- highlight the expertise that the program leaders bring.

It is critical to make your issue relevant and understandable to funders. Be careful to use layperson's terms in your writing, and do not assume that the person reading your proposal knows acronyms or technical terms. After you have written your proposal, ask someone who is unfamiliar with your program's goals to read the proposal. If your reader is unclear about any aspects of your proposal, your prospective funder will likely be unclear as well; a rewrite is necessary.

Keep Funders Happy!

No matter what your source of funding, it is important to keep your supporters happy! Remember: The same people who make decisions to support your program need to feel that their support is appreciated.

Be sure to acknowledge and thank your funders every time they provide any support. Keep them informed about the progress of the program and invite them to attend your receptions, banquets, workshops, training sessions, or demonstrations. Companies, foundations, and individuals often hope to increase their visibility within the community in return for their cash or in-kind donation. You can acknowledge their support by including their names and/or logos in press releases, brochures, reports, or even T-shirts made for the volunteer monitors. Make sure to get approval from the funders before using their names or logos; some donors prefer to remain anonymous.

Forming Partnerships

Being part of a partnership with other organizations can help your chances of getting a grant. Funders like to see that your program is in a partnership, as this shows that your program is supported by others in the community. Partnerships also convey that the expertise of many people will be contributing to the program. Many foundations like regional efforts and prefer to make larger grants, so partnering with other groups to make joint applications is very beneficial.

Some funders require nonprofit tax status [called 501(c)3 status] from the Internal Revenue Service. Obtaining this tax status is an important step for a nonprofit group, but the process can be lengthy and requires a fee of up to $500. If you do not have this tax status, then maybe you can partner with a group that does have it.

Partnerships have additional benefits. A volunteer program should look for other groups in the area doing similar projects in adjacent or complimentary waterways. Partnering with these groups could lead to cost savings on supplies (buying in bulk is cheaper than buying in small volumes) or hiring consultants or staff (one person could work on several projects).

Your monitoring program can also gain strength by taking advantage of opportunities provided by government agencies. Several agencies are involved in volunteer estuary monitoring on the federal, state, and local levels. Federal agencies, such as the U.S. Environmental Protection Agency (EPA), support volunteer monitoring by sponsoring symposia on volunteer monitoring, publishing newsletters, and developing guidance manuals (see references at the end of each chapter and in Appendix B).

Another federal program interested in assisting volunteer monitoring programs is the National Estuarine Research Reserve System (NERRS), which is administered by the National Oceanic and Atmospheric Administration (NOAA). Also, learn if your estuary is part of the National Estuary Program (NEP). This program, administered by the EPA, targets a broad range of estuary-related issues and engages local communities in the process. NEPs work with volunteer groups and federal and state agencies to gather critical data about their estuary. Many NEPs host informational workshops for volunteer monitors and support volunteer groups in other ways. ■

Some Funding Challenges

Many funders insist that all grants go toward direct project expenses and will not allow any money to go to administrative or overhead costs (e.g., rent, phone bills, electricity). This restriction can be a challenge, given that there are administrative overhead costs associated with running any program. There are other terms you can use in your budget instead of "administrative"; for example, you may use phrases like "contacting volunteers" and "program development costs" to cover some phone calls, photocopying, etc. Developing a partnership with other like-minded groups can also help defray some of these overhead costs.

Some grants are paid on a reimbursement basis. For new monitoring groups, this necessitates finding a source of money to pay the bills while waiting for the reimbursements.

Promoting the Program—Working with the Media

Now that you have clearly established the primary goal or goals and know the program priorities, your challenge is to meet your objectives by focusing your resources and mobilizing the community. Publicizing a volunteer monitoring program through the television, radio, or newspaper media is an effective, cost-efficient method to reach citizens in the watershed. The rewards of successful press coverage can be high as the public will learn about the estuary and the efforts of your group.

Working with the media requires logistical planning. Create a communications strategy that is an integral part of the monitoring program; make communications a priority and allow time to prepare press releases and meet press contacts.

People are interested in reading or hearing about their local environment—it is a quality-of-life issue to readers. Yet getting the press to pay attention to a volunteer monitoring program is sometimes a challenge. Reporters look for the "big story," but many of our current environmental woes are accumulative problems from what we do on a daily basis and have done for years. Onetime specific events, such as a sewer overflow, will usually receive coverage and can be good opportunities to include information about the bigger problems of water pollution. Many reporters want to write about community groups and environmental issues, but their first and most pressing concerns are breaking news.

Press Releases

To help get the word out about your program, press releases are priceless! A press release is a one- or two-page document that informs newspaper and electronic media about your program and its goals, findings, upcoming events, need for volunteers, and other topics of interest. Writing one press release and sending it to many local news outlets is a cost-efficient and effective method to inform the community about your program.

As you write a press release, know what you want to say, whom you want to reach, and what you want the reader or viewer to "take away." Think about why the health of the estuary is important to the readers or viewers.

To increase chances of getting an article in a newspaper, do your best to write the story for the reporter. A well-written press release stands a better chance of getting published without many modifications, thereby reducing the likelihood that your message gets presented incorrectly. You have to anticipate

how the press would present the topic. Frame the issue the way a journalist would, and think about what would be their lead. Give to the press the "who, what, where, when, why, and how." Remember: You often have to educate reporters and inform them why they should care about your issue.

Make it easy for reporters to contact you if they have questions or want to interview you. At the top of the press release, provide a contact person for the press to call for more information. You may also want to include at the end of the press release a contact name and number for the public to use (this may be a different number from the press contact).

The timing of press releases is important. Press releases are best sent to newspapers about two weeks before the event to allow photographers and writers to be scheduled. Television stations should receive your press release one to two weeks prior to the event. It is best to mail or fax press releases, then call the reporter to see if he or she has any follow-up questions. Take time to call reporters and give them "background" information about your organization.

When writing a press release, it helps to have a bold, recognizable masthead on your stationery. For other professional touches, contact a local advertising agency to learn if it would donate the time of its professional staff to assist you. Also, check with your local library for books with specific examples of model press releases.

Press Conferences

A press conference should be an organized event that has been well thought out and delivers specific news. In other words, press conferences must have substance. If your program has discovered an issue that is of interest to the community or if findings from your volunteer monitors have led to a significant event, hold a press conference. For good visuals, invite the press to cover a real activity (not a posed shot) and let volunteers know that they will be photographed. Also, prepare good charts or graphics to show the data you have collected. Local maps showing water conditions are also effective. Press conferences that merely announce upcoming events are seldom attended by busy reporters, and if the reporters show up and are disappointed by the lack of content, they may not come again to more "worthy" press conferences.

When working with the media, always be prepared for an interview. Have your facts together and use humor, analogies, and inspiration whenever possible (photo by PhotoDisc).

The timing and location for a press conference are important. Early in the day is preferred, as it allows plenty of time for TV stations to edit the tape before the noon and evening news broadcasts. Choose a place that has good visuals, such as a location along a waterbody that you have been studying or at your headquarters where volunteers can be shown working in the background. ■

Tips for Working Successfully with the Media:

- Develop long-term professional and personal relationships with reporters, editors, and producers at your local news stations and newspapers. Reporters value contacts with reliable, credible non-government groups like volunteer monitoring programs.
- Write a short fact sheet about your program.
- Create media materials that are clear, concise, and understandable to the general public. Edit and format materials so that reporters under deadline can read them quickly and easily.
- Localize. Make the issues into stories that address the local community.
- Use humor, analogies, and inspiration in your interviews.
- Include graphics, charts, and visuals, which draw the attention of reporters.
- Highlight citizen and student involvement.
- People are more interesting than facts, and animals are more interesting than people. Use animals, protesting citizens, or interested students as a "hook" with the press.
- Write a short summary of your group's findings (two pages with one visual aid) and send it out with a press release.
- If a reporter wants information over the phone, ask if you can return the call in five minutes. Take those five minutes to write down the major points you want to make, then call the reporter back. This way, you will be focused on the two or three most important points you want to make in the interview.
- Know reporters' deadlines. They tend to be busiest in the afternoon trying to meet deadlines, so call them in the morning.
- Always cover the important details: who, what, when, where, why, and how.
- Give good directions to the event or field site.
- Explain the topic in simple terms. Avoid terms like "nonpoint source pollution"; instead, show how people and animals will be impacted.
- Be flexible in scheduling the media. Understand that "late-breaking" stories may require you to reschedule an interview.
- Designate spokespeople and have them practice their communication skills.
- Always say the full name of your organization—not an acronym. In fact, avoid using acronyms altogether, since most people are unfamiliar with them and will not understand what you are talking about.
- Remember that television stations have broader geographical areas of interest than newspapers.
- Plan to have interesting visuals, an articulate spokesperson, and video to illustrate a point. These are required if you want to get television coverage.

References and Further Reading

Portions of this chapter were excerpted and adapted from:

Ely, E. 1996. "Are You Covered?" *The Volunteer Monitor* 8(1).

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

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.

Other references:

Chabot, W. 1999. "Volunteer Estuary Monitoring: Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. San Pedro, CA: February 22-24, 1999.

Courtmance, A. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Toms River, NJ: April 14-16, 1999.

Ellett, K. 1993. *Introduction to Water Quality Monitoring Using Volunteers*. 2nd ed. Alliance for the Chesapeake Bay. Baltimore, MD. 26 pp.

Ely, E. and E. Hamingson. 1998. *National Directory of Volunteer Environmental Monitoring Programs.* 5th ed. U.S. Environmental Protection Agency, Office of Wetland, Oceans, and Watersheds. EPA-841-B-98-009. Web site: http://yosemite.epa.gov/water/volmon.nsf.

Finch, B. 1999. "Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Mobile, AL: March 17-19, 1999.

Fritz, P. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Toms River, NJ: April 14-16, 1999.

Hines, M. 1999. "Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Hubbard, M. 1999. "Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Jordan, B. 1999. "Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Mobile, AL: March 17-19, 1999.

Larson, J. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Toms River, NJ: April 14-16, 1999.

Moore, K. 1999. "Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Toms River, NJ: April 14-16, 1999.

Rodgers, E. 1999. "Media, Outreach, Publicity." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Toms River, NJ: April 14-16, 1999.

Steiner Blore, V. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Sterling, J. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. San Pedro, CA: February 22-24, 1999.

Tamminen, T. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. San Pedro, CA: February 22-24, 1999.

Thompson, D. 1999. "Fundraising." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

U.S. Environmental Protection Agency. (USEPA) 1991. *Volunteer Lake Monitoring: A Methods Manual*. EPA 440/4-91-002. Office of Water, Washington, DC. 121 pp.

U.S. Environmental Protection Agency. (USEPA) 1992. *Proceedings of Third National Citizens' Volunteer Water Monitoring Conference*. EPA 841-R-92-004. Washington, DC. 183 pp.

Web sites:

Fundraising Information

Catalogue of Federal Domestic Assistance: http://www.gsa.gov/fdac

Environmental Grantmaking Foundations—Resources for Global Sustainability: http://www.environmentalgrants.com

The Foundation Center: http://www.fdncenter.org/. Phone: 212-620-4230.

Foundations and Grantmakers Directory: http://www.foundations.org/grantmakers.html

GrantsNet: http://www.hhs.gov/grantsnet

River Network: http://www.rivernetwork.org/library/libsou.cfm

Chapter 4

Recruiting, Training, and Retaining Volunteers

Volunteers are the basic ingredient of a successful volunteer monitoring program. These citizens bring more than just manpower to the monitoring program—they also bring a passion to understand, protect, and/or restore the estuary. Trained volunteers can serve an irreplaceable role as community educators as they conduct their monitoring duties and share their knowledge with others.

Photos (l to r): K. Register, E. Ely, R. Ohrel, The Ocean Conservancy

Overview

Not surprisingly, volunteers are the basic ingredient of a successful volunteer monitoring program. These citizens bring more than just manpower to the monitoring program—they also bring a passion to understand, protect, and/or restore the estuary. Trained volunteers can serve an irreplaceable role as community educators as they conduct their monitoring duties and share their knowledge with others.

Although states monitor water quality and other environmental parameters of estuaries, there are limits to the coverage they can provide. Volunteers can supplement this work by monitoring in areas where officials are not sampling. State officials can then use this information to screen for areas of possible contamination, habitat loss, or other conditions that impact the health of the estuary.

This chapter discusses how to recruit, train, and retain top-notch volunteers.

Recruiting Volunteers

As you recruit volunteers, it is helpful to understand what motivates people to donate their time and energy to a volunteer effort. Citizens may commit not only because of their conviction in the merits of the cause, but also because they will personally benefit from the experience. Many people volunteer for service reasons; they believe in the cause and want to help. Others hope for new friendships and enjoy the social interaction with like-minded individuals. People are also interested in personal and career growth, and enjoy meaningful work that gives them new skills and knowledge.

In addition to reasons why people initially volunteer for a project, there are important reasons why they continue with the program year after year—recognition, respect, and a sense of accomplishment. Volunteers must feel that their efforts are appreciated and recognized, that the group respects their skills, and that their work produces results. Keep these motivational factors in mind as you create your recruitment materials and as you develop a plan to recognize the efforts of long-term volunteers.

Before you recruit volunteers, you must first know how many the program requires in its "start-up" phase. For example, if you have enough monitoring equipment for 10 teams of volunteers and each team is to be comprised of 2 or 3 people, then your recruitment goal should be 20 to 30 volunteers. Some programs start with a small number of people who are invited personally to serve as volunteer monitors. Later, as the program grows and needs more assistance, all interested citizens can be invited to join the effort.

A first step in finding volunteers is to identify all organizations and individuals in the area who might want to participate in the project. Likely groups include civic associations, watershed associations, environmental advocacy groups, and government agencies. Individuals interested in volunteering might be waterfront property owners or commercial and recreational users of the estuary. Retired citizens and disabled individuals can make outstanding volunteers. Schools in the watershed are also potential sources of volunteers. Speak with teachers at local elementary, middle, and high schools, community colleges, and universities.

Strive to recruit volunteers from a wide range of backgrounds. This diversity helps establish the credibility of the program, ensures cooperation within the community, and provides the bonus of educating a greater variety of citizens in the community.

Certain types of individuals or groups may be more suitable than others for your particular project. If a primary goal of your monitoring program is education, then integrating students and youth groups into your program will help meet that goal. However, if your goal is year-round data collection using expensive and precise equipment, retired citizens may be more suitable and reliable. Some programs report a failure to integrate students and youth groups into long-term monitoring programs because of the commitment required and the need for summertime sampling.

Many towns and cities have volunteer centers or "hotlines" which serve to connect potential volunteers with programs. Inquire with towns located within the monitoring area to see if such volunteer centers exist. Other ways to reach potential volunteers are through your program Web site or sites managed by local communities. Local newspapers often will publish a "call for volunteers" as a community service.

A press release to local newspapers is an effective method to let the public know of your need for volunteers. See Chapter 3 for information on working with the media to publicize your program and its need for volunteers. An attractive brochure or flier describing the overall volunteer monitoring program can also be an effective recruitment tool.

Whether you promote by using a press release, brochure, or other method, be sure to include information on the objectives of the program and describe the benefits to the volunteer and to the estuary. Also explain what will be expected of recruits. Potential volunteers will need to know:

- monitoring site locations;
- project duration and length of commitment required;
- sampling frequency;
- required equipment (e.g., car, boat, sampling gear, etc.); and
- volunteer qualifications, if any (keep in mind that setting specific volunteer qualifications will limit participation in the program, possibly below an effective minimum level).

Short slide presentations that describe the program and show some of the sampling equipment and techniques can be a very effective recruitment tool. This will make it easier for potential volunteers to determine if they would be interested in volunteering and if they are capable of carrying out the activities requested of them. ■

Training Volunteers

A successful monitoring program requires well-trained volunteers. Few other aspects of the program are more important, so adequate time and money should be budgeted annually. Without volunteer training, usable, high-quality data cannot be obtained and volunteers will soon grow frustrated. Proper training provides the common ground necessary for a well-designed and scientifically valid data collection effort. Your program's volunteer coordinator plays an important, key role in the success of the entire effort.

Training citizen volunteers is time consuming and demanding. Nevertheless, successful training sessions are key to a long-term and effective monitoring program. It is well worth the effort to devote this time to the volunteers.

Introductory training ensures that all volunteers learn to collect and analyze samples in a consistent manner. This training will also introduce new volunteers to the program and its objectives, and will create a positive social climate for the volunteers. Such a climate enhances the exchange of information among participants and the volunteer coordinator. Training provides the volunteer with the critical information necessary to "do the job right."

Continuing education and retraining sessions, in which the volunteer coordinator reintroduces standard methodologies and presents new information, equipment, data results, or informative seminars, are also extremely useful. Such sessions:

- reinforce proper procedures;
- correct sloppy or imprecise techniques;
- facilitate resolution of equipment or logistics problems;
- allow volunteers to ask questions after familiarizing themselves with the field techniques;
- encourage a "team effort" attitude;
- make experienced volunteers feel integral to the program by encouraging

A volunteer collects a sample for bacteria testing. Practicing sampling techniques in the field is an effective way to reinforce what is learned in the classroom (photo by E. Ely).

Volunteers receive sampling instructions aboard a boat in California's Los Angeles River (photo by R. Ohrel).

Sample Job Description: Volunteer Monitoring Coordinator

The Volunteer Monitoring Coordinator has the following responsibilities:

- In consultation with state agency personnel and other interested parties, determine which waterbodies and which parameters in these waterbodies will be monitored.
- Recruit volunteers for each project. This will involve contacting interested groups, elected officials, and possibly businesses and industries in the area.
- Make arrangements for a place to conduct a training session and arrange a time to suit a majority of volunteer monitors. Train any volunteers who are unable to attend the training session.
- Keep in close touch with individuals at the beginning of project. Answer any questions volunteers may have. Read over each data sheet as it comes in and contact any monitors who seem to be having trouble. Send refill reagents and replacement equipment upon request.
- If required, enter all data in a suitable computer filing system. Carry out documentation and verification on the data. Provide plots of data to monitors and to data users. Carry out preliminary data interpretation. (Other staff or volunteers may carry out these management activities. If so, the volunteer monitoring coordinator will assume an advisory role.)
- Provide feedback to participants and data to users. This will involve writing progress reports and articles for publication in the program newsletter.
- Plan for and carry out quality control sessions.
- Prepare quarterly reports for the sponsoring agency.

(Excerpted and adapted from USEPA, 1990.)

them to supply valuable feedback to the instructors; and

- provide educational opportunities to the participants.

Volunteer training can be divided into three broad categories. Each has a different purpose, but together they should complement one another and make the training program well-rounded.

The categories are:

- introductory training to describe the program, teach standard methods, and motivate the volunteers;
- quality assurance and quality control (QA/QC) training to ensure consistency and reliability of data collection; and
- motivational sessions that encourage information exchange, identify problems, and provide a social atmosphere for participants.

Although the different sessions will vary in content, the procedures necessary to present the material are fairly constant. Volunteer training may be broken down into five separate steps, which are described below.

Step 1: *Describing the Volunteers' Duties*

Prior to citizen involvement, the program manager must develop a detailed blueprint of each volunteer monitoring task. This "job description" spells out in sufficient detail every step a volunteer must complete to col-

lect data for each parameter.

The job description standardizes the data collection process and ensures that each volunteer samples in a consistent and acceptable manner. Consistency allows for comparisons of one section of an estuary to another section or between estuaries. Additionally, when the sampling methods are consistent, managers can more easily identify data outside the norm and evaluate whether they result from unusual conditions or faulty collection techniques.

There are some critical questions that need to be answered as you create standard operating procedures (SOPs), or written protocols to be used by the volunteers for each parameter that your program will monitor. The questions include what water quality parameters are to be tested and what level of quality is required for each parameter sampled. These questions are discussed in detail in Chapters 3, 5, and 6.

Many programs provide their volunteers with a handbook or manual that has been written specifically for their program and details the program SOPs. This written description provides each volunteer with a readily available reference that clearly describes how to sample while serving as a reminder of the correct methodology. Additionally, it helps to minimize the number of times the volunteer coordinator has to answer the same questions. Throughout the handbook, safety should be stressed (see Chapter 7 for information on volunteer safety).

The handbook should include the steps for each sampling task. Many of the sampling protocols summarized in this manual are suitable as basic task descriptions. The author of your program handbook can excerpt the descriptions from these chapters and embellish them with information unique to your program and its data collection tools and methods. A separate protocol should be drafted for each major parameter being measured.

Volunteer coordinators can also use their handbook to:

- recruit new volunteers;
- evaluate the ability of volunteers to complete the monitoring tasks accurately; and
- assist new programs in developing their own protocols.

Volunteers review laboratory techniques (photo by The Ocean Conservancy).

Writing the monitoring tasks provides volunteer coordinators with the opportunity to fully evaluate the job at hand and improve potentially troublesome areas. Once the handbook is completed, volunteer coordinators and a few volunteers should test and refine the protocols under field conditions. Volunteer coordinators and key volunteers should reevaluate the handbook regularly—especially as the monitoring program expands to include more environmental parameters.

Step 2: *Planning the Training*

With a completed volunteer handbook, training sessions can be designed. Usually, programs will find that group sessions are the most cost-effective means of training the volunteers. In some situations, however, individual instruction may be the only feasible option.

Group sessions are preferred for all training classes because they are generally inexpensive, efficient, encourage interaction among the volunteers, and foster enthusiasm for the program. The training sessions should be scheduled according to the needs and availability of your volunteers. If your volunteers are mainly people who work during the day, schedule training sessions in the evenings or weekends. A better option would be to offer a variety of training times and let your volunteers pick the time that fits best into their schedules.

Training sessions are also the ideal time to outfit each new volunteer with a complete set of the required sampling equipment. Established volunteers may require additional equipment, blank data sheets, and refills of the reagents for their analysis kits.

Training Sessions

A training session agenda should include:

- A presentation on goals and objectives of the project. The presentation should include the reasons for monitoring, historical information on the estuary, the problems it faces, expected uses of the volunteer data, and how the project will benefit volunteers, the community, and the state. Let volunteers know how the monitoring program will make differences in the region and throughout the watershed.
- A review of what is expected of the participants including how long the training session will last and the proposed length of the entire volunteer effort.
- Distribution of all equipment, a general explanation of its use, and a discussion of what equipment is particularly fragile, what constitutes equipment abuse, the replacement policy and cost, and the return of equipment at the end of the project.
- A thorough overview of all necessary safety requirements.
- An overview of the monitoring procedures, preferably with an accompanying slide show.
- A demonstration of proper use of monitoring equipment and sampling techniques. The trainer should demonstrate the proper methods and then circulate among the participants as they practice the procedures.
- An overview of proper preparation of samples for shipment.

(Excerpted and adapted from Ellett, 1993.)

A volunteer coordinator reviews instructions with a team of volunteers (photo by K. Register).

If each volunteer is expected to monitor many parameters, the instructor may need to schedule more than one session. Too much information presented at a single session may overwhelm and eventually discourage the volunteers.

Training volunteers for field sampling ideally takes place in the field. Group field trips, either for advanced training or special educational sessions, are wonderful means of motivating volunteers while teaching them additional skills. Furthermore, problems that might not arise during training conditions in a classroom may emerge under less predictable field conditions. Most volunteers are quite enthusiastic about getting onto the water or seeing a new area of the estuary and they often approach their sampling with renewed enthusiasm after participating in a field trip.

When volunteers live over a widely scattered area, require assistance for a special problem, or are unable to attend a group session because of work or family obligations, a volunteer coordinator may need to meet with them individually. One-on-one training is certainly more time consuming and expensive, but it allows the instructor to focus on the particular problems or needs of a single volunteer. In return, this individual attention may help maintain the volunteer's dedication to the program.

Understanding Adults as Learners

Unlike schoolchildren who are trained by adult teachers, adults require a different tact when it comes to education. If some or all of your program volunteers are adults, then the trainer needs to appreciate the learning process for adults and design training programs accordingly. Four pertinent characteristics of adult learners are listed below, accompanied by suggested ways to address them during the training process.

- **Adults are mature and need to control their learning.**

  Traditional classroom learning gives the teacher the power while the student is passive, but adult training should allow the students to have a key role in directing the learning process. When beginning a training session, present your objectives and session agenda to the volunteers. Give them an opportunity to discuss and adjust the plan. Get to know your volunteers before or during the training. Find out why they are participating in the monitoring program and try to design their "job" to satisfy their interests.

- **Adult learning requires a climate that is collaborative, respectful, mutual, and informal.**

  Adults bring vast personal experiences to the learning process. It is essential that the trainer recognize and use this experience. ***Minimize lectures.*** Retention is increased when we become actively involved in the learning process. Training sessions should be paced to allow time for volunteers to hear about the monitoring program, perform the techniques themselves, and then reflect on the learning by asking and answering questions. ***Provide opportunities for group work.*** Use your experienced volunteers to mentor newer volunteers. ***Reinforce your instruction*** by designing problem-solving exercises for groups to work on. Traditional classroom teaching assumes that students learn well by listening, reading, and writing, but in reality people have a variety of learning styles. Some people learn best through logic and problem solving; others prefer to learn through pictures, charts, and maps. Some work best on their own, while others work best in groups. Learning styles are very individualized, and group exercises can be designed to provide a variety of learning environments. ***Encourage volunteers to share experiences and expertise,*** and provide them with additional learning materials.

- **Adults need to test their learning as they go along, rather than receive background theory and general information.**

  Adults need clear connections between content and application so that they can anticipate how they will use their learning. Start your training session with kits and techniques, and save the lecture on ecology for later. Let them know how their data will be used, and ask them what they think needs to be done to improve the estuary. Have them discuss how the monitoring will help them achieve project and personal goals. Provide time in the training to discuss how the volunteers will use their new knowledge. Remember that when volunteers are in the field, curious onlookers may ask them questions about what they are doing and why. Use role-playing to build their confidence so that they can educate their communities about the resources they are monitoring. Use other volunteers as trainers, and provide opportunities for volunteers to take on new challenges.

(continued)

(Understanding Adults . . . continued)

- **Adults expect performance improvements to result from their learning.**

  Adult learning needs to be clearly focused in the present and be "problem centered" rather than "subject centered." Help volunteers evaluate your training and their own performance. Train volunteers in groups. Encourage them to set goals for themselves and then mentor each other to achieve those goals.

(Excerpted and adapted from Kerr, 1997.)

Step 3: *Presenting the Training*

A well-conceived plan for instruction along with simple handouts is key to a useful training presentation. Instructors should make the most effective use of participants' time. Volunteers, like most students, appreciate a well-organized and smoothly paced class. Four major steps constitute an effective and lively training session: preparation, presentation, demonstration, and review.

Preparation

Preparation for class is critical. The sampling protocols provide a basic framework for the initial training session. With the basic information in hand, the instructor must then tailor the lesson to the audience. The instructor should try to anticipate those portions of the lesson that may cause confusion and be prepared to clarify these areas. Volunteers should be invited to ask questions throughout the session.

Instructors should make appropriate use of audiovisual materials to enhance the presentation. All equipment should be in the room at the start of the session, in good working condition, and ready for use. Slides of the estuary and of volunteers in action are a good teaching device and tend to hold an audience's attention.

Presentation

Knowing the material thoroughly and having the information well-organized are critical to an effective presentation. Ensure a successful session by using these tips:

- Be enthusiastic about the subject! Enthusiasm inspires dedication.
- Establish a good rapport with the audience.
- Get the audience involved in the talk and keep the presentation lively.
- Utilize visual aids.
- Speak loudly enough to be heard throughout the room and enunciate clearly.
- Be humorous.
- Use eye contact.
- Encourage questions and comments.
- Use anecdotes throughout the presentation.
- Maintain good posture and positive body language.

Volunteers with no background in science may require additional explanation or assistance so that they understand the importance of high quality data collection methods and the proper use of scientific equipment. Although separate sessions for experienced and untrained volunteers are preferable, some instructors may elect to have a single session with experienced volunteers helping those who are new to the program.

If the pace drags because one or two volunteers are slow, the rest of the volunteers may quickly become annoyed and bored. Slower students may require individualized attention at a later date.

Demonstration

Two types of demonstration are effective training tools: one in which the instructor shows the techniques to the volunteers and another in which the students practice the outlined procedures under the watchful eye of the instructor. An effective teacher can incorporate both into a training session.

The instructor should demonstrate the sampling protocols. Viewing the execution of a procedure is more meaningful than simply reading the instructions. Once the volunteers are familiar with the techniques, they can then repeat the procedures under the tutelage of the instructor. These practice sessions can take place in the field or classroom and give volunteers the confidence to transfer these newly learned skills to their own monitoring site.

Review

A good learning session should end with a review of the material. Summarizing reinforces the salient points and assists the volunteers in retaining the information. As in the training exercise, volunteers should be invited to ask questions during the review. At the close of the session, the instructor can inform participants about upcoming events and future training opportunities and reiterate the importance of citizen monitoring and data collection.

Step 4: *Evaluating the Training*

High quality data reflect successful volunteer training. To ensure that the sessions are effective and successful, include written evaluations as an integral part of the training process. While an instructor may feel that the sessions are adequate, only the volunteers know how much they have learned and retained.

Evaluation of the training should include an assessment of:

- training techniques and style;
- information presented;
- classroom atmosphere; and
- use of handouts and audiovisual aids.

Volunteers may provide feedback at the end of the sessions. The true test of an effective session, however, is how well the volunteers perform in the field. A follow-up evaluation form, sent to participants after a few weeks of sampling, may pinpoint any weaknesses in the presentation.

Members of the monitoring program may also want to accompany volunteers into the field and examine their sampling techniques as they work unassisted. Such spot checks can identify areas in which the volunteers are encountering difficulties. It is important to explain to volunteers that these observation sessions are an important part of the quality control that is needed for high quality data.

If large numbers of volunteers are experiencing problems in carrying out the sampling protocols, you may want to revise the format of the training sessions or have a new instructor take over. The evaluation process should be ongoing to ensure that all the sessions consistently meet a high standard.

Step 5: *Follow-Up Training/Providing Motivation and Feedback*

While the initial training sessions are designed to give volunteers all the basic skills to successfully complete their sampling, training does not stop there. Follow-up advanced training sessions, either through one-on-one interaction or with a group of volunteers, is imperative to keep volunteers enthusiastic, motivated, and collecting good data. In some monitoring programs, volunteer coordinators conduct site visits shortly after the training session in order to spend time with each volunteer personally. In addition to building a closer relationship between the volunteer and the coordinator, these visits can answer questions about the monitoring protocol.

One focus for advanced training sessions should be quality control (QC), which is extremely important in all monitoring

programs. The challenge of volunteer program managers is to carry out QC exercises that assess the precision and accuracy of the data being collected, but are also fun and interesting for the volunteers. Experienced volunteer coordinators recommend turning these quality control sessions into educational and social opportunities for the volunteers, while making sure that volunteers understand why QC is important. For more on QC, see Chapter 5.

The first QC session should be held about 3-4 months after sampling begins to make sure that all monitors are sampling and analyzing in a consistent fashion and to answer any questions. Thereafter, two QC sessions should be held each year if sampling goes on year-round. If sampling is carried out on a seasonal basis, training sessions for new monitors and retraining for program veterans can be held at the beginning of the sampling period, with a QC session scheduled for the middle of the season.

Volunteers should be expected to attend all scheduled sessions. If a volunteer cannot attend at least one session a year, the volunteer coordinator (or a trained assistant) should make a site visit and evaluate the sampling procedures of the volunteer.

Quality control exercises should be as interesting as possible. As two options, attendees can:

- carry out the tests on the same water sample with their own equipment the way they do it at their site, filling out and submitting a data collection form with their results; or
- read and record results from previously set up laboratory equipment and kits, similar to a classroom laboratory practical exam.

Data collection forms with the recorded results are submitted independently. The results can then be compared to determine bias. Results from these sessions also measure how well the group members perform and how precisely they measure the characteristics and constituents required.

In addition to ongoing training sessions that stress quality control, monitoring programs should offer individualized training to volunteers who require it. Though less time efficient than training a group of people, it has many other benefits. For example, an individual session:

- permits the volunteer to ask questions particular to a site;
- allows the instructor to solve specific problems in the field;
- indicates to the volunteer that his/her data are important;
- gives the instructor feedback on training effectiveness;
- enhances communication between the volunteer coordinator and the volunteer;
- motivates the volunteer; and
- provides a forum for introducing new methods.

Continuous communication with volunteers is critical. In addition to going into the field with specific volunteers, the volunteer coordinator should also consider phoning other volunteers who may not require face-to-face contact. A phone call lets volunteers know that the volunteer coordinator is interested in their progress and gives them an opportunity to ask questions. Informal gatherings, such as potluck dinners and slide shows, also give volunteer coordinators an opportunity to check on the progress of the participants and answer questions. Newsletters or updates by way of e-mail are also excellent ways to keep volunteers informed.

The success of the program is highly dependent on maintaining volunteer motivation and enthusiasm. An apathetic volunteer will likely not collect good data and may drop out of the program. The next section provides suggestions for retaining volunteers. ■

Backup Monitors

A program should have a backup monitor policy in place to assure data collection continuity. A backup volunteer can sample at a site when the primary monitor is sick, on vacation, or for some other reason unable to sample.

The backup should be trained as rigorously as the primary volunteer so that the data meet high quality standards. Many programs have strict backup policies in place, with requirements similar to the following:

- The backup monitor must be trained by the volunteer coordinator and attend a minimum of one quality control session every six months.
- The backup volunteer must be familiar with all the sites that he or she will monitor.
- The backup may monitor at any site but must use the proper data sheet and the kit assigned to the primary volunteer of the site.

Retaining Volunteers

Finding qualified volunteers and training them takes work, so losing volunteers on a regular basis can be a drain on resources. Your group should have a plan to ensure that volunteers continue to feel that supporting your efforts are worth their time. Show them that the benefits of volunteering outweigh the costs. Satisfied volunteers will become advocates for your mission and will help recruit additional support. Successful monitoring programs devote significant resources to activities designed to motivate their volunteers.

Communicate

Keep direct lines of communication open at all times using the telephone, personal memos, and/or some form of newsletter. Some monitoring groups use e-mail or Web sites to keep volunteers informed. Be easily accessible for questions and requests. Give volunteers a phone number where they can always leave a message, then respond to calls promptly. Ask for their advice on general administrative issues, bring them into the proofreading process, and help them develop a sense of shared ownership of the program.

Recognize the Effort

Give volunteers praise and recognition—it is the psychological equivalent of a salary!

Recognize their accomplishments through awards, letters of appreciation, publicity, and certificates. If at all possible, recognize the expertise of experienced volunteers by encouraging them to shoulder increased responsibilities such as becoming team leaders or coordinators, carrying out more advanced tests, or helping with data analyses. Also, as you keep the local media abreast of the findings of the monitoring effort, be sure to include the names of key volunteers.

Offer Educational Opportunities

Provide volunteers with educational opportunities so that they can continue to "grow." Have meetings and regular workshops where guest speakers can explain environmental sampling techniques or provide

information on environmental policies pertinent to the sampling effort.

Use the Data Your Volunteers Collect

Nothing discourages volunteers more than seeing that their data are not being used. Simple analyses and attractive displays of volunteer data should be prepared and sent to volunteers as well as to the data users. A Web site is an excellent place to present volunteer data.

Keep volunteers informed about all uses of their data. If they are contributing to a long-term database, prepare annual data summaries showing the current condition of the estuary compared to its previous condition. If the data are used for acute problem identification, send the volunteers information on areas where problems have been identified. If the data are being used to supplement state reports, send volunteers copies of the report. These actions will foster continued interest in the program and serve to educate and inform the volunteers about the conditions of the estuary. For more information on using data, see Chapter 8.

Be Flexible, Open, and Realistic

Start with a small program that you can easily handle. Synchronize the monitoring period to coincide with the period you can commit to supporting the volunteers. When starting a program, be frank about the chances for continued support and inform the group if resources disappear, or might disappear soon. Work with the strengths and interests of your volunteers and search for ways to make the most of your available resources. Talk with volunteer coordinators of similar programs elsewhere to learn new ways to handle obstacles. ■

Tips on Volunteer Motivation and Incentives

Successful monitoring programs have developed many methods to motivate both new and long-term volunteers. The following are tips and hints for increasing volunteer participation and keeping volunteers motivated:

- Remember that you are competing with other organizations for volunteers and their time.
- Volunteers need a sense of fulfillment. Match volunteer interests and skills with appropriate jobs. Invite top volunteers to take on leadership responsibilities. Experienced volunteers can become "captains" to help with training and organization. Create different "layers" of volunteers.
- Make person-to-person contact.
- Make it easy.
- Make it fun (for example, send a thank-you note saying, "You are a lifesaver!" and include some Lifesavers candy).
- If recruiting volunteers from schools or colleges, the key is getting a committed teacher to help coordinate.
- Tell volunteers "what's in it for them." Inform them about local water quality problems and their ownership in the problems/solutions. Show the human connection, and how their efforts are helping to solve problems.

(continued)

(Tips. . . continued)

- Present certificates to volunteers when they complete technical training in monitoring procedures.
- Be prepared for your volunteers. Have training sessions organized and equipment ready.
- Don't sign up volunteers if you don't have work or equipment for them.
- Recruit and train backup volunteers. Some programs recommend having three volunteers per team, plus backup volunteers.
- Re-certify volunteers every year.
- Get emergency contact information for all volunteers.
- Recognize that volunteers know their communities. Encourage them to share what they have learned with schools, press, etc.
- Conduct regular orientation and training sessions.
- Know that some volunteers have skills beyond serving as monitors (e.g., graphic design, public relations, making other contacts). Ask them what other talents they would be willing to share.
- Have your own liability waivers and keep in mind that some state parks, etc. require that their waivers also be signed. (See Chapter 3 for more information on waivers.)
- Keep equipment in backpacks, boxes, or fabric tote-bags for volunteers to use.
- Build into your volunteer program the capacity for feedback and true volunteer involvement.
- Reward volunteers after work sessions, sampling seasons, or other milestones with a party or other celebration, canoe trips, certificates, etc.
- Show volunteers and board members the impact their efforts have made by taking them on boat trips or field trips.
- Some communities sponsor awards, banquets, and other events to recognize outstanding volunteers. Nominate your volunteers for these honors.
- Thank the volunteers, then thank them again.

(Excerpted and adapted from Calesso, 1999; Closson, 1999; Davies, 1999; Fitzgibbons, 1999; Gerosa, 1999; and Sims, 1999.)

References and Further Reading

Portions of this chapter were excerpted and adapted from:

Ellett, K. 1993. *Introduction to Water Quality Monitoring Using Volunteers*. 2nd ed. Alliance for the Chesapeake Bay, Baltimore, MD. 26 pp.

Kerr, M. 1997. "Designing Effective Adult Training." In: *Proceedings of Fifth National Volunteer Monitoring Conference—Promoting Watershed Stewardship*. Aug. 3-7, 1996. University of Wisconsin-Madison. Madison, WI. EPA Office of Water, Washington, DC. EPA 841-R-97-007. Web site: http://www.epa.gov/owow/monitoring/vol.html

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.

Other references:

Calesso, D. 1999. "Volunteer Training, Motivation, Incentives." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Toms River, NJ: April 14-16, 1999.

Closson, J. 1999. "Volunteer Training, Motivation, Incentives." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Cook, J.S. 1989. *The Elements of Speechwriting and Public Speaking*. MacMillan Publishing Company. New York. 242 pp.

Davies, B. 1999. "Volunteer Training, Motivation, Incentives." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Ely, E. 1992. "Training and Testing Volunteers." *The Volunteer Monitor* 4(2): 3-4.

Fitzgibbons, J. 1999. "Volunteer Training, Motivation, Incentives." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Mobile, AL: March 17-19, 1999.

Gerosa, A. 1999. "Volunteer Training, Motivation, Incentives." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. San Pedro, CA: February 22-24, 1999.

Sims, G. 1999. "Volunteer Training, Motivation, Incentives." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Mobile, AL: March 17-19, 1999.

U.S. Environmental Protection Agency (USEPA). 1991. *Volunteer Lake Monitoring: A Methods Manual*. EPA 440/4-91-002. Office of Water, Washington, DC. 121 pp.

U.S. Environmental Protection Agency (USEPA). 1997. *Proceedings of Fifth National Volunteer Monitoring Conference-Promoting Watershed Stewardship*. Aug. 3-7, 1996. University of Wisconsin-Madison. Madison, WI. EPA Office of Water, Washington, DC. EPA 841-R-97-007. Web site: http://www.epa.gov/owow/monitoring/vol.html.

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Chapter 5

Quality Assurance Project Planning

While information about an estuary's health is valuable, many government agencies, universities, and other groups are reluctant to use volunteer data. Why? Volunteer monitoring organizations sometimes overlook a critical fact: reliable data means everything. Unless data are collected and analyzed using acceptable methods, potential users are less likely to employ the data. A quality assurance project plan (QAPP) is vital to overcoming this obstacle.

Photos (l to r): Tillamook Bay National Estuary Project and Battelle Marine Science Lab, U.S. Environmental Protection Agency, U.S. Environmental Protection Agency

Overview

While information about an estuary's health is valuable, many government agencies, universities, and other groups are reluctant to use volunteer data. Why? Volunteer monitoring organizations sometimes overlook a critical fact: **reliable data means everything**. Unless data are collected and analyzed using acceptable methods, potential users are less likely to employ the data. A quality assurance project plan (QAPP) is vital to overcoming this obstacle.

This chapter examines the elements of a QAPP. In the process, it reviews basic concepts that must be understood before developing any QAPP.

For comprehensive instructions and useful examples for creating a QAPP, along with a sample QAPP form, the reader should refer to *The Volunteer Monitor's Guide to Quality Assurance Project Plans* (USEPA, 1996).

The Importance of High Quality Data

Although the goals and objectives of volunteer projects vary greatly, virtually all volunteers hope to educate themselves and others about water quality problems and thereby promote a sense of stewardship for the environment. Many projects, in fact, establish these as their goals. Such projects might be called primarily *education*-oriented.

Other projects seek a more active role in the management of local water resources and therefore strive to collect data that can be used in making water quality management decisions. Common uses of volunteer data might include local planning decisions (e.g., identifying where to route a highway); local priority setting (e.g., determining which seagrass beds require restoration); screening for potential pollution problems (which might then be investigated more thoroughly by water quality agencies); and providing data for state water quality reports (which might then be used for statewide or national priority setting). Projects doing this type of monitoring are called primarily *data*-oriented.

One of the most difficult issues facing data-oriented volunteer monitoring programs today is data credibility. Some potential users of volunteer data mistakenly believe that only professionally trained scientists can conduct sampling and produce accurate and useful results. Potential data users are often skeptical about volunteer data—they may have doubts about the goals and objectives of the project; how volunteers were trained; how samples were collected, handled, and stored; or how data were analyzed and reports written. Given proper training and supervision, however, **dedicated volunteers CAN collect high quality data** that is:

- consistent over time throughout the project's duration, regardless of how many different monitors are involved in collecting the data;
- collected and analyzed using standardized and acceptable techniques; and
- comparable to data collected in other assessments using the same methods.

The quality assurance project plan is a key tool in breaking down this barrier of skepticism. ■

What Is a Quality Assurance Project Plan?

The QAPP is a document that outlines the procedures necessary to ensure that collected and analyzed data meet project requirements. It serves not only to convince skeptical data users about the quality of the project's findings, but also to record methods, goals, and project implementation steps for current and future volunteers and for those who may wish to use the project's data over time.

Volunteer monitoring projects must adopt protocols that are straightforward enough for volunteers to master, yet sophisticated enough to generate data of value for resource managers. This delicate and difficult path cannot be successfully navigated without a QAPP that details a project's standard operating procedures (SOPs) in the field and lab, outlines project organization, and addresses issues such as training requirements, instrument calibration, and internal checks on how data are collected, analyzed, and reported. **Just how detailed such a plan needs to be depends to a large extent on the goals of the volunteer monitoring project**. For example, if you want to use your data to screen for problems so that you can alert water quality agencies, you may need only a basic plan. If, however, you want

your data to support enforcement, guide policy decisions, or survive courtroom scrutiny, then a detailed plan is essential (Mattson, 1992).

Developing a QAPP is a dynamic, interactive process that should ideally involve quality assurance experts, potential data users, and members of the volunteer monitoring project team. The process is most effective when all participants fully contribute their talents to the effort, know their individual responsibilities for developing the QAPP, and understand the group's overall purpose and goals.

While it is a challenging and somewhat difficult process, the successful development and institution of a QAPP can be extremely rewarding. This chapter encourages and facilitates the development of volunteer estuary QAPPs by presenting explanations and examples. Readers are urged to consult the resources listed at the end of this chapter and to contact their state or U.S. Environmental Protection Agency (EPA) regional quality assurance staff for specific information or guidance on their projects. ■

Why Develop a QAPP?

The QAPP is an invaluable planning and operating tool that should be developed in the early stages of the volunteer monitoring project.

Any monitoring program sponsored by EPA through grants, contracts, or other formal agreement must have an approved QAPP. The purpose of this requirement is to ensure that the data collected by monitoring projects are of known and suitable quality and quantity.

Even if a volunteer monitoring project does not receive financial support from government agencies, the coordinating group should still consider developing a QAPP. This is especially true if it is a data-oriented project and seeks to have its information used by state, federal, or local resource managers. Few water quality agencies will use volunteer data unless methods of data collection, storage, and analysis have been documented.

Clear and concise documentation of procedures also allows newcomers to the project to quickly become familiar with the monitoring, using the same methods as those who came before them. This is particularly important to a volunteer project that may see volunteers come and go, but intends to establish a baseline of water quality information that can be compared over time.

Finally, written procedures in a QAPP can help ensure volunteer safety (Williams, 1999). Field safety requirements can be made part of standard operating practices, and proper training for equipment operation—a key element in any QAPP—takes user safety into account. ■

QAPPs and STORET

An updated, user-friendly version of EPA's national water and biological data storage and retrieval system, STORET, is now available. With STORET, volunteer programs can "feed" data to a centralized file server which permits national data analyses and through which data can be shared among organizations. A specific set of quality control measures is required for any data entered into the system to aid in data sharing. For more information, see the EPA Web page at www.epa.gov/storet.

Basic Concepts

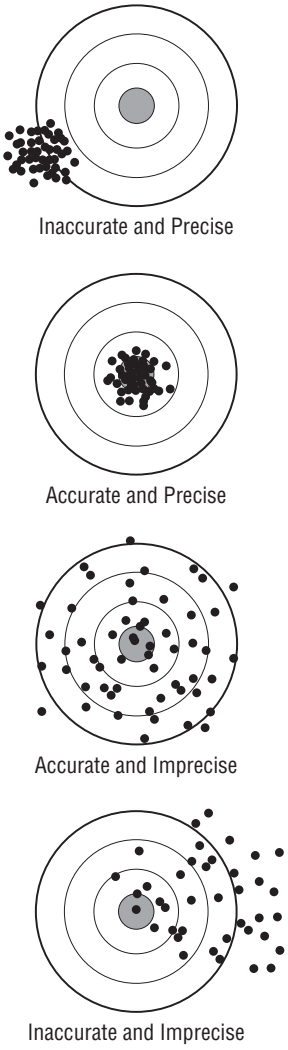


Figure 5-1. Accuracy and precision.

The coordinator of a volunteer monitoring program is likely to be involved in many aspects of project planning, sample collection, laboratory analysis, data review, and data assessment. The coordinator should be considering quality assurance and quality control in every one of these steps.

Quality assurance (QA) refers to the overall management system that includes the organization, planning, data collection, quality control, documentation, evaluation, and reporting of your group's activities. QA provides the information you need to ascertain the quality of your data and whether it meets the requirements of your project. It also ensures that your data will meet defined standards of quality with a stated level of confidence.

Quality control (QC) pertains to the routine technical activities in a project. The purpose of QC is, essentially, error control. Since errors can occur in the field, the laboratory, or the office, QC must be part of each of these functions and should include:

Internal quality control: a set of measures that the project undertakes among its own samplers and within its own lab to identify and correct analytical errors. Examples include:

- lab analyst training and certification;
- proper equipment calibration and documentation;
- laboratory analysis of samples with known concentrations or repeated analysis of the same sample; and
- collection and analysis of multiple samples from the field.

External quality control: a set of measures that involves both laboratories and people outside of the program. Measures may include:

- performance audits by outside personnel;
- collection of samples by people outside the program from a few of the same sites and at the same time as the volunteers; and
- splitting some of the samples for analysis at another lab.

Together, QA and QC help you to produce data of known quality, enhance the credibility of your group in reporting monitoring results, and ultimately save time and money. However, a good QA/QC program is only successful if everyone consents to follow it and if all project components are available in writing. The QAPP is the written record of your QA/QC program.

When formulating a QAPP, several measures will help to evaluate sources of variability and error and thereby increase confidence in the data. These measures are precision, accuracy, representativeness, completeness, comparability, and sensitivity.

Precision

Precision is the level of agreement among repeated measurements of the same parameter on the same sample or on separate samples collected as close as possible in time and place (Figure 5-1). It tells you how consistent and reproducible your methods are by showing how close your measurements are to each other. It does not mean that the sample results actually reflect the "true" value, but rather that your sampling and analysis are giving consistent results under similar conditions.

Precision can be measured by calculating the standard deviation, relative standard deviation (RSD), or the relative percent difference (RPD). Examples of each calculation are shown in Tables 5-1, 5-2, and 5-3.

The standard deviation (Table 5-1) is used

to describe the variability of your data points around their average value. In case you're a bit put off by the math in Table 5-1, you might be happy to know that many calculators can calculate standard deviation for you! Very similar data values will have a small standard deviation, while widely scattered data will have a much larger standard deviation. Therefore, a small standard deviation indicates high data precision.

The RSD, or coefficient of variation (Table 5-2), expresses the standard deviation as a percentage. This measurement is generally easier for others to understand. Similar to standard deviation, your measurements become more precise as the RSD gets smaller.

When you have only two replicate samples, determine precision by calculating the relative percent difference (RPD) of the two samples (Table 5-3). Again, the smaller the relative percent difference, the more precise your measurements will be.

Table 5-1. Example calculation of standard deviation. A low value for standard deviation indicates high precision data. *(Adapted from USEPA, 1996.)*

The Volunteer Estuary Monitoring Project wants to determine the precision of its temperature assessment procedure. They have taken 4 replicate samples:

Replicate 1 (X_1) = 21.1°C
Replicate 2 (X_2) = 21.1°C
Replicate 3 (X_3) = 20.5°C
Replicate 4 (X_4) = 20.0°C

To determine the **Standard Deviation (S)**, use the following formula:

$$S = \sqrt{\sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n-1}}$$

where X_i = measured value of the replicate; $\bar{X}$ = mean of replicate measurements; n = number of replicates; and Σ = the sum of the calculations for each measurement value—in this case, X_1 through X_4.

First, figure out the mean, or average, of the sample measurements. Mean = (X_1 + X_2 + X_3 + X_4) ÷ 4. In this example, the mean is equal to 20.68 °C.

Then, for each sample measurement (X_1 through X_4), calculate the next part of the formula. For X_1 and X_2, the calculation would look like this:

$$\frac{(21.1 - 20.68)^2}{4-1} = \frac{(-0.42)^2}{3} = \frac{0.1764}{3} = 0.0588$$

For X_3, the calculation would be 0.0108; and for X_4, it would be 0.1541.

Finally, add together the calculations for each measurement and find the square root of the sum: 0.0588 + 0.0588 + 0.0108 + 0.1541 = 0.2825. The square root of 0.2825 is 0.5315. So, the standard deviation for temperature is 0.532 (rounded off).

Table 5-2. Example calculation of relative standard deviation (RSD). A low RSD value indicates high precision data. *(Adapted from USEPA, 1996.)*

If we use the same measurements as in the standard deviation example (Table 5-1), we can determine the **Relative Standard Deviation (RSD)**, or coefficient of variation, using the following formula:

$$RSD = \frac{S}{\bar{X}} \times 100$$

where S = standard deviation, and $\bar{X}$ = mean of replicate samples.

We know that S = 0.5315 and that $\bar{X}$ = 20.68. So, the RSD = 2.57. This means that our measurements deviate by about 2.57%.

Table 5-3. Example calculation of relative percent difference (RPD). A low RPD indicates high precision data. *(Adapted from USEPA, 1996.)*

If the project had only two replicates (21.1°C and 20.5°C, for example), we would use the **Relative Percent Difference (RPD)** to determine precision, using the following formula:

$$RPD = \frac{(X_1 - X_2) \times 100}{(X_1 + X_2) \div 2}$$

where X_1 = the larger of the two values, and X_2 = the smaller of the two values. In this example, X_1 = 21.1° and X_2 = 20.5°. The calculation would look like this:

$$RPD = \frac{(21.1 - 20.5) \times 100}{(21.1 + 20.5) \div 2} = \frac{60.00}{20.8} = 2.88$$

So, in this example, the RPD between our sample measurements is 2.88%.

Accuracy

Accuracy is a measure of confidence in a measurement (Figure 5-1; Table 5-4). As the difference between the measurement of a parameter and its "true" or expected value becomes smaller, the measurement becomes more accurate. Repeated measurements that result in values at or near the "true value" would be considered accurate and precise.

Measurement accuracy can be determined by comparing a sample that has a known value, such as a standard reference material or a performance evaluation sample, to a volunteer's measurement of that sample. Increasingly, however, some scientists, especially those involved with statistical analysis of measurement data, have begun to use the term "bias" to reflect this error in the measurement system and to use "accuracy" as indicating both the degree of precision and bias. For the purpose of this document, the term "accuracy" will be used to describe how close a measurement is to a standard value or the true value.

Table 5-4. Example calculations of accuracy. *(Redrawn and adapted from USEPA, 1996.)*

Attendance at QC training sessions is required for Volunteer Estuary Monitoring Project field teams. In the field, monitors use a pH kit, which covers a full range of expected pH values. During a recent training session, the monitors recorded the following results when testing a pH standard buffer solution of 7.0 units:

7.5	7.2	6.5	7.0
7.4	6.8	7.2	7.4
6.7	7.3	6.8	7.2

In this example, the volunteer coordinator may wish to evaluate accuracy in two ways:

Group Accuracy

To determine the accuracy of the full group of volunteers, the coordinator can compare the average of all sample values to the true value, according to the equation:

$$\textit{Group accuracy} = \textit{average value} - \textit{true value}$$

In this case, the average of these measurements is equal to 7.08 units. Since we know that the reference or "true" value is 7.0 units, the difference between the average pH value is "off" or biased by + 0.08 units. The volunteer program's QAPP should specify whether this level of accuracy is satisfactory for the data quality objectives of the project.

Individual Accuracy

While the average pH value calculated above is 7.08 units, a quick scan reveals that several measurements are up to 0.5 units from the true value. Such individual differences from the true value may not fall within an acceptable limit of accuracy, but they are somewhat "hidden" when the group accuracy is calculated. Simply calculating the group accuracy could overlook particularly erroneous data that should be addressed.

To assess the accuracy of individual measurements, the coordinator should use the following equation:

$$\textit{Individual accuracy} = \textit{individual value} - \textit{true value}$$

The possible cause(s) of individual accuracy values that do not fall within the program's QAPP should be determined and remedied.

For many parameters such as Secchi depth, no standard reference or performance evaluation samples exist. In these cases, the trainer's results may be considered the reference value to which the volunteer's results are compared. This process will help evaluate if the volunteer measurements are biased as compared to the trainer's.

If you are monitoring biological conditions by collecting and identifying specimens, maintaining a **voucher collection** is a good way to determine if your identification procedures are accurate. The voucher collection is a preserved archive of the organisms that your volunteers have collected and identified. An expert taxonomist can then provide a "true" value by checking the identification in the voucher collection. In addition to preserved specimens, the collection may involve photography or microscopy.

It is important to note that the relationship between a voucher collection and accurate identification cannot be expressed numerically in your QAPP. Rather, the QAPP should indicate that you have a voucher collection and describe how it is used to evaluate identification accuracy in your program.

Representativeness

Representativeness is the extent to which measurements actually depict the true environmental condition or population you are evaluating. The questions asked in your QAPP will be the guide for defining what constitutes a representative sample.

A number of factors may affect the representativeness of your data. Are your sampling locations indicative of the waterbody? Data collected just below a pipe outfall, for example, is not representative of an entire estuary. Similarly, a sample collected in August is not representative of year-round conditions. Other potential errors, such as lab mistakes, data entry errors, or the use of the wrong type of sample container, may also affect data representativeness.

Completeness

Completeness is a measure of the number of samples you must take to be able to use the information, as compared to the number of samples you originally planned to take. Since there are many reasons why your volunteers may not collect as many samples as planned (e.g., equipment failure, weather-related problems, sickness, faulty handling of the samples), as a general rule you should try to take more samples than you determine you actually need. This issue should be discussed with your QAPP team and by peer reviewers before field activities begin.

Completeness requirements can be lowered if extra samples are factored into the project. The extra samples, in turn, increase the likelihood of more representative data.

Completeness is usually expressed as a percentage (Table 5-5), accounting for the number of times that the volunteers did not collect data. An 80-90 percent rate of collection is usually acceptable.

Table 5-5. Example calculation of completeness. *(Adapted from USEPA, 1996.)*

The Volunteer Estuary Monitoring Project planned to collect 20 samples, but because of volunteer illness and a severe storm, only 17 samples were actually collected. Furthermore, of these, two samples were judged invalid because too much time elapsed between sample collection and lab analysis. Thus, of the 20 samples planned, only 15 were judged valid.

The following formula is used to determine **Percent Completeness (%C)**:

$$\%C = \frac{v}{T} \; x \; 100$$

where v = the number of planned measurements judged valid, and T = the total number of measurements.

In this example, v = 15 and T = 20. In this case, percent completeness would be 75 percent. Notice that this percent completeness does not fall within the usually accepted range of 80-90 percent.

Comparability

Comparability is the extent to which data from one study can be compared directly to either past data from the current project or data from another study. For example, you may wish to compare two seasons of summer data from your project or compare your summer data set to one collected ten years ago by state water quality scientists. The key to data comparability is to follow established protocols or standard operating procedures. Comparing data also requires you to consider the conditions under which the samples were collected, including, for example, the season, time of day, and adjacent land uses.

Using standardized sampling and analytical methods, units of reporting, and site selection procedures helps ensure comparability. However, it is important to keep in mind that some types of monitoring rely heavily on best professional judgment and that standard methods may not always exist.

Sensitivity

Sensitivity refers to the capability of a method or instrument to discriminate between different measurement levels. The more sensitive a method is, the better able it is to detect lower concentrations of a water quality variable.

Sensitivity is related to **detection limit**, the lowest concentration of a given pollutant that your methods or equipment can detect and report as greater than zero. Readings that fall below the detection limit are too unreliable to use in your data set. Furthermore, as readings approach the detection limit (i.e., as they go from higher, easier-to-detect concentrations to lower, harder-to-detect concentrations), they become less and less reliable. Manufacturers generally provide detection limit information with their high-grade monitoring equipment, such as meters; however, volunteer groups should test the equipment themselves—using standards of progressively lower concentrations—to understand where the meter or method begins to have unacceptable accuracy.

Preassembled monitoring kits also usually come with information indicating the **measurement range** that applies. The measurement range is the range of reliable measurements of an instrument or measuring device. For example, you might purchase a kit that is capable of detecting pH between 6.1 and 8.1. If acidic conditions (below 6.0) are a problem in the waters you are monitoring, you will need to use a kit or meter that is sensitive to the lower pH readings.

Because all projects have different goals, data users and uses, capabilities, and methods, there are no universal levels of precision, accuracy, representativeness, completeness, comparability, and sensitivity that are acceptable for every monitoring project. You should consult your advisory panel, data users, support laboratory, and peer reviewers to determine acceptance criteria for your monitoring project. ■

Quality Control and Assessment

Contamination is a common source of error in both sampling and analytical procedures. QC samples help you identify when and how contamination might occur and assess the overall precision and accuracy of your data. The decision to accept data, reject it, or accept only a portion of it should be made after analysis of all QC data.

For most projects, there is no set number of field or laboratory QC samples which must be taken; the general rule is that 10 percent of all samples should be QC samples. Any participating laboratory must also run its own QC samples. For a new monitoring project or analytical procedure, it is a good idea to increase the number of QC samples (up to 20 percent) until you have full confidence in the procedures you are using.

Several different types of QC and assessment measures are presented below (USEPA, 1996; USEPA, 1997).

Internal Checks

Internal checks are performed by the project field volunteers, staff, and lab.

Field Blanks

A field blank (also known as a trip blank) is a "clean" sample, produced in the field, used to detect analytical problems during the whole process (sampling, transport, and lab analysis). To create a field blank, take a clean sampling container with "clean" water (i.e., distilled or deionized water that does not contain any of the substance you are analyzing) to the sampling site. Other sampling containers will be filled with water from the site. Except for the type of water in them, the field blank and all site samples should be handled and treated in the same way. For example, if your method calls for the addition of a preservative, this should be added to the field blank in the same manner as the other samples. When the field blank is analyzed, it should read as being free of the **analyte** (parameter being tested) or, at a minimum, the reading should be a factor of 5 below all sample results.

Negative and Positive Plates (for Bacteria)

A negative plate results when the buffered rinse water (the water used to rinse down the sides of the filter funnel during filtration) has been filtered the same way as a sample. This is different from a field blank in that it contains reagents used in the rinse water. There should be no bacteria growth on the filter after incubation. Bacteria growth indicates laboratory contamination of the sample.

Positive plates result when water known to contain bacteria (such as wastewater treatment plant influent) is filtered the same way as a sample. There should be plenty of bacteria growth on the filter after incubation. It is used to detect procedural errors or the presence of contaminants in the laboratory analysis that might inhibit bacteria growth.

Field Replicates

Replicate samples are obtained when two or more samples are taken from the same site, at the same time, using the same method, and independently analyzed in the same manner. When only two samples are taken, they are sometimes referred to as duplicate samples. These types of samples are representative of the same environmental condition and can be used to detect the natural variability in the environment, the variability caused by field sampling methods, and laboratory analysis precision.

Lab Replicates

A lab replicate is a sample that is split into subsamples at the lab. Each subsample is then analyzed using the same technique and the results compared. They are used to test the

precision of the laboratory measurements. For bacteria, they can be used to obtain an optimal number of bacteria colonies on filters for counting purposes.

Spiked Samples

Spiked samples are samples to which a known concentration of the analyte of interest has been added. Spiked samples are used to measure accuracy. If this is done in the field, the results reflect the effects of preservation, shipping, laboratory preparation, and analysis. If done in the laboratory, they reflect the effects of the analysis procedure. The percent of the spike material that is detected in the sample is used to calculate analytical accuracy.

Calibration Blank

A calibration blank is deionized water processed like any of the samples; it is the first "sample" analyzed and is used to set the instrument to zero. A calibration blank is also used to check the measuring instrument periodically for "drift" (the instrument should always read "0" when this blank is measured). It can also be compared to the field blank to pinpoint where contamination might have occurred.

Calibration Standards

Calibration standards are used to calibrate a meter. They consist of one or more "standard concentrations" (made up in the lab to specified concentrations or provided by any number of supply houses—see Appendix C) of the indicator being measured, one of which is the calibration blank. Calibration standards can be used to calibrate the meter before running the test, or they can be used to convert the units read on the meter to the reporting units (e.g., converting absorbance to milligrams per liter).

Helpful Hint

In addition to being used for meter calibration, standard reference material (in the form of solids or solutions with a certified known concentration of pollutant) can be used to check the accuracy of a procedure and the freshness of the reagents (chemicals) in test kits. If a known standard solution is tested and gives the correct concentration test result, the reagents are working properly and the procedure is being followed correctly.

External Checks

Non-volunteer field staff and a lab (also known as a "quality control lab") perform external checks. The results are compared with those obtained by the project lab.

External Field Duplicates

An external field duplicate is a duplicate sample collected and processed by an independent (e.g., professional) sampler or team at the same place and the same time that the volunteers collect and process their regular water samples. It is used to estimate sampling and laboratory analysis precision.

Split Samples

A split sample is one that is divided equally into two or more sample containers and then analyzed by different analysts or labs. The results are then compared.

Samples should be thoroughly mixed before they are divided. Large errors can occur if the analyte is not equally distributed into the two containers. A sample can be split in the field, called a field split, or in the laboratory—a lab split. The lab split measures analytical precision, while the field split measures both analytical and field sampling precision. Split samples can also be submitted to two different laboratories for analysis to measure the variability in results between laboratories independently using the same analytical procedures.

Outside Lab Analysis of Duplicate Samples

Either internal or external field duplicates can be analyzed at an independent lab. The results should be comparable with those obtained by the project lab.

Knowns

The quality control lab sends samples for selected indicators, labeled with the concentrations, to the project lab for analysis prior to the first sample run. These samples are analyzed and the results compared with the known concentrations. Problems are reported to the quality control lab.

Unknowns

The quality control lab sends samples to the project lab for analysis for selected indicators, prior to the first sample run. The concentrations of these samples are unknown to the project lab. These samples are analyzed and the results reported to the quality control lab. Discrepancies are reported to the project lab and a problem identification and solving process follows.

Table 5-6 shows the applicability of common quality control measures to several water quality variables covered in this manual. ■

Table 5-6. Common quality control measures and their applicability to some water quality parameters. *(Adapted from USEPA, 1997.)*

	Dissolved Oxygen	Nutrients	pH	Total Alkalinity	Temp.	Salinity/ Conductivity	Turbidity	Total Solids	Bacteria
Internal Checks									
Field blanks		X				X	X	X	X
Neg./ pos. plates									X
Field replicates	X	X	X	X	X	X	X	X	X
Lab replicates	X	X	X	X		X	X	X	X[b]
Spiked samples		X		X					X
Calibration blank		X				X	X		
Calibration standard	X[a]	X	X			X	X		
External Checks									
Ext. field duplicates		X	X	X		X	X	X	X
Split samples		X	X	X		X	X	X	X
Outside lab analysis	X	X		X		X	X	X	X
Knowns	X	X	X	X		X	X		X
Unknowns	X	X	X		X	X		X	X

a—using an oxygen-saturated sample
b—using subsamples of different sizes

Developing a QAPP

Developing a QAPP is a dynamic, interactive process. Seek as much feedback as possible from those who have gone before you in the QAPP development process. You will be investing a substantial amount of time and energy, but don't be discouraged: the person who writes the QAPP is usually the one who ends up with the most technical expertise and monitoring insights. Your efforts will pay off in a living document that helps current and future volunteers, staff, and data users understand exactly how your project works.

The purpose of this section is to discuss the steps a volunteer monitoring program might take in preparing a QAPP (Table 5-7). It is recommended that you consult your data users, such as the state or county water quality agency, regarding their QAPP requirements. In fact, many states have prepared QAPPs that, if adopted by your group, can save a great deal of time. If you are receiving EPA grant or contract money to conduct your monitoring, you must also submit your QAPP to EPA for approval. Working with water quality agencies, EPA, and other potential data users to develop your QAPP increases the likelihood that your data will actually be used to make management decisions.

Table 5-7. Steps to develop a QAPP *(USEPA, 1996).*

1. Establish a QAPP team.
2. Determine the goals and objectives of your project.
3. Collect background information.
4. Refine your project.
5. Design your project's sampling, analytical, and data requirements.
6. Develop an implementation plan.
7. Draft your standard operating procedures and QAPP.
8. Solicit feedback on your draft SOPs and QAPP.
9. Revise your QAPP and submit it for final approval.
10. Begin your monitoring project.
11. Evaluate and refine your QAPP.

Step 1: *Establish a QAPP Team*

Pull together a small team of 2-3 people who can help you develop the QAPP. Include representatives from groups participating in the monitoring project who have technical expertise in different areas of the project.

Take time to establish contact with your state, local, or EPA quality assurance officer or other experienced volunteer organizations. Remember: If you are receiving any EPA funding through a grant or contract, EPA must approve your QAPP. However, even if EPA approval isn't needed, you can consult with EPA representatives for advice; they may have resources that can help you. Ask your contacts if they will review your draft plan.

Step 2: *Determine the Goals and Objectives of Your Project*

Why are you developing this monitoring project? Who will use its information, and how will it be used? What will be the basis for judging the usability of the data collected? If you don't have answers to these questions, you may flounder when it comes time to put your QAPP down on paper.

Project goals could include, for example:

- identifying trends in an estuary to determine if non-indigenous species occurrences are on the rise;
- monitoring in conjunction with the county health department to be sure a beach is safe for swimmers;
- monitoring the effectiveness of a submerged aquatic vegetation (SAV) restoration project; or
- teaching local high school students about water quality.

Write down your goal. The more specific your project's goal, the easier it will be to design a QAPP. Identify the objectives for your project—that is, the specific statements of how you will achieve your goal. For

example, if your project's goal is to monitor an SAV restoration project, your objectives might be to collect three years of data on SAV beds, turbidity, algae, and nutrients, and to develop yearly reports for state water quality and fish and wildlife agencies.

Each use of volunteer data has potentially different requirements. Knowing the use of the collected data will help you determine the right kind of data to collect and the level of effort necessary to collect, analyze, store, and report the data.

While sophisticated analyses generally yield more accurate and precise data, they are also more costly and time consuming. One should closely examine the program budget when forming the data quality objectives. Decisions regarding the ultimate objectives must always strike a balance between the needs of the data users and the fiscal constraints of the program (Figure 5-2). If the program's main goal is to supplement state-collected data, for example, the extra expense may be worthwhile. Programs with an educational or participatory focus can often use less sensitive equipment, analyses, or methodologies and still meet their data objectives.

Step 3: *Collect Background Information*

As you learn more about the area you are choosing to monitor, you will be better able to design an effective monitoring project. Begin by contacting programs and agencies that might already monitor in your area. Talk to the state water quality agency, the county and/or city environmental office, local universities, and neighboring volunteer monitoring programs. Ask about their sampling locations, the parameters they monitor, and the methods they use.

If those groups are already monitoring in your chosen area, find out if they will share their data, and identify what gaps exist that your project could fill. If no monitoring is ongoing, find out what kind of data your local or state agencies could use (if one of your goals is that these agencies use your data), where they would prefer you to locate your sampling sites, and what monitoring methods they recommend. **Government agencies are not likely to use your data unless it fills a gap in their monitoring network and was collected using approved protocols.**

A watershed survey can help you set the foundation for your monitoring project design. This is simply a practical investigation of how the watershed works, its history, and its stressors. For information on conducting a watershed survey, consult the USEPA (1997) and Maine DEP (1996) references listed at the end of this chapter.

Step 4: *Refine Your Project*

Once you have collected background information for your project and coordinated with potential data users, you may find it necessary to refine your original goals and objectives. You might have found, for example, that your state already monitors SAV and algae in your estuary. In that case, your project might better examine nutrient inputs from tributaries or other parameters.

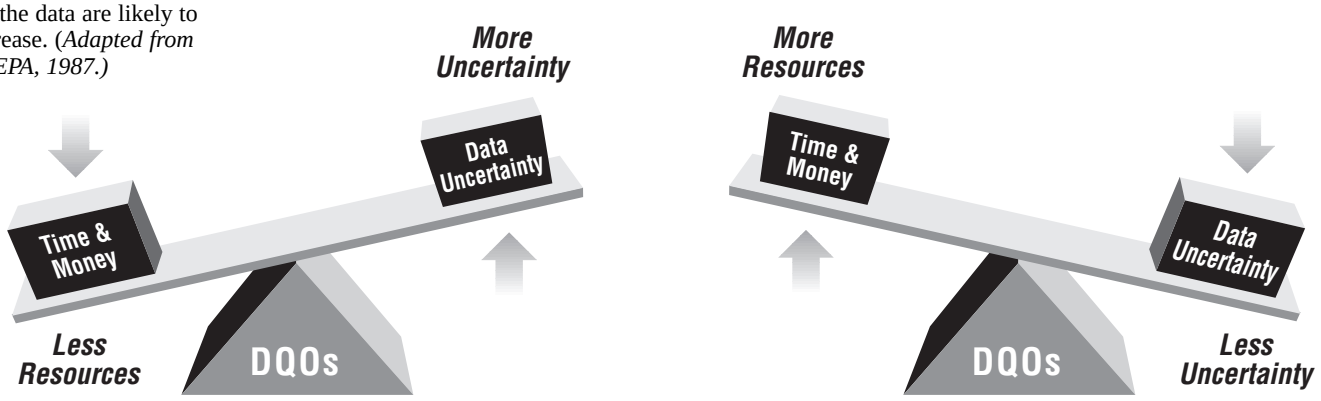


Figure 5-2. The balancing act of data quality objectives. Volunteer programs must balance data quality needs with financial limitations, understanding that as data quality becomes more important, the resources necessary to get the data are likely to increase. (*Adapted from USEPA, 1987.)*

Don't hesitate to reevaluate your project goals and objectives. Now is the best possible time to do so-*before* you invest time, money, and effort in equipment purchases, training, grant proposals, and QAPP development.

Step 5: *Design Your Project's Sampling, Analytical, and Data Requirements*

Once you feel comfortable with your project's goals and objectives and have gathered as much background information as possible on the area you will be monitoring, it is time to focus on the details of your project. Convene a planning committee consisting of the project coordinator, key volunteers, scientific advisors, and data users, along with your QAPP team. This committee should address the following questions:

- What parameters or conditions will you monitor, and which are most important to your needs? Which are of secondary importance?
- How good does your monitoring data need to be?
- How will you pick your sampling sites, and how will you identify them over time?
- What methods or protocols will you use for sampling and analyzing samples?
- When will you conduct the monitoring?
- How will you manage your data and ensure that your data are credible?

As a general rule, it is a good idea to start small and build to a more ambitious project as your volunteers and staff grow more experienced.

Step 6: *Develop an Implementation Plan*

Decide the particulars—the who's and when's of your project. Determine who will carry out the individual tasks such as volunteer training, data management, report generation, assuring lab and field quality assurance, and recruiting volunteers. If you send your samples to an outside lab, choose the lab and specify why you chose it.

Set up schedules for when you will recruit and train volunteers, conduct sampling and lab work, produce reports, and report back to volunteers or the community.

Step 7: *Draft Your Standard Operating Procedures and QAPP*

Now is the time to actually write your standard operating procedures (SOPs) and develop a draft QAPP. SOPs are the details on all the methods you expect your volunteers to

A Word About Metadata

The term **metadata** is loosely defined as "data about data." It is information that helps characterize the data that volunteers collect. Metadata answer who, what, when, where, why, and how about every facet of the data being documented (USGS Web site). This information will help others understand exactly how the data was obtained.

Most shared datasets require metadata. This helps users of the data—who may be unfamiliar with the monitoring site—understand the details behind the data.

Examples of metadata include *(from Williams, 1999):*

- name of organization;
- name of the estuary;
- monitoring station identification number;
- monitoring site location;
- site elevation;
- latitude, longitude;
- source describing how latitude and longitude were determined; and
- date and time of collection.

Volunteer leaders—especially those who want to share their data with government and other organizations—should include metadata on their field data sheets and emphasize the importance to volunteers of recording this information.

use. They can serve as the project handbook you give your volunteers. There are many SOPs already available for sampling and analytical procedures—check with your state water quality agency or other volunteer monitoring groups for pointers. Where possible, adapt your procedures from existing methods and modify them as needed to fit your project objectives. Be sure to reference and cite any existing methods and documents that you use in your project.

You should append your SOPs to your QAPP and refer to them throughout the QAPP document. Your written plan can be elaborate or simple, depending on your project goals.

Step 8: *Solicit Feedback on Your Draft SOPs and QAPP*

Your next step is to get the draft reviewed by people "in the know." These include state and EPA regional volunteer monitoring coordinators and quality assurance officers and any other potential data users. Ask for feedback and suggestions from as many sources as possible. Expect their reviews to take up to two or three months (times will vary). In addition, expect some resistance from some reviewers who might be overburdened with other duties. Don't be offended by this; instead, call back a reasonable time after submitting your plan and inquire if you should submit the draft elsewhere for review.

While waiting for comments, you should try out your procedures with volunteers on a trial basis. Don't plan to use the data at this early stage; data users generally will not accept your data until the QAPP has been approved and accepted. Rather, use this opportunity to find quirks in your plan.

Step 9: *Revise Your QAPP and Submit It for Final Approval*

Based on the comments you receive, you may have to revise your QAPP. This could involve simply being more specific about existing methods and quality control procedures in the plan, or actually modifying your procedures to meet agency requirements.

Once you have revised or fine-tuned your QAPP, submit it to the proper agency for formal approval. If you are developing a QAPP simply to document your methods and are not working in cooperation with a state, local, or federal agency, you do not need to submit a QAPP for review and approval.

Step 10: *Begin Your Monitoring Project*

Once you've received formal approval of your QAPP, your monitoring project can begin. Follow the procedures described in your QAPP to train volunteers and staff, conduct sampling, analyze samples, compile results, and develop any reports.

Step 11: *Evaluate and Refine Your Project over Time*

As time goes on, you may decide to improve on sampling techniques, site selection, lab procedures, or any of the other elements of your monitoring project design. Project evaluation should occur *during* the course of your project rather than after the project or a sampling season is completed.

If you make any substantive changes to your QAPP, document them and, if necessary, seek approval from the appropriate agency. A phone call to your quality assurance official can help you determine if the changes require a new QAPP. Also, always be prepared for formal audits or QC inquiries from data users during the course of your project.

Ongoing experience may require small changes to the QAPP. These can be made without having to rewrite the entire plan, as long as the original reviewers approve the changes. One helpful way to make changes without rewriting the entire plan is to have the pages individually dated; changes to the document can then be made on a page-by-page basis. ■

Elements of a QAPP

A QAPP helps your group determine responsibilities, training, methods, equipment and other resources needed to ensure that data quality is good enough to meet its intended use. This section discusses the 24 elements of a QAPP (Table 5-8), which can guide the QAPP team as it determines whether all necessary aspects are covered.

It is very likely that not all elements will apply to your project, and other elements may be required that are not addressed here. These issues should be discussed with your QAPP team and any group who will be approving your QAPP. If EPA must approve your QAPP and your project does not require all 24 elements, you should indicate in your QAPP which elements you will not be including. This will make review and approval of your QAPP faster and easier.

Readers should refer to the document, *The Volunteer Monitor's Guide to Quality Assurance Project Plans* (USEPA, 1996—see "References and Further Reading" in this chapter) for useful examples of developing a QAPP. The document also includes a sample QAPP form.

Table 5-8. Elements of a QAPP *(USEPA, 1996).*

Project Management	**(elements 1-9)**
1. Title and Approval Page	
2. Table of Contents	
3. Distribution List	
4. Project/Task Organization	
5. Problem Identification/Background	
6. Project/Task Description	
7. Data Quality Objectives for Measurement Data	
8. Training Requirements/Certification	
9. Documentation and Records	
Measurement/Data Acquisition	**(elements 10-19)**
10. Sampling Process Design	
11. Sampling Methods Requirements	
12. Sample Handling and Custody Requirements	
13. Analytical Methods Requirements	
14. Quality Control Requirements	
15. Instrument/Equipment Testing, Inspection, and Maintenance Requirements	
16. Instrument Calibration and Frequency	
17. Inspection/Acceptance Requirements for Supplies	
18. Data Acquisition Requirements	
19. Data Management	
Assessment and Oversight	**(elements 20-21)**
20. Assessments and Response Actions	
21. Reports	
Data Validation and Usability	**(elements 22-24)**
22. Data Review, Validation, and Verification Requirements	
23. Validation and Verification Methods	
24. Reconciliation with Data Quality Objectives	

Element 1: *Title and Approval Page*

Your title page should include the following:

- title and date of the QAPP;
- names of the organizations involved in the project; and
- names, titles, signatures, and document signature dates of all appropriate approving officials, such as project manager, project QA officer, and if the project is funded by EPA, the EPA project manager and QA officer.

Element 2: *Table of Contents*

A table of contents should include section headings with appropriate page numbers and a list of figures and tables.

Element 3: *Distribution List*

List the individuals and organizations that will receive a copy of your approved QAPP and any subsequent revisions. Include representatives of all groups involved in your monitoring effort.

Element 4: *Project/Task Organization*

Identify all key personnel and organizations that are involved in your program, including data users. List their specific roles and responsibilities. In many monitoring projects, one individual may have several responsibilities. An organizational chart is a good way to graphically display the roles of key players.

Element 5: *Problem Identification/ Background*

In a narrative, briefly state the problem your monitoring project is designed to address. Include any background information such as previous studies that indicate why this project is needed. Identify how your data will be used and who will use it.

Element 6: *Project/Task Description*

In general terms, describe the work your volunteers will perform and where it will take place. Identify what kinds of samples will be taken, what kinds of conditions they will measure, which ones are critical, and which are of secondary importance. Indicate how you will evaluate your results—that is, how you will be making sense out of what you find. For example, you may be comparing your water quality readings to state or EPA standards, or comparing your submerged aquatic vegetation (SAV) evaluations to state-established reference conditions or historical information.

Include an overall project timetable that outlines beginning and ending dates for the entire project as well as for specific activities within the project. The timetable should include information about sampling frequency, lab schedules, and reporting cycles.

Element 7: *Data Quality Objectives for Measurement Data*

Data Quality Objectives (DQOs) are the quantitative and qualitative terms used to describe how good your data must be to meet the project's objectives. DQOs for water quality variables should address precision, accuracy, representativeness, completeness, comparability, and sensitivity (see "Basic Concepts" in this chapter for a discussion of these terms).

If possible, provide information on DQOs in quantitative terms. Since it is important to develop a QAPP prior to monitoring, it may not be possible to include actual numbers for some of the water quality measurement variables within the first version of the document. You will need, however, to discuss your goals or objectives for data quality and the methods you will use to make actual determinations after monitoring has begun. DQOs should be given for each parameter you are measuring and in each "matrix" (i.e., substance you are sampling from, such as

Table 5-9. Sample Data Quality Objectives (DQOs) for a volunteer estuary monitoring program. *(Adapted from USEPA, 1990 and USEPA, 1996.)*

Parameter	Method/Range	Units	Sensitivity	Precision	Accuracy
Temperature	thermometer -5.0° to 45°C	°C	0.5°C	±1.0°C	±0.2°C
pH	wide-range colorimetric field kit 3.0 to 10.0 units	standard pH units	0.5 units	±0.6 units	±0.4 units
Salinity	hydrometer	parts per thousand (ppt)	0.1 ppt	±1.0 ppt	±0.82 ppt
Dissolved Oxygen	Winkler titration 1 to 20 mg/l	mg/l	0.2 mg/l	±0.9 mg/l	±0.3 mg/l
Limit of Visibility	Secchi disk	meters	0.05m	NA	NA

water or sediment). A table is the easiest way to present quantitative DQOs (see Table 5-9).

In some types of monitoring, particularly macroinvertebrate monitoring and habitat assessment, some data quality indicators cannot be quantitatively expressed. In that case, you can fulfill this requirement of the QAPP by citing and describing the method used and by providing as many of the data quality indicators as possible (e.g., completeness, representativeness, and comparability) in narrative form.

DQOs should be set realistically. The volunteer program should closely examine its budget when forming its DQOs. Decisions regarding the ultimate objectives must always strike a balance between the needs of data users and the fiscal restraints of the program (Figure 5-2).

Element 8: *Training Requirements/ Certification*

Identify any specialized training or certification requirements your volunteers will need to successfully complete their tasks. Discuss how you will provide such training, who will conduct the training, and how you will evaluate volunteer performance.

Element 9: *Documentation and Records*

Identify the field and laboratory information and records you need for the project. These records may include raw data, QC checks, field data sheets, laboratory forms, and voucher collections. Include information on where and for how long records will be maintained. Copies of all forms to be used in the project should be attached to the QAPP.

Element 10: *Sampling Process Design*

Outline the experimental design of the project including information on types of samples required, sampling frequency, sampling period (e.g., season), and how you will select sample sites and identify them over time. (A discussion on how to select monitoring sites can be found in Chapter 6.) Indicate whether any constraints such as weather, seasonal variations, or site access might affect scheduled activities and how you will handle those constraints. Include site safety plans. In place of extensive discussion, you may cite the sections of your program's SOPs that detail the sampling design of the project.

Element 11: *Sampling Methods Requirements*

Describe your sampling methods. Include information on parameters to be sampled, how samples will be taken, equipment and containers used, sample preservation methods, and holding times (time between taking samples and analyzing them). If samples are composited (i.e., mixed), describe how this will be done. Describe procedures for decontamination and equipment cleaning. Most of this information can be presented in a table or you may also cite any SOPs that contain this information.

Element 12: *Sample Handling and Custody Requirements*

Sample handling procedures apply to projects that bring samples from the field or monitoring site to the lab for analysis, identification, or storage. These samples should be properly labeled in the field. At a minimum, the sample identification label should include sample location, sample number, date and time of collection, sample type, sampler's name, and method used to preserve the sample.

Describe the procedures used to keep track of samples that will be delivered or shipped to a laboratory for analysis. Include any chain-of-custody forms and written procedures that field crews and lab personnel should follow when collecting, transferring, storing, analyzing, and disposing of samples and associated waste materials.

Element 13: *Analytical Methods Requirements*

List the methods and equipment needed for the analysis of each parameter, either in the field or in the lab. If your program uses standard methods, cite these (see, for example, APHA, 1998). If your program's methods differ from the standard or are not readily available in a standard reference, describe the analytical methods or cite and attach the program's SOPs.

Element 14: *Quality Control Requirements*

List the number and types of field and laboratory quality control samples your volunteers will take (see "Quality Control and Assessment" earlier in this chapter). This information can be presented in a table. If you use an outside laboratory, cite or attach the lab's QA/QC plan.

What Is a Performance Based Measurement System (PBMS)?

Volunteer monitors may hear increased discussion about a fundamentally different approach to environmental monitoring, known as a "performance based measurement system," or PBMS. Rather than requiring that a prescribed analytical method be used for a particular measurement, PBMS permits any method to be used provided that it demonstrates an ability to meet required performance standards. In other words, PBMS conveys "what" needs to be accomplished, but not prescriptively "how" to do it.

Under PBMS, the U.S. Environmental Protection Agency (EPA) would specify:

- questions to be answered by monitoring;
- decisions to be supported by the data;
- the level of uncertainty acceptable for making decisions; and
- documentation to be generated to support this approach.

EPA believes that this approach will be more flexible and cost-effective for monitoring organizations. Volunteer groups should check with their data users (e.g., state water quality agencies) to determine acceptable performance based methods.

QC checks for biological monitoring programs can be described in narrative form, and, if appropriate, should discuss replicate sample collection, cross checks by different field crews, periodic sorting checks of lab samples, and maintenance of voucher and reference collections. Describe what actions you will take if the QC samples reveal a sampling or analytical problem.

Element 15: *Instrument/Equipment Testing, Inspection, and Maintenance Requirements*

Describe your plan for routine inspection and preventive maintenance of field and lab equipment facilities. Identify what equipment will be routinely inspected, and what spare parts and replacement equipment will be on hand to keep field and lab operations running smoothly. Include an equipment maintenance schedule, if appropriate.

Element 16: *Instrument Calibration and Frequency*

Identify how you will calibrate sampling and analytical instruments. Include information on how frequently instruments will be calibrated, and the types of standards or certified equipment that will be used to calibrate sampling instruments. Indicate how you will maintain calibration records and ensure that records can be traced to each instrument. Instrument calibration procedures for biological monitoring programs should include routine steps that ensure equipment is clean and in good working order.

Element 17: *Inspection and Acceptance Requirements for Supplies*

Describe how you determine if supplies, such as sample bottles, nets, and reagents, are adequate for your program's needs.

Element 18: *Data Acquisition Requirements*

Identify any types of data your project uses that are not obtained through your monitoring exercises. Examples of these types of data include historical information, information from topographical maps or aerial photos, or reports from other monitoring groups. Discuss any limits on the use of this data resulting from uncertainty about its quality.

Element 19: *Data Management*

Trace the path of your data, from field collection and lab analysis to data storage and use. Discuss how you check for accuracy and completeness of field and lab forms, and how you minimize and correct errors in calculations, data entry to forms and databases, and report writing. Provide examples of forms and checklists. Identify the computer hardware and software you use to manage your data.

Element 20: *Assessments and Response Actions*

Discuss how you evaluate field, lab, and data management activities, organizations (such as contract labs), and individuals in the course of your project. These can include evaluations of volunteer performance (e.g., through field visits by staff or in laboratory refresher sessions); audits of systems (e.g., equipment and analytical procedures); and audits of data quality (e.g., comparing actual data results with project quality objectives).

Include information on how your project will correct any problems identified through these assessments. Corrective actions might include calibrating equipment more frequently, increasing the number of regularly scheduled training sessions, or rescheduling field or lab activities.

Element 21: *Reports*

Identify the frequency, content, and distribution of reports to data users, sponsors, and partnership organizations that detail project status, results of internal assessments and audits, and how QA problems have been resolved.

Element 22: *Data Review, Validation, and Verification Requirements*

State how you review data and make decisions about accepting, rejecting, or qualifying the data. All that is needed here is a brief statement of what will be done and by whom.

Element 23: *Validation and Verification Methods*

Describe the procedures you use to validate and verify data. This can include, for example, comparing computer entries to field data sheets; looking for data gaps; analyzing quality control data such as chain of custody information, spikes, and equipment calibrations; checking calculations; examining raw data for outliers or nonsensical readings; and reviewing graphs, tables, and charts. Include a description of how detected errors will be corrected and how results will be conveyed to data users.

Element 24: *Reconciliation with Data Quality Objectives*

Once the data results are compiled, describe the process for determining whether the data meet project objectives. This should include calculating and comparing the project's actual data quality indicators (precision, accuracy, completeness, representativeness, and comparability) to those you specified at the start of the project and describing what will be done if they are not the same. Actions might include discarding data, setting limits on the use of the data, or revising the project's data quality objectives. ■

References and Further Reading

Much of this chapter was excerpted and adapted from:

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: http://www.epa.gov/OWOW/monitoring/volunteer/qappcovr.htm

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Other references:

Alliance for the Chesapeake Bay. 1987. Quality Assurance *Project Plan for the Citizen Monitoring Project*. Chesapeake Bay Citizen Monitoring Program. Baltimore, MD. 94 pp.

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.

Ely, E. (ed.) 1992. *The Volunteer Monitor*. "Special Topic: Building Credibility." 4(2). 24 pp.

Maine Department of Environmental Protection (DEP). 1996. *A Citizen's Guide to Coastal Watershed Surveys.* 78 pp.

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

U.S. Environmental Protection Agency (USEPA). 1987. Data Quality Objectives Workshop, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1988. *Guide for the Preparation of Quality Assurance Project Plans for the National Estuary Program.* EPA 556/2-88-001. Washington, DC. 31 pp.

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.

U.S. Environmental Protection Agency (USEPA). 1995. *Bibliography of Methods for Marine and Estuarine Monitoring.* EPA 842-B-95-002. April. Office of Water, Washington, DC.

Williams, K. F. 1999. "Quality Assurance Procedures." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future.* Astoria, OR: May 19-21, 1999.

Web sites:

Metadata Information:

Federal Geographic Data Committee: http://www.fgdc.gov/metadata/

U.S. Geological Survey: http://geology.usgs.gov/tools/metadata/tools/doc/faq.html#1.1

Chapter 6

Sampling Considerations

In the very early stages of developing any volunteer estuary monitoring program, four important decisions must be made: what environmental parameters to monitor, how the parameters will be measured, where monitoring sites will be located, and when monitoring will occur.

Photos (l to r): Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab, K. Register, R. Ohrel, R. Ohrel

Overview

In the very early stages of developing any volunteer estuary monitoring program, four important decisions must be made. Program leaders, with input from their volunteers, must decide what environmental parameters they will monitor, how the parameters will be measured, where monitoring sites will be located, and when monitoring will occur.

This chapter discusses some considerations that should be taken into account when making these decisions.

Four Critical Questions

Many field test kits require the monitor to compare the colors of a prepared water sample with a standard (photo by K. Register).

Previous chapters laid the groundwork for developing and operating a volunteer estuary monitoring program. Discussions focused on the need for volunteer programs to understand why it is necessary to collect data, how the data will be used, and who will use it. Involving potential data users in program development is essential.

There are many additional components to the development of an overall monitoring program and its quality assurance project plan (QAPP). Most revolve around four fundamental questions:

- What parameters will the volunteer program monitor?
- How will the selected parameters be monitored?
- Where will monitoring sites be located?
- When will monitoring occur?

While the questions may seem basic enough, they can hardly be overlooked or brushed aside. Clear and concise answers to these simple yet focused questions will form the backbone of your monitoring program, providing the foundation upon which the program will rest.

Over time, it will be valuable to reevaluate your answers to ensure that the goals and objectives of the program are still being met. Such evaluations may reveal a need for program adjustments.

What to Monitor? Selecting Sampling Parameters

What aspects of the estuary should your volunteer program monitor? There are many options from which to choose, but ultimately the parameters should be selected to help characterize the health of your estuary. By assessing the problems—and potential problems—facing the estuary, it should become clear which parameters will be most important to monitor. Of course, the costs (time and money) associated with monitoring will factor into your decision.

There are several common water quality parameters that volunteer programs measure (see Ely and Hamingson, 1998). These include:

- water temperature;
- turbidity or transparency;
- dissolved oxygen;
- pH;
- salinity; and
- nutrients.

As techniques are mastered and monitoring skills improve, many volunteer groups go on to include additional parameters to their monitoring repertoire, including:

- fecal coliform and other indicator bacteria;
- chlorophyll;
- sulfates;
- pesticides;
- metals;
- changes in water color following storm events;
- effects of erosion and sediment control measures;
- habitat conditions and availability;
- macroinvertebrates;
- condition and abundance of fish and birds; and
- phytoplankton, submerged aquatic vegetation (SAV) and shoreline plants.

Helpful Hint

When deciding what water quality variables to monitor, consider the needs of your data users. They can help you select the variables that most effectively detect potential problems in the estuary. In addition to your data users, also consult with the following:

- *state, federal, and regional environmental quality agencies;*
- *municipal governments;*
- *county planning offices;*
- *wastewater treatment plants;*
- *local nonprofit environmental groups;*
- *university and college environmental departments (e.g., environmental science, oceanography, civil engineering, hydrology, biology); and*
- *middle and high school teachers.*

How to Monitor? Selecting Monitoring Methods and Equipment

An important question for any monitoring program concerns monitoring methods and equipment. As you will see in later chapters, there are usually two or more ways to monitor any water quality parameter.

Your selection of methods and equipment will be based partly on data accuracy requirements and cost. For a state water quality agency to accept volunteer-generated data, for example, the data must be collected using state-approved methods and equipment. If the purpose of the monitoring is to "screen" for potential problems, you may purchase less expensive and perhaps less accurate or precise equipment.

Electronic meters (powered by batteries) are available to measure many different water quality parameters, including pH, dissolved oxygen, conductivity, salinity, temperature, total dissolved solids, and biochemical oxygen demand. Many meters will test for two or more of these parameters. Meters can provide quick and accurate data, but they require frequent calibration and regular maintenance to ensure proper functioning. They can also be expensive, ranging from $300 to $5000, depending on the number of functions, accuracy, range, and resolution of the instrument. Nevertheless, meters may prove cost-effective, especially when a large number of samples need to be analyzed.

Field test kits measure many of the same water quality parameters as meters and tend to be much less expensive, but pollutant detection levels can be unacceptable to some data users. Again, part of the decision to use meters or field kits will depend on the quality of data that your program is trying to achieve. In some states, the data from volunteers using field kits will be accepted, while in other states, the data will be considered valuable only as a "screen" for potential problems.

Some Tips on Kits

Suppose you intend to use inexpensive field kits that rely on a visual color comparison using a "color wheel" or "color comparator." How would you go about shopping for the most suitable kits? Here are a few suggestions:

- Look for reagents that produce a blue or green color; the human eye is better at perceiving the density of blue or green.
- Look for less toxic reagents (e.g., salicylate versus Nessler for ammonia, zinc rather than cadmium for nitrate).
- Look for kits that report the lowest possible concentration range, relying on the option of diluting the sample if the concentration is too high (make sure you have the equipment for making dilutions—a small syringe without needle, distilled water, and a dedicated jar).
- Look for reagents in liquid form rather than powder—it is often tedious to wrestle with powder packets, especially with wind that may blow and scatter the powder.

(Excerpted and adapted from Katznelson, 1997.)

Where to Sample? Selecting Monitoring Locations

Volunteer program leaders must determine the geographic location where monitoring efforts will provide the most useful information. After monitoring sites are selected, a decision must be made about where in the water column volunteers will collect their samples.

Picking Monitoring Sites

Selecting representative sampling sites is one of the most important elements in setting up a monitoring effort. In any type of water quality monitoring, basic information about the area of interest is essential for the program manager to consider before selecting monitoring sites. Several things to consider are listed in the box below.

Considerations for Selecting Monitoring Sites

Background Information

- Obtain a map of the watershed with all areas that drain into the estuary identified and a bathymetric map of the estuary showing depth information.
- Gather reports and/or data that supply general information on the estuary.
- Check with your state water quality agency and other monitoring groups to learn their monitoring site locations. Monitoring at the same sites monitored by other groups can help provide trend data; monitoring different sites can improve coverage of the entire estuary.
- Collect information on adjoining estuaries if there are plans to conduct data comparisons.
- Compile data on current and past activities in the basin that could affect pollutant levels (e.g., locations of wastewater treatment plants, areas of urban or agricultural runoff, new development sites).
- Investigate sites in areas of known or suspected pollution.

Decision-Making

- Determine whether there is a real need for data to be collected from the area, thereby ensuring the immediate use of data collected.
- Consider whether you have a sufficient pool of volunteers to monitor the site in the manner and time required.
- Consider sites where there may be little or no data (e.g., areas near land targeted to be developed) to establish baseline conditions.
- Consider how long data will need to be collected at the site in order to be useful. For example, several years of data collection may be necessary to make justifiable conclusions about water quality trends.

Verification

- Confirm that you will have safe, physical, and legal access to the site(s).
- If the monitoring effort requires the collection of water samples, verify that the site is underwater at all times, including low tide.
- Ensure that sampling sites are representative of the estuary and its watershed, if your goal is to assess overall estuary health (e.g., a site immediately downstream of a bridge is not likely to be representative of overall estuary conditions).
- Confirm that volunteers can precisely relocate the site.

(Adapted from USEPA, 1990, and Stancioff, 1996.)

Site location will depend a great deal on the purpose of data collection. If, for example, the program is attempting to pinpoint trouble spots in the estuary, the manager should cluster monitoring sites where point and nonpoint pollution sources enter the water. To help ensure the data's scientific validity, volunteers should monitor sample locations both upstream and downstream from the pollutant inflow point, as well as at the point of entry, to provide comparative data.

Some programs may wish to obtain baseline data that, over several years, will reveal water quality trends. Rather than concentrating on a few critical sites, this type of program should choose a sufficient number of sites scattered throughout the estuary or in the area of interest that will paint a representative picture of water quality status over time.

Deciding Where to Sample in the Water Column

Monitors must consider that water quality parameters are always changing. At any given time, conditions at the surface may not be the same as those at the bottom. For most citizen monitoring programs and most water quality parameters, however, samples taken from the estuary's surface will suffice. These samples will provide a reasonably accurate indication of water quality in the vicinity of the sampling site. For more sophisticated studies in which water quality parameters throughout the water column are of interest, volunteers may need to collect samples using a standard water sampler at precise depths.

The stratification of the estuary may also influence where samples are taken in the water column. For instance, a well-stratified estuary may require surface, intermediate, and bottom water samples or a complete profile to fully characterize the status of different water quality variables in its waters. A reasonably well-mixed estuary, however, or one in which the monitoring sites are located only in shallow waters (where stratification often breaks down) may require only a single surface sample at each site.

While tidal range (the difference between high and low tides) is negligible in some estuaries, programs studying areas with large swings in tides will have to consider this effect. Tides strong enough to cause mixing may weaken the stratification in the estuary. This effect is particularly apparent during spring tides (the highest tides of the month). By mixing the upper and lower layers, for example, the tides allow nutrients trapped in bottom waters to mix upward and oxygen from the surface to move down.

When to Sample? Selecting the Right Time

The timing of most sampling efforts will depend largely on the goals of the monitoring program, accessibility of the site, weather, number of monitors, and the water quality variables to be measured. The time of day and season can significantly affect your results. In addition, the maximum holding time for each sample and the sampling frequency necessary to get the right information can influence when samples will need to be collected (Dates, 1992).

Time of Day

Sampling results can fluctuate dramatically, depending on the time of day that samples are collected. For example, during the day aquatic plants utilize sunlight for photosynthesis, releasing oxygen as a byproduct. At night, the plants respire, consuming oxygen. As a result, dissolved oxygen levels can rise and fall significantly, especially in areas with dense aquatic vegetation. Under these circumstances, oxygen concentrations are lowest at sunrise and highest in the afternoon.

The time of day will also influence where many organisms will be found in the water column. Zooplankton, for example, migrate from deeper water to the surface at night to feed, while many fish species travel daily throughout the water column in search of food.

The time of day has other impacts on monitoring. A common tool for measuring

water clarity is the Secchi disk. One condition for its optimal use is that the disk be used when the sun is directly overhead. (The disk can be used at other times during the day, but this would result in less than optimal results; see Chapter 15). To comply with this condition means that there is a small window of opportunity for which monitoring conditions are ideal.

Because of these daily considerations, it is often helpful to select consistent sampling times for many water quality parameters. However, ideal sampling times may also depend on tides, which could expose nothing but mud where there had been water only a few hours earlier. Tidal stages vary from day to day.

Time of Year

Environmental conditions change with the seasons, and monitoring results can reflect those variations. For example, nutrient and pesticide concentrations in estuaries vary considerably from season to season. More runoff enters the estuary during wet weather periods, delivering pollutants and fresh water. Consequently, pollution concentrations can be higher and salinity lower at these times. When runoff occurs, higher estuarine concentrations correspond to times of the year when fertilizers and pesticides are most commonly applied on land (USGS, 1999).

On the other hand, dry weather periods mean less runoff to the estuary. Higher salinity and lower pollutant levels may mark such dry periods. The same observation may be made in colder climates during the winter, when snow remains on land and the spring thaw is months away.

The seasons have a profound influence on several other water quality measures, particularly dissolved oxygen. For example:

- cold water retains dissolved oxygen better than warmer water;
- increased plant activity in the warmer months has a strong influence on daily oxygen concentrations;
- vertical temperature gradients in the estuary—usually greater during the summer months—hinder oxygen diffusion; and
- seasonal storms help mix estuarine waters.

Seasonal sampling may also be influenced by program objectives. If your program is interested in determining whether the estuary is safe for swimming, for example, it is best to sample when people are most likely to be in the water. For this purpose, it is unnecessary in most places to sample during the winter.

Finally, there is the practicality issue. Seasons may influence the level of volunteer participation. Will enough volunteers be willing to go out in freezing weather or under a scorching sun to collect samples?

Holding Time

Consider the maximum duration that a sample can be held before it is tested. Many bacteria samples must be chilled and sent to a laboratory for testing within six hours. Because of the stringent holding time requirements, sampling during weekends and evenings—when most laboratories are closed—may not be a good idea for some water quality measures.

Frequency

Like most issues of timing, sampling frequency usually depends on the goals of the monitoring effort. For example, if you are monitoring to detect pollution from point sources, very frequent sampling—daily or even hourly—is usually necessary. On the other hand, some biological parameters, which indicate estuarine conditions over long periods of time, need to be sampled only a couple of times each year (usually the spring and fall).

Sampling frequency may also be determined based on atmospheric or other events. It is often useful to have volunteers

available to collect data during or after large storms as long as the program manager deems it safe to sample. Such data is often invaluable to state managers who may be unable to mobilize forces quickly enough to capture such events. Storm data gives a snapshot of how severe wind and precipitation affect the status of water quality variables in the water. The occurrence of extraordinary events, such as fish kills or "crab jubilees" (phenomena characterized by crabs crawling onto the land because of low oxygen concentrations in the water), can also trigger additional monitoring efforts to determine the cause of the events. ■

References and Further Reading

Dates, G. 1992. "Study Design: The Foundation of Credibility." *The Volunteer Monitor* 4(2): 1, 13-15.

Ely, E. and E. Hamingson. 1998. *National Directory of Volunteer Environmental Monitoring Programs.* 5th ed. U.S. Environmental Protection Agency, Office of Wetland, Oceans, and Watersheds. EPA-841-B-98-009. Web site: http://yosemite.epa.gov/water/volmon.nsf.

Stancioff, E. 1996. Clean Water: *A Guide to Water Quality Monitoring for Volunteer Monitors of Coastal Waters.* Maine/New Hampshire Sea Grant Marine Advisory Program and University of Maine Cooperative Extension. Orono, ME. 73 pp.

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.

U.S. Geological Survey (USGS). 1999. *The Quality of Our Nation's Waters—Nutrients and Pesticides*. USGS Circular 1225. 82 pp.

Chapter 7

In the Field

Being in the estuarine environment has great appeal for many volunteers. The key for any program leader is to maintain volunteer interest while ensuring the quality of data. To meet these goals, the program leader must recognize that several elements go into the collection of estuary data. Failure to consider these elements can cause problems for volunteers and program managers.

Photos (l to r): Weeks Bay Watershed Project, U.S. Environmental Protection Agency, E. Ely, K. Register

Overview

Being in the estuarine environment has great appeal for many volunteers. The key for any program leader is to maintain volunteer interest while ensuring the quality of data. To meet these goals, the program leader must recognize that several elements go into the collection of estuary data. Failure to consider these elements can cause problems for volunteers and program managers.

Previous chapters discussed planning a volunteer monitoring program, establishing a quality assurance project plan, and general sampling considerations. This chapter reviews several topics applicable when volunteers travel into the estuary to collect and analyze samples. It includes discussions of safety, supplies and equipment, locating the sampling site, making observations about the site, collecting data, and completing the data collection form.

Fun in the Field

As discussed in Chapter 4, volunteers have different reasons for getting involved with an estuary monitoring program. One common motive is the opportunity to be outside, on the water, helping the estuary. Many volunteers look forward to going, as scientists say, "into the field" to collect and analyze water samples. For them, being in the field is an enjoyable experience.

While being in the field is more often than not an entertaining experience for all involved, volunteer leaders need to be aware of several potential pitfalls. Sampling errors can compromise data quality. Disappointed or angry volunteers can return, after hours of mucking around, with no data because they discovered too late that their equipment was not operating properly. Data interpretation may be hampered because volunteers fail to complete data forms properly. Volunteer injuries, while uncommon, must always be in the back of every leader's mind.

With proper planning and training, the monitoring leader can avoid these problems. A bit of forethought before sending volunteers to monitoring sites can ensure volunteer safety, data quality, and fun in the field. ■

Preliminary Steps for Field Sampling

The following steps generally apply when monitoring most estuary water quality variables. Elaboration on these steps is provided throughout this chapter. These are not the only necessary steps, however. Additional steps should be taken for each water quality parameter. Refer to each respective chapter for details.

STEP 1: *Prepare for the field*

Before proceeding to the monitoring site, the volunteer should confirm sampling date and time, understand safety precautions, check weather conditions and verify directions to the monitoring site.

STEP 2: *Check equipment*

The volunteer should also ensure that all necessary personal gear and sampling equipment are present and in working order. Results may be inaccurate if the volunteer has to improvise because a sampling device or chemical bottle has been left behind.

STEP 3: *Confirm proper sampling location*

The volunteer should have specific directions for locating a sampling site. If unsure whether he or she is in the correct spot, the volunteer should record a detailed description of where the sample was taken so that it can be compared to the intended site later.

STEP 4: *Record preliminary observations and field measurements*

The volunteer should record general field observations and measurements (e.g., potential pollution sources, indicators of pollution, presence and apparent health of wild and domestic animals, water color, debris or oil, algal blooms, air temperature, weather conditions, etc.) once at the site. This information is valuable when it comes time to interpret your results.

Record any condition or situation that seems unusual. Descriptive notes should be as detailed as possible.

Before Leaving Home

Chapter 4 detailed volunteer training, emphasizing safety, proper monitoring techniques, and quality assurance/quality control procedures. No volunteer should begin monitoring until properly trained.

Before heading out to sample for the first time, the volunteer should select a sampling timetable that fits into his or her personal schedule. Adherence to the sampling schedule is ideal, but program managers should recognize that occasionally scheduled sampling days and times will be missed due to weather, illness, holidays, vacations, etc. If possible, a makeup date should be arranged within two days on either side of the original date or a trained backup volunteer should substitute for an unavailable volunteer.

The volunteer should confirm the sampling date and time with the program manager and laboratory (if samples are being sent for lab analysis) each time before going out to collect samples. This is especially true if the samples need to be analyzed in a laboratory within a particular timeframe.

The volunteer, in collaboration with the program manager, should also characterize the collection site with a written description, map, and accompanying photograph. This information serves as an initial status report with which to compare any future changes of the site. Use a global positioning system unit, nautical map, or topographic map to determine the latitude and longitude of the site. Maps and photographs may be available for your area (see Appendix C). ■

Safety Considerations

Safety is one of the most critical considerations for a volunteer monitoring program and can never be overemphasized. All volunteers should be trained in safety procedures and should carry with them a set of safety instructions and the phone number of their program coordinator or team leader.

The following are some basic commonsense safety rules for volunteers:

- Develop a safety plan. Find out the location and telephone number of the nearest telephone and write it down, or have a cellular phone available. Locate the nearest medical center and write down directions for guiding emergency personnel from the center to your site(s). Have each member of the sampling team complete a medical form that includes emergency contacts, insurance information, and relevant health information such as allergies, diabetes, epilepsy, etc.
- Listen to weather reports. Never go sampling if severe weather or high waves are predicted or if a storm occurs while at the site. Training should include information on the appropriate circumstances for both proceeding with and waiving data collection. If volunteers elect to go out in poor conditions, they should be aware of the risks and always take proper safety gear (particularly if proceeding by boat). No one should go out on the water during thunderstorms or high wave conditions.
- Always monitor with at least one partner (teams of three or four are best). Let someone know where you will be, when you plan to return, and what to do if you don't return at the designated time.

- Have a first aid kit handy (see box, page 7-5). Know any important medical health conditions of volunteers (e.g., heart conditions or allergic reactions to bee stings). It is best if at least one team member has current first aid/CPR training.
- Dress properly. In cold weather, bring layered clothing, gloves, and boots. In warm weather, dress to avoid sunburn, insects, jellyfish, and brambles. Always bring goggles and latex gloves (or some alternative gloves for those allergic to latex). Wear hunter's orange during hunting season.
- Bring water and snacks.
- If you drive, park in a safe location. Be sure your car doesn't pose a hazard to other drivers and that you don't block traffic.
- Put your wallet and keys in a safe place, such as a floatable, watertight bag that can be kept in a pouch strapped to your waist.
- Never cross private property without the permission of the landowner. A better option, depending on the project's objectives, might be to sample at public access points (e.g., public parks). Take along a card identifying you as a volunteer monitor.
- Watch for irate dogs, farm animals, and wildlife (particularly snakes, ticks, hornets, and wasps). Know what to do if you get bitten or stung.
- Watch for poison ivy, poison oak, sumac, and other types of vegetation in your area that can cause rashes and irritation.
- Do not walk on unstable riverbanks. Disturbing these banks can accelerate erosion and might prove dangerous if the bank collapses. Do not disturb vegetation on the banks.
- Be very careful when walking in the estuary itself. Rocky-bottom areas can be very slippery and soft-bottom areas may prove treacherous in areas where mud, silt, or sand have accumulated in sinkholes. Your partner(s) should wait on dry land, ready to assist you if you fall. Wear waders and rubber gloves at sites suspected of having significant pollution problems.
- Never wade in swift or high water.
- Confirm that you are at the proper site by checking maps, site descriptions, directions, or a global positioning system.
- Do not monitor if the site is posted as unsafe for body contact. If the water appears to be severely polluted, contact your program coordinator.
- Pay attention to the tidal stage. Don't get trapped by rising or falling tides.
- If you are sampling from a bridge, be wary of passing traffic. Wear bright orange safety vests and hats and set out orange traffic cones. Never lean over bridge rails unless you are firmly anchored to the ground or the bridge with good hand/foot holds.
- Wash your hands with antibacterial soap after monitoring. Eat nothing until you have washed your hands.
- If you are using a boat, ensure that hulls, engines, equipment, and trailers are inspected and in good working order.
- **If at any time you feel uncomfortable about the condition of the monitoring site or your surroundings, immediately stop monitoring and leave the site. Your safety is more important than the data!**

When using chemicals:

- Know your equipment, sampling instructions, and procedures before going out into the field. Prepare labels and clean equipment before you get started.
- Keep the sampling equipment clean before and after each use.
- Keep all equipment and chemicals away from small children and animals. Many of the chemicals used in monitoring are poisonous. Tape the phone number of the local poison control center to your sampling kit.
- Avoid contact between chemical reagents and skin, eye, nose, and mouth. Never use your fingers to stopper a bottle (e.g., when you are shaking a solution). Wear safety goggles and gloves when performing any chemical test or handling preservatives.
- Know how to use and store chemicals. Do not expose chemicals or equipment to temperature extremes or long-term direct sunlight (see "Getting the Most Out of Reagents," page 7-6).
- Any work surface should be kept clean of chemicals and sponged with clean water after the test is complete.
- Know chemical cleanup and disposal procedures. Wipe up all spills when they occur. Return all unused chemicals to your program coordinator for safe disposal. Close all containers tightly after use. Do not put the cap of one reagent onto the bottle of another. Dispose of waste materials and spent chemicals properly (see box, page 7-8).
- When working with bacteria samples, wash your hands between samples and when you are finished with testing. Avoid contact with bacterial colonies after they have been incubated (Stancioff, 1996). ■

First Aid

At a minimum, a first aid kit should contain the following items:

- Telephone numbers of emergency personnel (e.g., police, ambulance service)
- First aid manual which outlines diagnosis and treatment procedures
- Antibacterial or alcohol wipes
- First aid cream or ointment
- Acetaminophen for relieving pain and reducing fever
- Several band-aids
- Several gauze pads 3 or 4 inches square
- 2-inch roll of gauze bandage
- Triangular bandage
- Large compress bandage
- 3-inch wide elastic bandage
- Needle for removing splinters
- Tweezers for removing ticks
- Single-edged razor blade
- Snakebite kit
- Doctor-prescribed antihistamine of participant who is allergic to bee stings

Be sure to carry emergency telephone numbers and medical information for everyone participating in field work (including the leader) in case of emergency.

(Excerpted and adapted from USEPA, 1997.)

Getting the Most Out of Reagents

Most volunteer monitoring programs use chemicals called **reagents** to help analyze water samples. Because the reagents are chemically reactive, they can easily degrade. Test reagents are also very susceptible to contamination under field conditions.

Replacing degraded reagents results in additional expense for the monitoring program. If bad reagents are not discovered in time, their use can also lead to erroneous water quality measurements and disappointed volunteers whose hard work in the field is wasted. It is therefore wise—financially and programmatically—to check reagent quality and extend their useful life whenever possible.

Reagent Enemies

Temperature

In general, the speed of a chemical reaction doubles with every 10°C increase in temperature. Since reagent decomposition occurs by means of chemical reactions, high temperatures will speed decomposition.

Sunlight

Many reagents will decompose when exposed to direct sunlight. Reagents containing silver—commonly found in kits that use a titration method to test chloride or salinity—are especially sensitive to sunlight and will turn black when decomposition occurs due to sunlight exposure. This reagent is supplied in an amber glass, amber plastic, or other opaque plastic container to protect it from sunlight.

Air

Evaporation can concentrate reagents, a condition which is especially critical for a titrant. Many reagents can also react chemically with oxygen or carbon dioxide in the air.

Contamination

Any foreign material introduced into a reagent bottle can cause test results to be in error. Mold or algae can grow in starch reagents. Other common sources of contamination are inadequate cleaning of equipment that is used to analyze more than one sample and failure to use a dedicated dropper for each reagent.

(continued)

(Getting the Most . . .continued)

Recognizing Bad Reagents

One of the easiest ways to tell if a reagent has gone bad is by its appearance. Note the reagent's color when you first receive it. Over time, look for any changes in color or clarity, or for formation of solids (e.g., a crust on the lip of the bottle, floating particles, or solids settled at the bottom).

If you suspect that a reagent has gone bad, you can test it by using a standard (a solution of known pollutant concentration). Standards can be purchased from test kit manufacturers or other chemical companies, or obtained from cooperative laboratories. Most reagents will also have expiration dates printed on their containers.

You can also test your reagents by checking the suspect test kit against another kit that has fresh reagents, or by cross-checking the kit against another method, such as a meter.

Preventing Degradation

There are many steps you can take in the field to get the most use out of reagents:

- Keep reagent bottles inside test kit during storage.
- Store kits away from heat and sunlight (this includes car trunks!).
- Minimize the amount of reagent exposure to heat and sunlight during testing.
- Do not leave reagent containers open any longer than necessary when performing tests.
- Be sure to place sunlight-sensitive reagents in opaque bottles when replacing or refilling them.
- Keep reagent bottles tightly capped.
- Use dedicated droppers and dedicated equipment whenever possible.
- Always bring a container to the field for washing equipment between tests.
- Keep reagents in a refrigerator that is not used to store food.

Of course, check expiration dates and replace reagents before they expire.

(Excerpted from McAninch, 1997.)

Dealing with Waste

Waste Liquids:

Many water quality monitoring kits produce waste liquids that you cannot pour into the estuary. Read the "Material Safety Data Sheet" that comes with your monitoring equipment for specific disposal procedures. Here is one method used to dispose of waste liquids:

- Pour all waste liquids into a separate container, such as a bottle or jug with a screw cap. **Beverage containers should not be used for this purpose, since the contents could be mistaken for a beverage. Containers into which liquid wastes are poured should be clearly labeled with appropriate warnings.** It is usually acceptable to mix the waste from all your field tests, but confirm this by reading the "Material Safety Data Sheet" that comes with the monitoring equipment.
- Take the waste container home (don't dump it outside).
- At home, add kitty litter to the container, cap it tightly, and put it out with the trash.

Some manufacturers' Material Safety Data Sheets will tell monitors to dilute waste liquids and pour them down the drain if the monitors' homes are served by centralized wastewater treatment systems. It is recommended that volunteer leaders contact their local wastewater management agency to get exact instructions. It is important to tell the wastewater management agency the names of each chemical used. Never put the waste liquids down the drain if you have a septic system, and never dispose of mercury from a broken thermometer by pouring it down any drain. Many volunteer programs avoid this potential problem by using alcohol thermometers.

Bacteria Cultures:

After counting the colonies that have grown in petri dishes, two methods to safely destroy the bacteria cultures are:

Autoclave

Place all petri dishes in a container in an autoclave. Heat for 15 to 18 minutes at 121^{o}C and at a pressure of 15 pounds per square inch. Throw away the petri dishes.

Bleach

Disinfection with bleach should be done in a well-ventilated area, since it can react with organic matter to produce toxic and irritating fumes. Pour a 10-25 percent bleach solution into each petri dish. Let the petri dishes stand overnight. Place all petri dishes in a sealed plastic bag and throw away.

What to Bring

Much of the equipment a volunteer will need in the field is easily obtained from either hardware stores or scientific supply houses. Other equipment can be found around the house. In either case, the volunteer program should clearly specify the equipment its volunteers will need and where it should be obtained.

Listed below are some basic supplies appropriate for any volunteer field activity. Much of this equipment is optional but will enhance the volunteers' safety and effectiveness.

Safety and Health Supplies

- rubber gloves to guard against contamination (warning: some people are allergic to latex; ask volunteers if they are allergic);
- eye protection;
- insect repellent;
- sunblock;
- small first aid kit (see box, page 7-5);
- flashlight and extra batteries;
- whistle to summon help in emergencies;
- cellular phone;
- refreshments and drinking water;
- personal identification (e.g., driver's license);
- compass or Global Positioning System receiver; and
- information sheet with safety instructions, site location information, and numbers to call in emergencies (heavily laminated or printed on waterproof "write in rain" paper, if possible).

Clothing

- boots or waders;
- hat;
- foul/cold weather gear;
- extra pair of socks;
- sweater or other warm clothing;
- all-weather footwear; and
- bright-colored snag- and thorn-resistant clothes (long sleeves and pants are best).

Sampling Gear

- sampling equipment—properly calibrated and checked for accuracy—appropriate for the parameter(s) being measured (may include meters, test kits, etc.);
- water sampler (see "How to Collect Samples" in this chapter);
- sample containers;
- sufficient supply of reagents;
- instruction manual(s) for operating sampling equipment;
- field data sheets (printed on waterproof "write in rain" paper, if possible);
- clipboard, preferably with plastic cover;
- several pencils (ink runs when it gets wet; soft pencils will write on damp surfaces);
- black indelible ink pens and markers;
- map or photograph of sampling location(s);
- compass or global positioning system to help find sampling location(s);
- tide chart;
- cooler and ice (blue ice pack preferably);
- tape measure;
- armored thermometer (non-mercury preferred);
- wash bottles with distilled or deionized water for rinsing equipment;
- containers for waste materials (e.g., used reagents);
- camera and film, to document particular conditions;

- extra rope/line;
- duct tape, electrical tape, zip ties, sealable plastic bags, and other items for quick repair and modification of equipment; and
- walking stick of known length for balance, probing, and measuring.

If monitoring from a boat, volunteers should bring the following additional equipment:

- one U.S. Coast Guard-approved personal flotation device for each person aboard (it is recommended that you wear a life jacket at all times);
- equipment required by state and local law (your state boating administration will have a list, which usually includes such items as a fire extinguisher and bell);
- anchor;
- weighted line to measure depth; and
- nautical chart of area.

Helpful Hint

Personal journals kept by volunteers can be valuable supplements to the information recorded on data sheets. Volunteer notes on field observations and sampling activities can give feedback on sampling methods, aid data interpretation, and provide a useful historic record to accompany the data. In addition, their insights can help future volunteers understand specific nuances of their monitoring sites.

The tools, equipment, instruments, and forms that you take into the field will often depend on where you are monitoring, your monitoring techniques, and the parameters you are measuring. Additional equipment needed for specific chemical, physical, and biological monitoring procedures included in this manual are provided in the relevant chapters. ■

Locating Monitoring Sites, or How Do I Get There from Here?

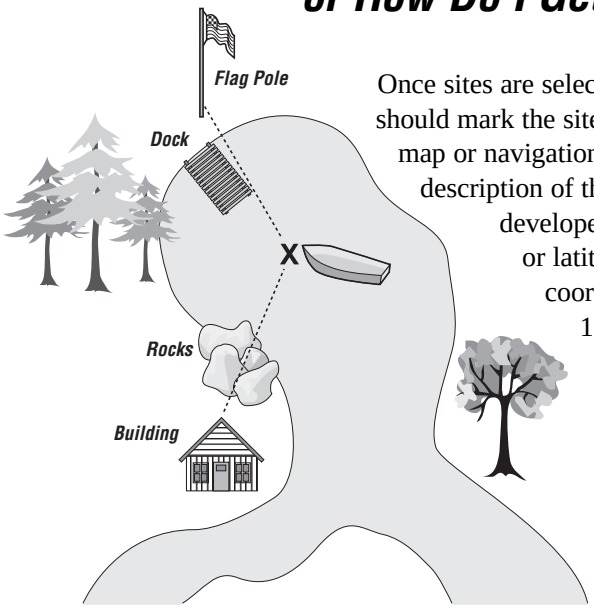


Figure 7-1. The shoreline landmark method.

Once sites are selected, the manager should mark the sites on a topographic map or navigational chart. A written description of the sites should be developed, using landmarks or latitude and longitude coordinates (Stancioff, 1996). Photographs of the sites can also be useful to volunteers.

The manager may also want to create a map showing the location of volunteers' homes if the program relies on citizens sampling from their own dock or pier. This map will illustrate which areas of the estuary still need coverage and where sites may be too tightly clustered.

Returning to the Same Monitoring Sites

Once the program manager and volunteers have chosen monitoring sites, quality control demands that each volunteer sample from exactly the same location each time. If the site is off the end of a dock or pier, returning to the monitoring site is a simple matter. If, however, the volunteer reaches the site by boat, the task becomes more complicated. Some basic methods to ensure that volunteers return to the same site are:

The Shoreline Landmark Method

Landmarks—conspicuous natural or manmade objects—provide a ready means of identifying a specific monitoring site. Once the program manager and volunteer have identified a permanent site, they should anchor the boat and scan the landscape for distinctive features. Such features can include tall or solitary trees, large rocks, water towers, flag poles, or any other highly visible and identifiable object.

Two landmarks, in front-to-back alignment, should be chosen. The sight line created by the landmarks will lead directly back to the site. The volunteer should then pick another set of aligned landmarks onshore about 90 degrees from the sight line of the first set. The two sight or bearing lines should intersect at the boat (Figure 7-1). The volunteer should practice repositioning the boat at this point.

In some cases, volunteers must return to monitoring sites on a coastal pond, sound, or lagoon located in the middle of a salt marsh or in some other rather featureless landscape. If no obvious landmarks are available, volunteers may want to post two sets of brightly colored signal flags (Figure 7-2). They should obtain permission from the landowner before posting the flags.

The Marker Buoy Method

In wind- and wave-protected sections of an estuary, volunteers may want to set buoys to mark the monitoring site (Figure 7-3). The buoy should be brightly colored and easily distinguishable from fishing buoys floating in the area. The program manager should check on local and state regulations regarding buoy placement before using this method.

Although a simple means of marking a site, buoys do not always stay in place; wind, waves, and passersby may move the buoy or remove it entirely. Volunteers should use the shoreline landmark method as a backup to ensure that the buoy is correctly positioned.

Global Positioning System (GPS)

In many cases, the lack of a definitive landmark (e.g., a pier, outfall pipe, or marker buoy) can hinder volunteers from reaching the right sampling location. In addition, monitoring groups using certain data management systems (e.g., Geographic Information Systems; see Chapter 8) may need to report specific geographic locations, often by latitude and longitude. In such cases, reporting a location as "across the street from the firehouse" is unacceptable.

While latitude and longitude can be estimated from a U.S. Geological Survey topographic map, volunteers might still be guessing about their exact position. The most accurate method for determining position is using a Global Positioning System (GPS) receiver. This tool helps to ensure that the volunteer is collecting samples at the same location time after time. As a result, quality control is maintained.

GPS uses a network of satellites to provide users with, among other things, data about their positions on Earth. With relative ease, users can locate their latitude, longitude, and elevation (although elevation is usually less accurate). The volunteer must be sure to minimize the blocking of satellite transmissions by holding the receiver away from the body. Buildings or trees can also cause interference.

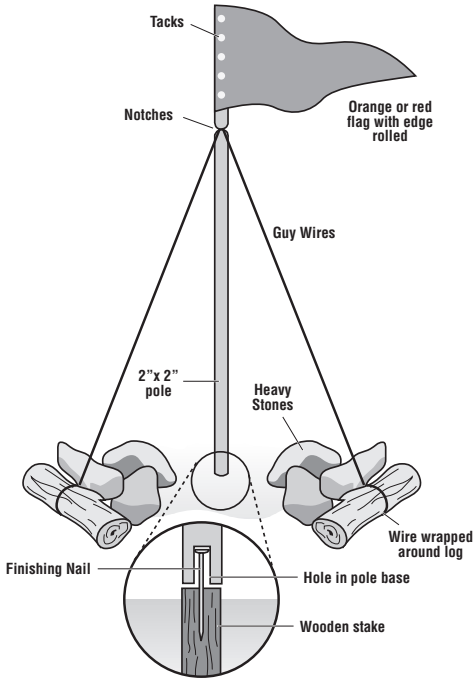


Figure 7-2. Construction of a landmark flag *(adapted from Compton, 1962).*

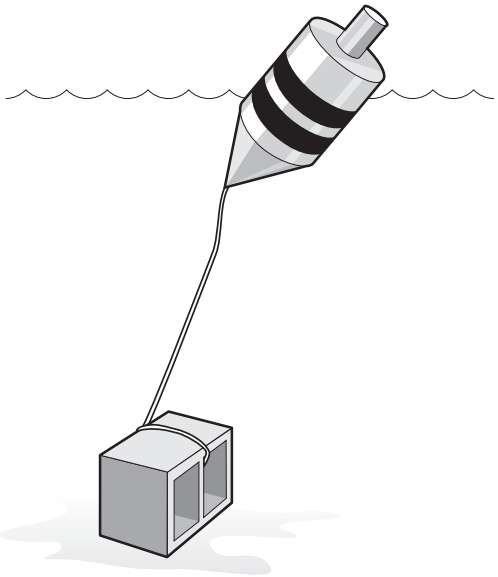


Figure 7-3. The marker buoy. This instrument may be used to identify monitoring sites in sheltered areas of the estuary.

A variety of GPS receivers exist. Generally, as a receiver's accuracy increases, so does its cost. For example, a GPS unit with a differential antenna can be very accurate, but it tends to be more expensive than a unit without the antenna. ■

Helpful Hint

Accurate GPS receivers can be expensive, but volunteer groups do not always have to buy them. Some government agencies loan them out and some GPS receivers can be donated. A monitoring group may be able to borrow a receiver to help pinpoint a sampling location. Once at the location, they can place a marker to ensure that they can easily return to the site.

Making Field Observations: Visual Assessments

Usually, taking a water sample to obtain a water quality variable concentration is not enough; in fact, it is only part of what is needed. Once at the monitoring location, volunteers should take a **visual assessment**, which is simply observing and recording the environmental conditions at the site. Volunteers should always be on the lookout for environmental clues that might help explain the data. A visual assessment of the monitoring site can provide invaluable information and make interpretation of other data easier and more meaningful. For example, if dead fish are floating at the water surface, they may signal a sudden drop in dissolved oxygen (DO) levels, the influx of some toxic substance, or disease or infestation of the fish. Unusual visual data are like bait; they should lure you in for further investigation.

The most value is gained when volunteers assess the same area each time they collect samples. In this way, **the volunteers will become the local experts**—growing familiar with baseline estuary conditions and land and water uses, and being better able to identify changes over time (USEPA, 1997).

When making a visual assessment of the site, look for and record information about:

Potential Pollution Sources

Several programs have started shoreline or watershed assessment projects to characterize land uses and land use changes around an estuary. An assessment can quantify the amount of—and changes in—residential, industrial, urban, agricultural, and forested areas within a watershed. A broader-scope project could further map the location of construction sites, marinas, industrial and municipal discharges, stormwater discharge points, landfills, agricultural feedlots, and any other potential pollution sources to the estuary.

Such an undertaking also provides the program leaders with information that may prove useful in selecting additional monitoring sites.

Indicators of Pollution

Water pollution may not be visually apparent, so other clues can serve as warning of possible contamination. Lesions on fish, for example, suggest the possible presence of toxic contaminants. Surface foam and scum downstream from a plant's discharge could be cause for concern. Although the discharge could lie within legal limits, a citizen group may want to investigate the situation further. Other

pollutant indicators include large numbers of dead fish or other animals, rust-colored oozes, large quantities of floatable debris, and highly turbid water.

Record all unusual conditions on a data sheet. Descriptive notes should be as detailed as possible. Volunteers should bring such conditions to the attention of the program leaders so that they can report them to the appropriate authority, if warranted. Monitoring groups which function as watchdogs may want to follow up with an investigation of their own.

Living Resources

A simple assessment of the quantity and type of living resources can round out the set of data taken at one site. Numbers of waterfowl, schools of fish, presence or absence of submerged aquatic vegetation beds, change in shoreline vegetation, and other information relate directly to the area's water quality. Fish kills or widespread shellfish bed die-offs may indicate episodes of intolerable water quality conditions. The presence of birds, pets, sea lions, and cattle may help explain high bacteria concentrations.

Remember, however, that the presence or absence of a living resource does not definitively speak to the estuary's water quality. Many animals are migratory and will not be seen at certain times of the year. Others may remain year-round, but become inactive at times and are difficult to find.

Color

We tend to think of pure water as blue, yet few waterbodies north of the sub-tropics fit this description. Clean water may have a color depending upon the water source and its content of dissolved and suspended materials. Plankton, plant pigments, metallic ions, and pollutants can all color water (Table 7-1). Even the color of the substrate can cause the water to take on an apparent color. To assess color, use one of the established color scales such as the Borger Color System or the Forel-Ule Color Scale from scientific supply houses.

Table 7-1. Water colors and their possible causes.

Apparent Color	Possible Reason
Peacock blue	Light-colored substrate
Green	Phytoplankton
Yellow/Brown	Peat, dissolved organics
Red/Yellow/Mahogany	Algae, dinoflagellates
Myriad colors	Soil erosion
Rainbow	Oil slick

Oil Slicks

Oil slicks are easily recognized by their iridescent sheen and often noxious odor. Oil may indicate anything from a worrisome oil spill to bilge water pumped from a nearby boat. Estimate the size of the slick, if possible, and report any spill to local authorities or the U.S. Coast Guard's National Response Center (1-800-424-8802).

Weather Conditions

The weather, recorded at the time of sampling and for several days beforehand, helps in the interpretation of other data.

Water Surface Conditions

Whether calm, rippled, or with waves and whitecaps, surface water conditions indicate how much mixing is occurring in the top layer of the estuary. When the surface is placid, very little wind-induced mixing occurs. Waves whipped up by wind, however, indicate substantial mixing and the introduction of oxygen to the water. This information may be especially helpful in interpreting dissolved oxygen data.

Ice

Ice cover can affect dissolved oxygen levels in the water by limiting the interaction of water with the atmosphere. In addition, ice in shallow areas may damage submerged aquatic plants and temporarily deprive estuarine animals and waterfowl of their habitat.

Erosion

Evidence of recent erosion, such as a steeply cut bank, may indicate recent storm activity or substantial wakes from boats. In either case, highly turbid water may accompany the erosion. ■

Helpful Field Measurements

Volunteer monitoring programs should consider including several other parameters in their suite of regular measurements. Most are simple to carry out and provide additional background information helpful in the final analysis of an estuary's status. These parameters include:

Air Temperature

Air temperature can be measured with the same meter or thermometer used for reading water temperature. Prior to placing the instrument in the water sample, allow the thermometer to equilibrate with the surrounding air temperature for three to five minutes; a wet thermometer will give an erroneous air temperature reading. Make sure the thermometer is out of direct sunlight to avoid a false high reading.

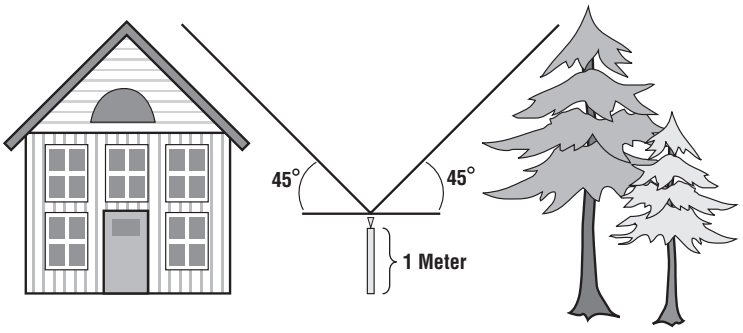


Figure 7-4. Rain gauge placement *(adapted from Campbell and Wildberger, 1992).*

Odor

Though quite subjective, water odor can reveal water quality problems that may not be visually apparent. Industrial and municipal effluents, rotting organic matter and phytoplankton blooms, and bacteria can all produce distinctive odors. Raw sewage, for example, has an unmistakable aroma. Make note of the odor in the data record and describe the smell.

Precipitation

Precipitation data help the program manager determine the possible causes of turbidity and erosion. Turbidity, for instance, generally rises during and after a rainstorm due to soil runoff. A wind storm (without precipitation), on the other hand, might cause turbidity due to bottom mixing. Precipitation also may help explain why nutrient concentrations rise (with rain) or decline (with little rain).

Be sure to place the rain gauge in an open area away from interference from overhead obstructions and post it more than one meter above the ground (Figure 7-4). Check the gauge each morning, record the amount of precipitation and the time of measurement, then empty the gauge. If the gauge sits after a rainfall, evaporation can falsify the measurement.

Tides

Programs studying highly stratified estuaries or estuaries with tidal ranges over a few feet may want to measure tidal stage. Tides of sufficient magnitude are effective mixers of estuarine waters and may break down stratification. Even if tidal stage data are not included at the beginning of the sampling effort, the National Oceanic and Atmospheric Administration (NOAA) publishes tide tables for most of the U.S., and this information can be obtained and applied after the fact if the monitoring station is reasonably close to one of the published tide table sites. ■

How to Collect Samples

Units 1-3 in this manual specify sampling and equipment procedures for different chemical, physical, and biological water quality parameters. There are, however, several general tasks that apply whenever water samples are collected. As always, program managers should consult with their laboratory or their sampling equipment instructions for exact requirements.

Before Leaving Home: Preparation of Sampling Containers

Reused sample containers and glassware must be cleaned and rinsed before and after samples are taken. When preparing sampling containers for most chemical and physical water quality parameters, follow these steps:

1. Wear latex or rubber gloves.
2. Wash each sample bottle or piece of glassware with a brush and phosphate-free detergent.
3. Rinse three times with cold tap water.
4. (This step is only for sample containers and glassware used to monitor nitrogen and phosphorus.) Rinse with 10 percent hydrochloric acid.
5. Rinse three times with deionized water.

Equipment used for bacteria sampling must be sterilized in an autoclave, which may require the assistance of a certified lab.

In the Field: Sample Collection

There are several different water collection devices available today. They can be used for most water quality analyses in the field or laboratory.

Surface Samples

Screw-cap bottles and Whirl-pak bags (Figure 7-5) are among the most popular tools for collecting water samples near the surface. The following steps should generally be taken (USEPA, 1997):

- Screw-Cap Bottle

1. Using a waterproof pen, label the bottle with the site number, date, and time.
2. Unscrew the bottle cap immediately prior to sampling. Avoid touching the inside of the bottle, its lip, or the cap. If you accidentally touch either, use another one.
3. Wading:
   Try to disturb as little bottom sediment as possible and take care not to collect water that has sediment from bottom disturbance. Stand facing against the current or tide (if it can be detected). Collect the sample against the current, in front of you (Figure 7-6). You may also tape your bottle to an extension pole to sample from deeper water.

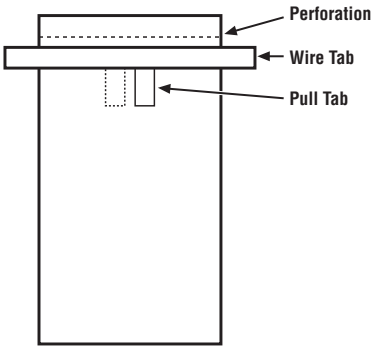


Figure 7-5. Whirl-pak bag. Volunteers can be easily trained to collect water samples with these factory-sealed, disposable bags.

Boat:
Carefully reach over the side; collect the water sample on the upcurrent side of the boat.

4. Hold the bottle near its base and plunge it (opening downward) below the water surface (Figure 7-6). If you are using an extension pole, remove the cap, turn the bottle upside down, and plunge it into the water, against the current or tide. Collect the water sample 8-12 inches below the water surface whenever possible.
5. Turn the bottle into the current and away from you. In slow-moving waters, push the bottle underneath the surface and away from you against the current or tide.
6. Leave a 1-inch air space (except for dissolved oxygen and biochemical oxygen demand samples), so that the bottle can be shaken just before analysis. Recap the bottle carefully, remembering not to touch the inside of the bottle or its lip.
7. Fill in the bottle number and/or site number on the appropriate field data sheet.
8. If the samples are to be analyzed in the lab, place them in the cooler for transport to the lab.

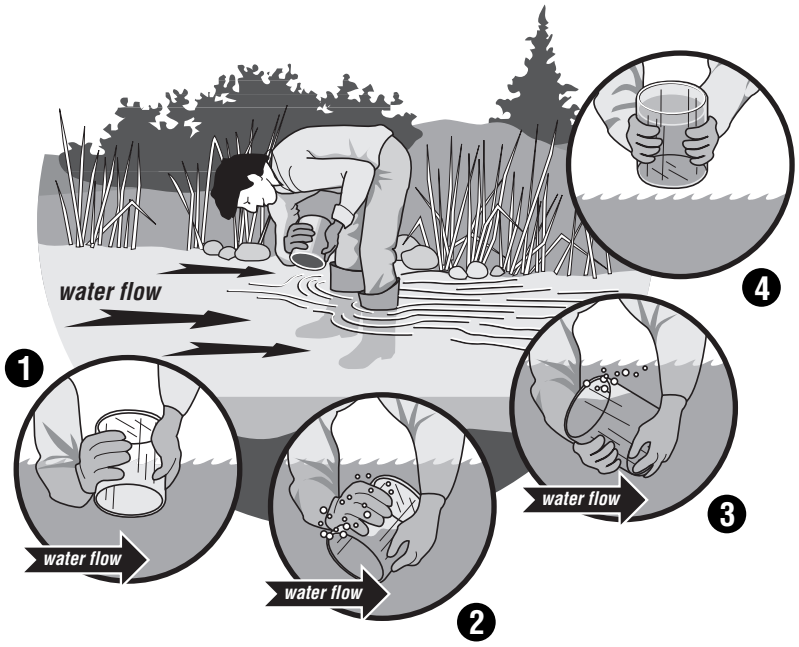


Figure 7-6. Taking a water sample. Turn the container into the current or tide and scoop in an upcurrent direction *(redrawn from USEPA, 1997).*

- Whirl-pak Bag

1. Using a waterproof pen, label the bag with the site number, date, and time.
2. Tear off the top of the bag along the perforation above the wire tab just prior to sampling (Figure 7-5). Avoid touching the inside of the bag. If you accidentally touch the inside of the bag, use another one.
3. Wading:
   Try to disturb as little bottom sediment as possible. In any case, be careful not to collect water that contains sediment. Stand facing against the current or tide. Collect the water sample in front of you.
   Boat:
   Carefully reach over the side; collect the water sample on the upcurrent side of the boat.
4. Hold the two white pull tabs in each hand and lower the bag into the water with the opening facing against the current. Open the bag midway between the surface and the bottom by pulling the white pull tabs. The bag should begin to fill with water. You may need to "scoop" water into the bag by drawing it through the water against the current and away from you. Fill the bag no more than 3/4 full.
5. Lift the bag out of the water, pouring out excess sample. Pull on the wire tabs to close the bag. Continue holding the wire tabs and flip the bag over several times away from you to quickly seal the bag. Fold the ends of the wire tabs together at the top of the bag, being careful not to puncture the bag. Twist them together, forming a loop.

6. Fill in the bag number and/or site number on the appropriate field data sheet.
7. If the samples are to be analyzed in the lab, place them in the cooler for transport to the lab.

Samples at Depth

To accommodate at-depth measurements, equipment supply companies produce several types of water samplers designed to collect water at specific depths through the water column.

Two of the most commonly used samplers in citizen monitoring programs are the Van Dorn and Kemmerer samplers (Figure 7-7). Both samplers have an open cylinder with stoppers at both ends. A calibrated line attaches to the device and allows the volunteer to lower the unit into the water to a precise depth.

After lowering the unit into the water to the proper depth, the volunteer then releases a "messenger"—or weight—down the line. When the messenger hits the sampler, it trips a releasing mechanism and two stoppers seal off the ends of the tube.

If sampling routinely takes place from a bridge, the manager should install a lighter weight messenger on the sampler. Be warned, however, that repeated use of the standard messenger from such heights will eventually damage the unit.

The volunteer should pull the sampler to the surface and transfer the collected water into a sample bottle or—depending on the parameter to be measured—a Whirl-pak bag. Pouring the water from one container to another can aerate the sample, thereby biasing some results (e.g., for dissolved oxygen). To avoid aeration, the volunteer should transfer the water using a rubber hose with an attached push valve. With the end of the hose at the bottom of the empty sample container, the volunteer should fill the bottle to overflowing.

Van Dorn and Kemmerer samplers, their derivations, and samplers designed for particular water quality parameters (e.g., dissolved oxygen) are available from equipment suppliers (Appendix C). Several volunteer groups have also constructed their own samplers. ■

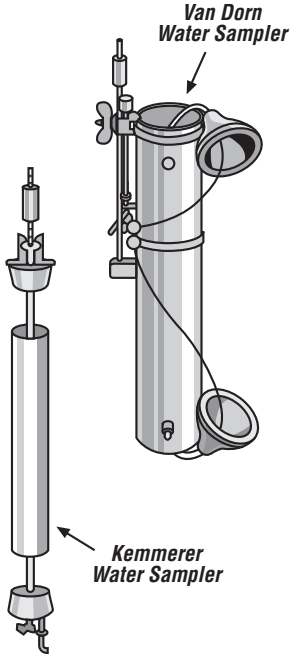


Figure 7-7. Two common water samplers: Kemmerer and Van Dorn *(from APHA et al., 1998).*

The Data Form

In several places in this chapter and throughout the manual, the importance of volunteers completing the data form or data sheet is expressed. The forms, when properly filled out, provide a set of standardized data useful to both managers and scientists. Volunteer program leaders are responsible for continuously emphasizing that properly completed data forms are essential to data quality. Rarely can a data manager feel comfortable asking a volunteer about details from the previous week's sampling exercise; relying on memory is risky.

Data forms should be easy to use and have space for water quality data and all information necessary to analyze, present, and manage the data. Sample data forms are provided in Appendix A. As a backup to the data form, some volunteers may wish to bring a tape recorder into the field to record observations.

While data users and the database manager should be

Volunteers collecting bacteria samples using an extension pole (photo by Weeks Bay Watershed Project).

Volunteers collecting a water sample from a dock using a dissolved oxygen sampler (photo by K. Register).

involved in the development of the data collection form, consideration should also be given to the ease with which volunteers can fill out and understand the form (USEPA, 1990). If the information is not important to the project, it should not be asked for on the data form.

One way to better ensure that volunteers complete the data forms correctly and completely is to involve them in the forms' development. Periodic reviews of the forms should also be conducted. As volunteers gain experience with the forms and monitoring sites, they can provide excellent suggestions for improving the data forms. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

Maine Department of Environmental Protection (DEP). 1996. *A Citizen's Guide to Coastal Watershed Surveys*. 78 pp.

U.S. Environmental Protection Agency *(USEPA). 1997. Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Other references:

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.

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

Compton, R. 1962. *Manual of Field Geology*. John Wiley and Sons. New York.

Ellett, K. 1993. *Chesapeake Bay Citizen Monitoring Program Manual*. Alliance for the Chesapeake Bay. Richmond, VA. 57 pp.

Ely, E. 1995. "Determining Site Locations." *The Volunteer Monitor* 7(1).

Lee, V., D. Avery, E. Martin, and N. Wetherill. 1992. *Salt Pond Watchers Protocol #1: Field Sampling Manual*. Coastal Resources Center, University of Rhode Island. Tech. Rpt. No. 14. 27 pp.

McAninch, T. 1997. "Guarding Against Reagent Degradation." *The Volunteer Monitor* 9(1).

Stancioff, E. 1996. *Clean Water: A Guide to Water Quality Monitoring for Volunteer Monitors of Coastal Waters*. Maine/New Hampshire Sea Grant Marine Advisory Program and University of Maine Cooperative Extension. Orono, ME. 73 pp.

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.

U.S. Fish and Wildlife Service. 1997. *Introduction to GPS for Field Biologists* (TEC7132). Sept. 25-26, 1997. Shepherdstown, WV. National Conservation Training Center.

Chapter 8

Data Management, Interpretation, and Presentation

Data are like letters of the alphabet: taken individually, they reveal very little. Put together with a little thought and organization, however, those same letters can tell a complete story. By highlighting data management, interpretation, and presentation, this chapter shows how data can be used to tell a story about your estuary.

Photos (l to r): The Ocean Conservancy, L. Monk, The Ocean Conservancy, K. Register

Overview

Volunteer estuary monitoring objectives differ from one program to the next. Meeting those objectives, however, usually requires similar steps. Regardless of whether a volunteer program wants to use its data for citizen education or resource management, the program must make its data understandable to its audience. Many goals will be unmet if the volunteer program cannot clearly convey what its data say about the estuary.

Data are like letters of the alphabet: taken individually, they reveal very little. Put together with a little thought and organization, however, those same letters can tell a complete story. By highlighting data management, interpretation, and presentation, this chapter shows how data can be used to tell a story about your estuary.

After Data Collection: What Does It Mean?

Consider this situation: You have the monitoring equipment. Volunteers are in the field collecting data. Enthusiasm is high. Everything is going smoothly and it's time to relax.

But is it really?

As difficult as it may be to accept, the aforementioned situation means one thing: there is much more work to be done. What will you do with the incoming data? As discussed in previous chapters, monitoring organizations should know the answer to this question *before* they collect their first sample. These decisions are made, in part, based on the needs of potential data users, who are particularly concerned about:

- databases and software used to manage the data;
- procedures followed in order to verify and check the raw volunteer data;
- analytical procedures employed to convert the raw data into findings and conclusions; and
- reporting formats.

Knowing how the data will be used should drive the development and everyday management of a volunteer monitoring program.

Most programs intend to use their data to tell a story about the estuary's health. Similarly, most volunteers who collect the data want to know what their information reveals about the estuary. Without communicating that data in a meaningful way to your intended audience, the hard work of many volunteers and volunteer leaders could be wasted. To take information from data sheets and convert it to something that makes sense to your audience requires several elements, which are summarized in Figure 8-1 and described in the remainder of this chapter. ■

Data Management

As discussed in previous chapters, data sheets should not only be easy for volunteers to complete, but should also record all desired information about the estuary and the sampling sessions. The volunteer leader cannot overemphasize to volunteers the importance of careful and accurate data recording. Incomplete or inaccurate data sheets can cause serious problems when it comes time to interpret the data. Such problems can damage your program's credibility and/or render the data useless, making all worthwhile efforts futile.

Data management is everyone's responsibility. The commitment by volunteers to collect high quality data must be matched by the program's commitment to make the information understandable to its volunteers and other data users. From the very early stages of planning a volunteer monitoring program, a sound data management plan must be a priority. It should be clear how the data will be processed, when it will be processed and reported, and who will be responsible for each task. An attitude of "Let's just get the data now and figure out what to do with it

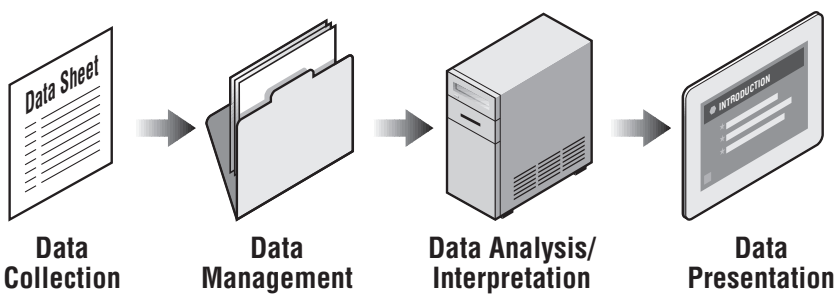


Figure 8-1. Steps necessary to prepare data for presentation. Data tell a story about the estuary.

later" can lead to wasted time and effort and a huge data backlog.

Where Does the Data Go?

It is difficult to get any meaning from boxes full of data sheets. The information collected by volunteers needs to be organized and readily accessible. Years ago, this may have meant that the data might be organized in handwritten tables. This method is still an option, but a computerized data management system provides a great deal of advantages, especially if the data collection effort is conducted at many sites and/or over a long time period (Lease, 1995).

Database or Spreadsheet?

Today's computer software includes a variety of spreadsheet and database packages that allow you to organize the data and perform statistical analyses. These options make it easier to detect relationships between data points. Spreadsheets are adequate for most data management needs and have the advantage of being relatively simple to use. Most spreadsheet packages have graphics capabilities that will allow you to plot your data onto a graph of your choice (i.e., bar, line, or pie chart). Examples of common spreadsheet software packages are Lotus 1-2-3, Excel, and Quattro Pro.

Database software may be more difficult to master and usually lack the graphics capabilities of spreadsheet software. If you manage large amounts of data, however, having a database is almost a necessity. It can store and manipulate very large data sets without sacrificing speed. The database can also relate records in one file to records in another. This feature allows you to break your data up into smaller, more easily managed files that can work together as though they were one.

The ability to query data is one of the most significant advantages of using a database. For example, the user can search for records that show water temperature exceeding X degrees over a specified time period, or identify monitoring sites that have dissolved oxygen levels between X and Y and the dates of those observations. The questions can be simple or quite complex and the answers or output can be organized in a variety of ways.

If you use a database for data storage and retrieval, you may still want to use a spreadsheet or other program with graphics capabilities. Many spreadsheet and database software packages are compatible and will allow you to transport data sets back and forth with relative ease. Specific parts of the database (such as results for a particular water quality variable from all stations and all sampling events) can then be transported into the spreadsheet, statistically analyzed, and graphically displayed. Examples of popular database software packages are dBase, Access, FileMaker Pro, and FoxPro.

Designing a Data Management System

Many people are capable of writing their own programs to manipulate and display data. The disadvantage of using a "homegrown" software program, however, is that if its author leaves the monitoring program, so too does all knowledge about how the program works. Commercial software, on the other hand, comes with consumer services that provide over-the-phone help and instructions, users' guides, replacement guarantees, and updates as the company improves its product. Most commercial programs are developed to import and export data in standard formats. This feature is important because if you want to share data with other programs or organizations, all you need are compatible software programs. However, some file conversions may be more difficult than advertised by the software manufacturer. To avoid potential problems, consult with any groups, government agencies, or laboratories with whom you plan to share data and ensure that your software packages are compatible (Lease, 1995).

Shared Databases

Greater efforts are being made to develop data storage systems that facilitate data exchange among different monitoring groups. A shared database serves to assimilate all the data being collected in a particular region and therefore helps to increase understanding of environmental conditions. Volunteer organizations are increasingly being encouraged to submit their data to these shared databases.

To participate in a shared database, the volunteer organization usually must have a quality assurance project plan (see Chapter 5) that meets the requirements of the group maintaining the shared database. Using software programs that are compatible with the shared database may also be necessary.

Shared databases may be developed for a specific resource (e.g., a river) or as a general clearinghouse of information. One example of a broad database is the U.S. Environmental Protection Agency's (EPA's) national water and biological data storage and retrieval system, called STORET. With STORET, volunteer programs can submit data to a centralized file server which permits national data analyses and through which data can be shared among organizations. A specific set of quality control measures is required for any data entered into the system. For more information, see the EPA Web page at www.epa.gov/owow/STORET/.

Data sharing also occurs at the state level. For example, the Oregon Department of Environmental Quality (DEQ) will accept data from volunteers and load it into an in-house monitoring database, the Laboratory Analytical Storage and Retrieval (LASAR). These data are then periodically uploaded to the STORET system. The Department has established a Required Data Elements Policy to enhance the widest use of data collected in Oregon. Visit the DEQ Web site for contact information and a copy of the policy: http://www.deq.state.or.us/wq/.

When designing databases or spreadsheets, always keep in mind what you will ultimately do with the data. Will you produce graphs or reports? Will you need to show a map with key data collection sites? Try to design your data management system in a manner that will make it easy to generate your final product.

Another consideration is who will input the data and create the final products. As more people, and especially volunteers, are involved in data entry and management, more emphasis should be placed on making the system easy to use.

Helpful Hint

Ease of data entry is always an important element to consider. Here are some suggestions:

- *Design the database or spreadsheet before you collect any data—this will help in the creation of your data sheets.*
- *Ideally, the database or spreadsheet input screen and the field data sheets used by volunteer monitors should look alike.*
- *Design the database or spreadsheet in such a way that it is readily apparent where data should be entered. Data cells can be highlighted with a special color, for example.*

Coding Systems

Any data management system should be flexible enough to meet future needs, especially as data start to accumulate. An easily understood coding system will help simplify the tracking and recording of data. Codes developed for sample sites, parameters, and other information on field and lab sheets should parallel the codes you use in your database. If you will be sharing your information with a state or local natural resource agency, you may want your coding system to match or complement the agency's system.

Sample Sites

Because sample sites tend to change or grow in number over time, it is important to have an accommodating site numbering system. A good convention to follow is to use a site coding system that includes an abbreviation of the waterbody or project plus a site number (e.g., GOR021 for a site on the Gooms River). By using a site abbreviation and three-digit code, 999 sites can be created for each project, which is plenty for most volunteer programs.

Water Quality Parameters

It is also important to develop a coding system for each of the water quality parameters you are testing. These are the codes you will use in the database or spreadsheet to identify and extract results. To keep the amount of clerical work to a minimum, abbreviate without losing the ability to distinguish parameters from one another. For example, EC could represent *E. coli* bacteria and FC could be the code for fecal coliform bacteria.

Reviewing Data Sheets

Writers have editors to look for mistakes in grammar, punctuation, etc. Similarly, someone should be available to review volunteers' data sheets. Even the best professionals and volunteers can make data recording mistakes; misplaced decimal points, forgotten calculations, or data values accidentally left blank are entirely possible.

The program coordinator or designated data analyst should screen and review the field data sheets immediately as they are received and before the data are entered into the database or spreadsheet. Waiting to review the data sheets for discrepancies is not advised; the longer you wait, the more likely it is that the person who collected the data will forget important details about the sampling effort that could clarify any inconsistencies.

When reviewing the data sheets, the program coordinator or other designated person should ask the following:

- *Are the field data sheets complete?*

If a person is consistently leaving a section of the sheet incomplete, ask why. You may learn that he or she is unclear about a monitoring procedure or has misunderstood some instructions.

- *Are the monitoring results very different from what might usually be expected for the site? If unexpected, are they still within the realm of possibility?*

For example, can the kit or technique used actually produce the reported results? Does the monitor offer any possible explanations for the results (e.g., a sewage treatment plant malfunction had been recently reported)? Is there additional corollary information that supports the data (e.g., a fish kill has been observed along with the extremely low dissolved oxygen readings)?

Also check for consistency between similar parameters. For example, total solids and turbidity should track together—if one goes up, so should the other.

- *Are there **outliers**—findings that differ radically from past data or other data from similar sites?*

Values that are off by a factor of 10 or 100 should be questioned. Follow up on any data that seem suspect. If you cannot explain why the results are so unusual, but they are still within the realm of possibility, you may want to

flag the data as questionable. Ask an experienced volunteer or program staff member to sample at that site as a backup until uncertainties are resolved, or work to verify that proper sampling and analytical protocols are being followed. Besides suggesting human error, monitoring results that are radically different than usual can indicate a problem with the monitoring technique or a new and serious problem at the monitoring site.

- *Are all measurements reported in the correct units?*

Minimize the chance for error by including on the data form itself any equations needed to convert measurements and specify on the form what units should be used. Check the math, making sure that the monitor has followed the program's rules for rounding numbers and reporting the appropriate number of decimal places. A value of zero should not be reported; instead, report the value as less than the lowest value that can be read with the equipment (Miller, 1995). For example, if the range of a test is 0-1 mg/l, the smallest increment is 0.01 mg/l, and the test result is zero, report the value as "less than 0.01 mg/l" or "<0.01 mg/l."

All field data sheets should be kept on file in the event that findings are brought into question at a later date and to serve as backup in case the computer-entered data are lost.

Helpful Hint

Reviewing data sheets doesn't only make you aware of recording mistakes, but it can also alert you to problems with your test procedures. Ideally, results for a particular test procedure should fall within the middle range of the test. For example, if a test range is 0-100 mg/l, most values should fall somewhere in the middle. If your volunteers are reporting many values of less than 10 mg/l, the precision for that test will not be very good. You may need to switch to a method having a range of 0-10 mg/l.

(Excerpted and adapted from Miller, 1995.)

Double-Checking Data Entry

Just as mistakes can be made recording data on paper, errors can also be made entering data into a computerized database or spreadsheet. This possibility requires that the data be printed and proofread against the original field data sheets. Preferably, someone other than the person who entered the data should serve as proofreader.

As a further check, you can make some simple calculations to ensure that no errors have slipped through. For example, if the median and the mean are very different, an outlier may be skewing the results. If you find an outlier, check for calculation or data entry errors. If the unusual data points cannot be explained by backup information on the field data sheets or the comment field in the database, flag the data as questionable until they can be verified.

Your database or spreadsheet can also be designed to minimize common data entry errors. One way to reduce error is to restrict acceptable input possibilities to those that are within the realistic range of values for a particular water quality variable. For example, the data program can be made to reject pH data values greater than 14, since such values are not possible. ■

Helpful Hint

It is always a good idea to make backups of any electronic database or spreadsheet. Duplicate files should be made on disk or tape and stored at another site, if possible. To further protect your data from some unfortunate disaster, print and store hardcopies of all data sets and keep the original data sheets.

(Excerpted and adapted from Sayce, 1999.)

Data Interpretation

While computers are quite helpful in organizing data, deciphering the story behind these facts remains a human job. The overall purpose of data interpretation is to get answers to your study design questions—the same questions that originally provoked you to start your monitoring program.

As an example, imagine that you want to determine where water quality criteria are not being met in the estuary. To do this, you must first develop preliminary findings, or objective observations about your data (Dates, 1995). By looking at the data, for example, you might be able to identify:

- variables that failed to meet water quality criteria;
- monitoring sites that regularly failed to meet the criteria;
- dates on which most or all of the sites did not meet the criteria, and the environmental conditions (e.g., weather, flow) on those dates;
- sites upstream and downstream of a suspected pollution source that show different monitoring results; and
- changes in one water quality variable that coincide with changes in another.

Your findings will help you look more critically at the data. With the facts in hand, you might naturally want to figure out why the data are what they are, especially if your findings reveal that water quality criteria are not met in certain areas. This will require more effort, but is certainly worthwhile: once reasons for poor water quality are found, solutions can be developed.

Ask yourself questions to help you decide whether human alterations, natural conditions, and/or data collection processing mistakes might explain your results.

- Could weather influence your results (e.g., do problem levels coincide with intense rainstorms)?
- Do specific sources explain your results (e.g., can increased bacteria levels be attributed to a wastewater treatment plant, failing septic system, or a large population of waterfowl or domesticated animals)?
- Do changes in one of your indicators appear to explain changes in another? For example, high temperatures (caused by a thermal discharge or a heat wave) might explain low oxygen levels.
- Do your visual observations explain any of your results? Did your samplers report any strange pipes, construction activity, flocks of birds, or dry weather discharges from storm drain pipes?
- For multiple years of data, are there overall trends? For example, did the submerged aquatic vegetation (SAV) community improve or deteriorate over time? The former could be explained by improved pollution control; the latter, by new pollution sources.
- If you are monitoring the impact of a pollution source (e.g., a wastewater treatment plant), are there other upstream impacts that might be influencing and confusing your results? For example, if a dairy farm is located immediately upstream from the wastewater treatment plant that you are monitoring, it might be difficult to figure out which source is causing the water quality problems revealed by your data. Alternatively, it could be difficult to determine how the two sources combine to cause the problems.
- Could unusual or unexpected data be attributed to contaminated samples or human sampling error?
- Did the time of sampling affect your results? For example, dissolved oxygen levels are generally lowest in the early morning hours. Sampling for dissolved

oxygen in the afternoon could overlook the estuary's worst-case conditions.

- Could the water quality variable occur in several places throughout the ecosystem? For example, if you found low levels of phosphorus in the water column, there might be high levels in bottom sediments or plants. Algae blooms are evidence of nutrient enrichment that may not be apparent in water samples.

Helpful Hint

Comparing older photos with more recent ones from the same location can help volunteers understand changing land uses and perhaps help you interpret water quality changes.

Summary Statistics

Summary statistics describe the basic attributes of a set of data for a given parameter. There are many different types of statistics that can be used. Program leaders should consult a standard statistics manual, their data users, and their quality assurance project plan to determine which statistical methods are most appropriate for their data. Two of the most frequently used descriptors of environmental data are the **mean** and **standard deviation**. They are briefly described here.

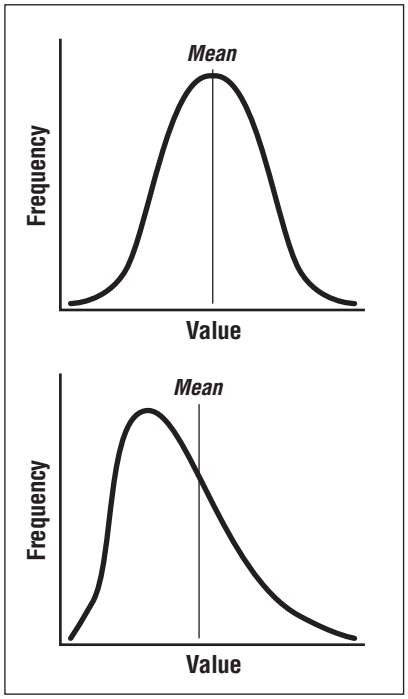


Figure 8-2. Graphic representation of the mean. The mean is located at the peak of a normal or bell-shaped distribution curve.

Textbook statistics commonly assume that if a parameter is measured many times under the same conditions, then the measurement values will be randomly distributed around the average with more values clustering near the average than further away. In this ideal situation, a graph of the frequency of each measure plotted against its magnitude should yield a bell-shaped or normal curve. The mean and the standard deviation determine the height and breadth of this curve, respectively (Figures 8-2 and 8-3).

The mean is simply the sum of all the measurement values divided by the number of measurements. Commonly referred to as the "average," this statistic marks the highest point at the center of a normal curve (Figure 8-2).

The standard deviation, on the other hand, describes the variability of the data points around the mean. Very similar measurement values will have a small standard deviation, while widely scattered data will have a much larger standard deviation (Figure 8-3). A high standard deviation indicates imprecise data (see Chapter 5 for a discussion of precision and an equation for calculating standard deviation).

While both the mean and the standard deviation are quite useful in describing estuarine data, often the actual measures do not fit a normal distribution. Other statistics sometimes come into play to describe the data. Some data are skewed in one direction or the other, while others might produce a flattened bell shape (Figure 8-4).

Deviation from the normal distribution often occurs in estuary sampling because the estuary is dynamic, with many factors influencing the condition of its waters. The various methods used to collect data can also cause non-normal distributions. For example, if volunteers are collecting water quality data in SAV beds (see Chapter 18), the distribution of water quality variables will tend to be skewed toward good water quality because water quality has to be of a certain minimum standard to support the growth of these underwater plants.

Another common cause of non-normal distribution occurs because of detection limits. A detection limit marks the boundary above or below the concentrations or values measured by a particular method. Secchi depth measurements, for example, have an upper detection limit determined by water depth (i.e., the Secchi depth cannot exceed the water depth) and a lower limit determined by

the smallest increment of measure on the rope. Figure 8-5 shows how both low and high values may be truncated by these detection limits.

Mystery Solved?

We might like to think our data will tell us everything about what is happening in the estuary. In reality, the data may not tell the whole story—or even part of it. As with any scientific study, your data may be inconclusive, especially if your program has been monitoring for only a short time (Dates, 1995). Indeed, since the workings of an estuary are complex, it is often difficult to determine trends for many water quality variables (e.g., nutrients) unless the monitoring has occurred over several seasons. In fact, several years' worth of unusual data may be quite misleading and tell a story very different than the long-term situation. Concluding that you need additional information to better understand the estuary is completely acceptable.

On the other hand, anomalous data can indicate problems requiring immediate action. For example, data showing high turbidity and accompanied by visual observations of abnormally cloudy water could indicate a significant sediment or nutrient runoff problem from many possible sources (e.g., construction sites, farmland, forestry operations, golf courses, etc.). Such information should be brought to the immediate attention of proper authorities for further investigation.

Keep in mind that your data should support your interpretations. Still, your interpretations are simply your best judgments about the data. Even if you include your volunteers, data users, and others who are knowledgeable about the estuary in reviewing the data, others may disagree with your interpretation. That is not atypical. However, as long as your data support your interpretation and you have followed a reasonable data interpretation process, you should be able to defend your position. ■

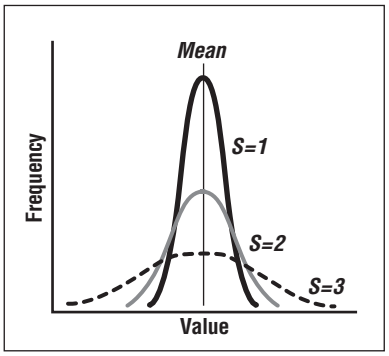


Figure 8-3. Graphic representation of the standard deviation. A small standard deviation corresponds to a "peaked" frequency distribution, while a larger standard deviation corresponds to a more "flattened" distribution.

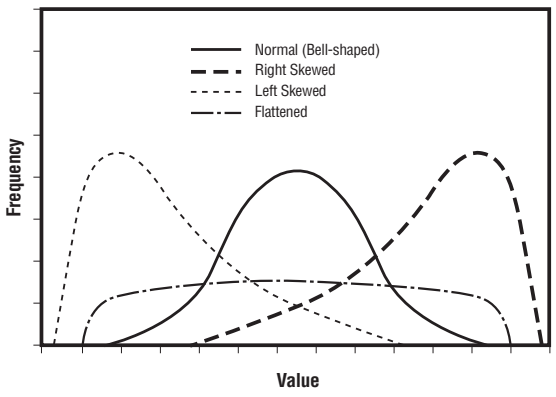


Figure 8-4. Examples of frequency distributions. Because of the complexity of estuarine systems, deviations to the normal bell-shaped distribution curve are common.

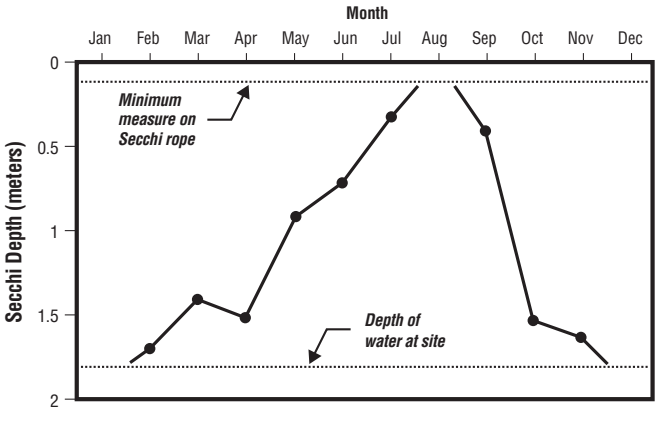


Figure 8-5. Example of limitations on Secchi depth measurements in an hypothetical monitoring program.

Data Presentation

A project coordinator in Puerto Rico reviews the significance of marine debris data with her young volunteers. Presentations should be designed according to the type of audience (photo by L. Monk).

When you feel fully confident that you have assembled the best possible picture of environmental conditions in your study areas, it is your job to make others—your volunteers, data users, local fishing clubs, or any other audience—aware of what you found.

Know Your Audience

Whether citizen programs convey monitoring results in a periodic newsletter, annual report, or by verbal presentation, the key to rousing and sustaining the interest of the audience remains the same. The speaker or writer must determine the interests, background, and level of technical understanding of the target audience and prepare the presentation accordingly. Remember: The burden of communication is on the presenter to convey the information, not on the audience to understand (Sayce, 1999).

In presenting data results to volunteers or other interested parties, several points merit consideration:

- Highly technical or extremely simplistic presentations bore the audience. An informative and lively approach, molded to the expectations of the audience, will be far more effective. Simple graphics often help make complicated issues much more understandable.
- A presentation should focus on a clear message related to your audience's interests. Your audience will likely be more interested in specifics such as trends in water quality, seasonal variation, quality assurance issues, or the identification of trouble spots in the estuary rather than an across-the-board synopsis of all the monitoring results.
- Data presentations, whether written or verbal, should be both timely and relevant. Volunteers will maintain a higher level of interest if they see a quick turnaround of their data into usable and informative graphics and summaries. Moreover, your nutrient data won't have much influence on community decision-makers if you miss the public hearing on a sewer upgrade project. As mentioned earlier, trends may be difficult to determine with limited data, so one should exercise caution when implying that data show long term trends.
- Better understanding on the part of your audience may lead to more community support, more funding, better management policies, and greater citizen involvement.

When presenting data, one of your chief goals should be to maintain the attention and interest of your audience. This is very difficult using tables filled with numbers. Most people will not be interested in the absolute values of each parameter at each sampling site; rather, they will want to know the bottom line for each site (e.g., is it good or bad) and seasonal and year-to-year trends.

Technical vs. Non-Technical Audiences

When addressing water quality or planning professionals, you should provide information about:

- the purpose of the study;
- who conducted it;
- how it was funded;
- the methods used;
- the quality control measures taken;
- your interpretation of the results;
- your conclusions and recommendations; and
- further questions that have arisen as a result of the study.

Graphics, tables, and maps may be fairly sophisticated. Be sure to include the raw data in a written report's appendix and note any problems encountered.

A report for the general public should be short and direct. It is very important to convey information in a non-technical style and to include definitions for terms and concepts that may be unfamiliar to the layperson. Simple charts, summary tables, and maps with accompanying explanations can be especially useful. Include a brief description of the program, the purpose of the monitoring, an explanation of the parameters that were monitored, the location of sample sites, a summary of the results, and any recommendations that may have been made.

In any written report or presentation, you should acknowledge the volunteers and the sources of funding and other support.

(Excerpted and adapted from USEPA, 1997.)

Graphics

Graphics, when used properly, are excellent tools to present a great deal of information in a condensed yet understandable format. They enliven the presentation, highlight trends, and illustrate comparative relationships. Graphics include flowcharts, maps, and graphs or charts of the data. Such graphics, along with narrative interpretation, summary statistics, tables, overheads, and slides, help construct a well-rounded and interesting presentation.

Graphs and Charts

Results summarized from the volunteer-collected data can be displayed in any of several styles of graphs. Choosing the style that best conveys the information is critical and requires careful thought. Although more sophisticated graphic styles may be required to present some data, three basic types are often used for volunteer monitoring data: the bar graph, pie chart, and line graph.

Bar Graph

The bar graph uses simple columns (Figure 8-6). The height of each column represents the value of a data point, making comparisons of the data relatively easy.

Modifications can be made to the standard bar graph for visual appeal. For example, Figure 8-7 shows

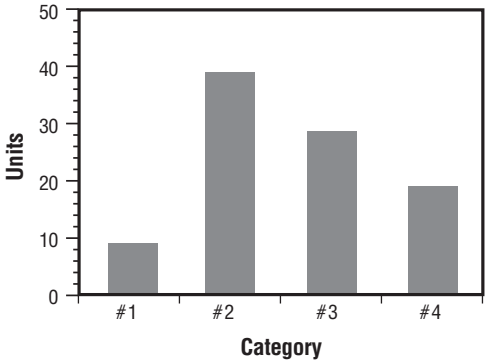


Figure 8-6. Bar graph.

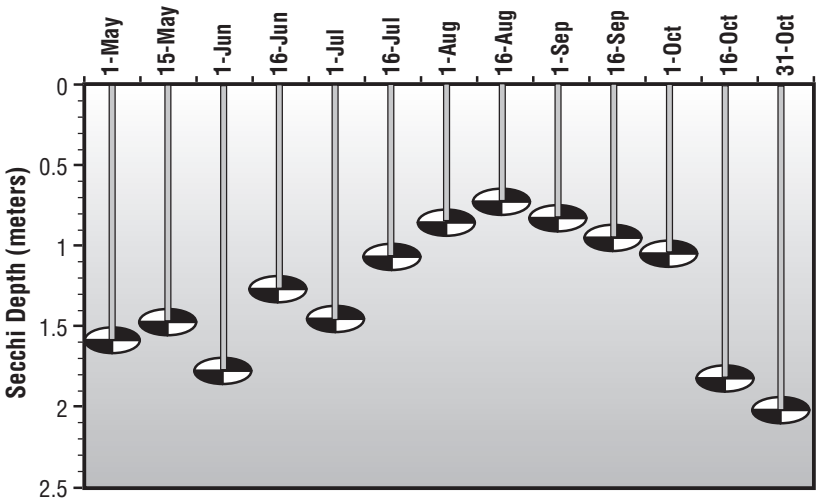


Figure 8-7. Modification of typical bar graph to illustrate Secchi depth data.

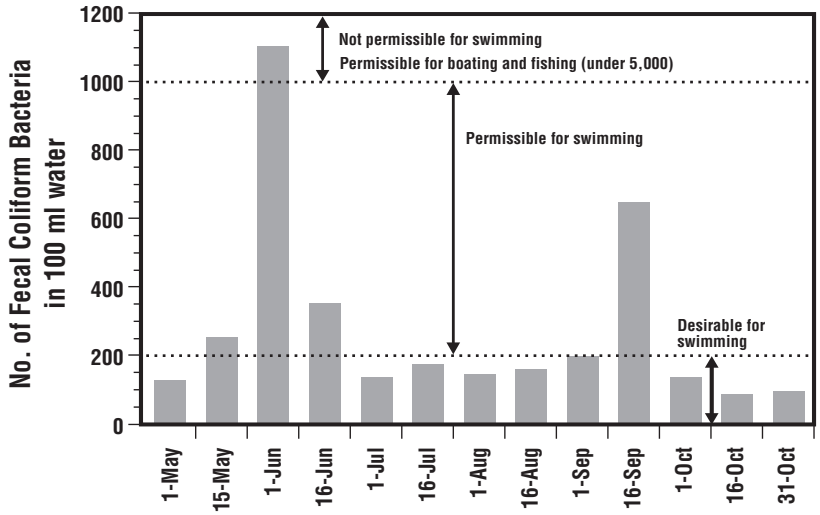


Figure 8-8. Bar graph showing fecal coliform data values and comparing them with water quality standards.

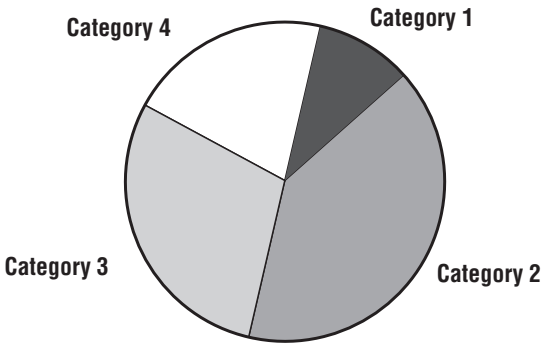


Figure 8-9. Pie chart.

turbidity data, as measured by a Secchi disk. In this graphic, depth increases in a downward direction along the vertical axis to simulate actual water depth. This minor change from the norm, along with the use of Secchi disk icons extending down from the "surface," makes the data easy to understand.

In bar graphs of pH, dissolved oxygen, bacteria, or other water quality variables for which a standard value exists, consider inserting a line across the graphic showing the standard (Figure 8-8). This helps in understanding when your results indicate problems.

Pie Chart

The pie chart (Figure 8-9) is a simple yet effective means of comparing each category within the data set to the whole. It is best used to present relational data, such as percentages. The chart's pie shape, with the pie representing the total and the individual wedges representing distinct categories, makes this graphic style popular due to its simplicity and clarity.

Certain data may be better described by a pie chart than others. For example, it can be very useful for summarizing the composition percentages of marine debris found at a particular site (e.g., the percent of plastic, paper, glass, etc., debris), but not for presenting dissolved oxygen trends.

Helpful Hint

If there are many small percentages in your pie chart, consider reducing the clutter by grouping the values together as an "other" category. Identify the items in the "other" slice of the pie elsewhere, especially if you are presenting the information to a technical audience.

Line Graph

A line graph (Figure 8-10) is constructed by connecting the data points with a line. It can be effectively used for depicting changes over time or space. This type of graph places more emphasis on trends and the relationship among data points and less emphasis on any particular data point.

Line graphs can also be used to compare two water quality variables that may be related. Figure 8-11, for example, shows dissolved oxygen concentrations and water temperature. The plot of the two parameters shows that as water temperature increases through the summer, oxygen levels generally decline. The opposite occurs as cooler autumn temperatures set in.

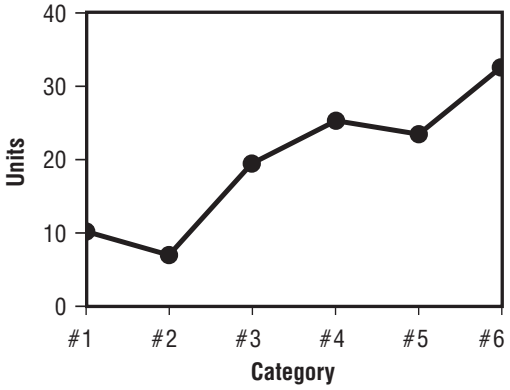


Figure 8-10. Line graph.

Maps and Photographs

Displaying the results of your monitoring data on a map can be a very effective way of helping people understand what the data signify. A map can show the location of sample sites in relation to features such as cities, wastewater treatment plants, farmland, and tributaries that may have an effect on water quality. This type of graphic display can be used to effectively show the correlation between specific activities or land uses and the impacts they have on the ecosystem. Because a map displays the estuary's relationship to neighborhoods, parks, and recreational areas, it can also help to elicit concern for the estuary and strengthen interest in protecting it.

There are different types of maps available. These include:

- topographic maps, which show natural features and elevations;
- bathymetric maps, which show the relief (deep and shallow portions) on the bottom of estuaries;
- Geographic Information System (GIS) maps, which are computer-generated and can show a variety of features (see box, page 8-14);
- highway or street atlas maps;
- geologic maps;
- soil maps;
- geologic or engineering hazards maps;
- flood inundation maps; and
- hand-drawn maps.

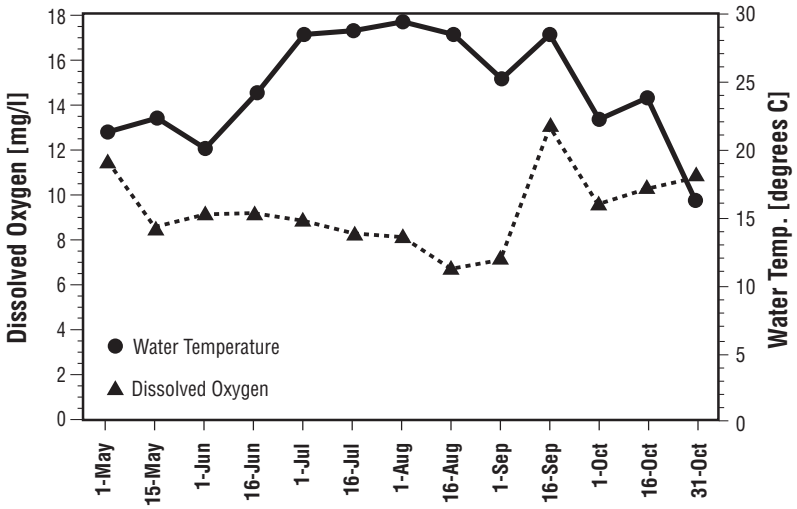


Figure 8-11. Line graph comparing values for two related water quality variables.

Helpful Hint

Here are some tips for making your graphics easy to understand:

- *Have the graph serve a clear purpose. The information contained in the graph should be relatively easy to interpret and relate closely to the text of a document or script of a presentation.*
- *Do not distort the meaning of the data. Graphical representations of the data points should be proportional to each point's actual value (Figure 8-12).*
- *Ensure that the labeling of graphics is clear and accurate. A table of the data values should accompany any graph that is likely to be misunderstood.*
- *Keep the graphic design simple. Complex or tricky graphics often hide the true meaning of the data. Avoid cluttering the graph with labels, arrows, grids, fill patterns, and other "visual noise" that unnecessarily complicate the graphic. Use simple fonts that are easy to read.*
- *Limit the number of graphic elements. A pie chart, for example, should be divided into no more than five or six wedges. Keep the number of superimposed lines on a line graph and the quantity of columns in a bar graph to a minimum.*
- *Consider the proportions of the chart and the legibility of the type and graphic elements. A horizontal format is generally more visually appealing, simpler to understand, and makes labels easier to read. The elements should fill the dimensions of the graph to create a balanced effect. Ensure that the axes are labeled with legible titles and that the tick marks showing data intervals are not crowded along the axis lines. Avoid cryptic abbreviations whenever possible, remembering that you want your audience to fully understand the information in the graphic.*
- *Create a title for the chart that is simple yet informative.*
- *Remember that 8 percent of the U.S. population is colorblind. When color-coding results, don't use both red and green on the same graphic. You may also use shapes or symbols in addition to color.*
- *Whether you use color, shading, or patterns, be sure that an easy-to-understand data key is included or that the data are clearly labeled.*
- *If you will need to photocopy color graphics, make sure that the colors are still distinguishable when the graphics are photocopied in black and white.*
- *Be consistent when comparing data; for example, don't mix pie charts with bar graphs.*

(Portions excerpted and adapted from Schoen et al., 1999.)

Geographic Information Systems

Computer software systems that allow you to map and manipulate various layers of information (such as water quality data, land use information, county boundaries, or geologic conditions) are known as Geographic Information Systems (GIS). They can vary from simple systems run on personal computers to sophisticated and very powerful ones that run on large mainframes. For any GIS application, you need to know the coordinates of your sample sites—either their latitude and longitude, or some alternate system. You can also locate your sites on a topographic map that can be digitized onto an electronic map of the watershed. Once these points have been established, you can link your database to the points on the map, query your database, and create graphic displays of the data.

Powerful GIS applications typically require expensive hardware, software, and technical training. Any volunteer program interested in GIS applications may consider working in partnership with other organizations such as universities, natural resource agencies, or large nonprofit groups that can provide access to a GIS.

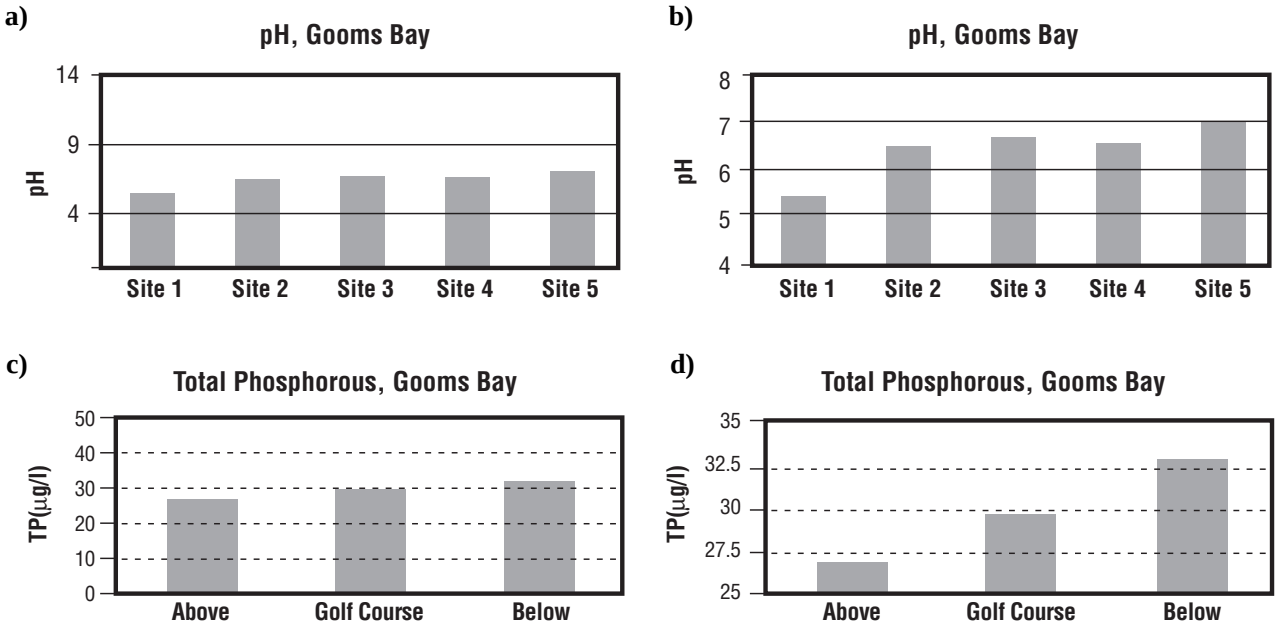


Figure 8-12. Scale considerations for presenting data. The pH graph in (a) gives the mistaken impression that the results are similar at each site. The graph in (b) uses a narrower y-axis scale, thereby doing a better job of showing the significant differences among monitoring sites. Changing scales to dramatize insignificant differences (c and d), however, is not recommended.

The display map should show principal features such as roads, municipal boundaries, waterways, and other familiar landmarks (e.g., schools and churches). It should have sufficient detail and scale to show the location of sample sites and have space for summary information about each site.

When displaying your data on a map, consider the following:

- Keep the amount of information presented on each map to a minimum. Do not try to put so much on one map that it becomes visually complicated and difficult to read or understand. A good rule of thumb is to read the map without referring to the legend. If the map is not easily understood or if symbols, lines, and colors are not distinct from each other, then you should use another map to display a different layer or "view" of the data. For example, if there are several dates for which you wish to display sampling results, use one map for each date.
- Clearly label the map and provide an explanation of how to interpret it. If you need a long and complicated explanation, you may want to present the data differently. If you have reached a clear conclusion, state the conclusion on the map. For example, if a map shows that tributaries are cleaner than the mainstem, use that information as the subtitle of the map.
- Provide a key to the symbols that are used on the map.
- Rather than packing lots of information into a small area of the map, use a "blowup" or enlargement of the area elsewhere on the map to adequately display the information.
- Use symbols that vary in size and pattern to represent the magnitude of results. For example, a site with a fecal coliform level of 10 colonies/100 ml could be a light gray circle with a 1/16-inch diameter while a site with a level of 200 colonies/100 ml would be a dark gray circle 1/4-inch

A volunteer distributes information to passersby at an Earth Day event in Washington, DC (photo by The Ocean Conservancy).

in diameter. Start by finding the highest and lowest values, assign diameters and patterns to those values, and then fill in steps along the way. For the above example you might have four ranges: 0 to 99, 100 to 199, 200 to 500, and 500+.

Photographs also add great value to your project. Aerial photos of the monitoring sites add a "personal touch," allowing citizens to see their houses or favorite fishing spots. This can pique their interest in the project.

Ground-level pictures of algal blooms, monitoring sites, and volunteers in action are also helpful. They are qualitative records of your estuary's health or your monitoring project and help your audience understand your project and program's activities. Compiling a photo library is always a good idea, especially when last-minute additions are needed for reports, press releases, display booths, and presentations.

Getting the Word Out

On a regular basis, a successful volunteer estuary monitoring program should report key findings to volunteers, data users, and the general public, including the media. As mentioned previously, state water quality agencies will require detailed reports, whereas shorter and less technical summaries are more appropriate for the general public.

The volunteer program should develop a strategy for distributing and publicizing reports. All reports should be subjected to the review process prescribed by your quality assurance project plan, and your program's leaders should be confident about the data and comfortable with the statements and conclusions before the report is made public. When your report's findings and conclusions are released to the public, you will need to be prepared to respond to questions regarding the data and your interpretation of that data.

Some ideas for distributing project results and informing the public include the following:

Written Report

A written document is a good instrument for getting your information out to a wide audience. If you have access to a mailing list of people who are interested in your estuary, mail the report with a cover letter that summarizes the major findings of the study. The cover letter should be brief and enticing so that the recipient will be curious enough to read the report. If you want people to take some kind of action, such as supporting the expenditure of public funds to upgrade a sewage treatment plant, you may want to ask for their support in the cover letter. If you do not have an extensive mailing list, perhaps other organizations that share your goals would be willing to supply you with their lists. Be sure to also send the report to state and federal agencies; newspapers; radio and television stations; local libraries; colleges and universities; research stations; and high schools, if appropriate.

Instead of long technical reports, you may want to develop fact sheets for public distribution. These summaries of your findings and conclusions should make your points quickly and instruct the reader on how to obtain more information.

Speaking Tour

Develop an oral presentation (with slides, overheads, etc.) that could be offered to groups such as the local chamber of commerce, civic clubs, conservation organizations, schools, and government entities. Your presentation could even be videotaped for distribution to a wider audience.

Public Meetings

Schedule a series of public meetings that highlight the monitoring program, its findings, and its recommendations. At the meetings, distribute the written report, answer questions, and tell your audience how they can get involved. These meetings can also help you recruit more volunteers.

Be sure to schedule the meetings at times when people are more likely to attend (i.e., weekday evenings, weekend days) and avoid periods when people are usually busy or on vacation. Invite the media and publicize the meetings in newspaper calendars; send press releases to radio and television stations, newspapers, and other organizations; and ask volunteers to distribute fliers at grocery stores, city hall, etc.

Press Releases and Press Conferences

As explained in Chapter 3, distributing a press release is a cost-effective means of informing the public about the results and accomplishments of your program. Develop a mailing list of newspapers, radio and television stations, and organizations that solicit articles for publication. Send the news release to volunteers and others who are interested in publicizing the monitoring program.

If your report contains some real news or if it has led to a significant event (e.g., the mayor or city council has recognized the value of the report and issued a statement of support), hold a press conference (see Chapter 3 for details).

Exhibits

Set up displays at river festivals, county fairs, conferences, libraries, storefront windows, boat ramps, or parks. Exhibits allow you to show your data to a variety of audiences, usually in an informal setting.

Web Sites

Placing data on your program's Web site or the sites of project partners can be a useful and convenient way to make your data available. Almost everyone has access to the Internet and developing a Web page is relatively easy.

People curious about your project can view the Web site for raw data, graphics, photos, and commentary. In addition, posting information on the site can save staff resources that would otherwise be spent printing and mailing the results or explaining results over the phone.

Once people know where they can find your data, they can continue to check the site for updates.

Other Publicity

Be creative in getting your report and message out. Try writing letters to the editor or op-ed articles for local or statewide papers, producing radio feeds (a recording of the group's leader played over the phone to a radio station), issuing media advisories, and even advertising in publications. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

Dates, G. 1995. "Interpreting Your Data." *The Volunteer Monitor* 7(1).

Lease, F. 1995. "Designing a Data Management System." *The Volunteer Monitor* 7(1).

Schoen, J., M-F. Walk, and M.L. Tremblay. 1999. *Ready, Set, Present! A Data Presentation Manual for Volunteer Water Quality Monitoring Groups*. Massachusetts Water Watch Partnership. Univ. of Massachusetts, Amherst.
Web site: http://www.umass.edu/tei/mwwp/datapresmanual.html.

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Other references:

Dates, G., and J. Schloss. 1998. *Data to Information: A Guide for Coastal Water Quality Monitoring Groups in New Hampshire and Maine*. Univ. of Maine Cooperative Extension and ME/NH Sea Grant. Waldoboro, ME.

Ely, E. (ed.) 1995. *The Volunteer Monitor*. "Special Topic: Managing and Presenting Your Data." 7(1).

Hubbell, S. 1995. "Seize the Data." *The Volunteer Monitor* 7(1).

Miller, J.K. 1995. "Data Screening and Common Sense." *The Volunteer Monitor* 7(1).

Rector, J. 1995. "'Variability Happens': Basic Descriptive Statistics for Volunteer Programs." *The Volunteer Monitor* 7(1).

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

Sayce, K. 1999. "Data Analysis and Presentation." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

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.

U.S. Environmental Protection Agency (USEPA). 1997. *Proceedings—Fifth National Volunteer Monitoring Conference: Promoting Watershed Stewardship.* August 3-7, 1996, University of Wisconsin-Madison. EPA 841-R-97-007.
Web site: http://www.epa.gov/owow/volunteer/proceedings/toc.html.

Unit One

Chemical Measures

Oxygen • Nutrients • pH and Alkalinity • Toxins

Photos (l to r): G. Carver, R. Ohrel, R. Ohrel

Chapter 9

Oxygen



Dissolved oxygen concentrations indicate how well aerated the water is, and vary according to a number of factors, including season, time of day, temperature, and salinity. Biochemical oxygen demand measures the amount of oxygen consumed in the water by chemical and biological processes.

Photos (l to r) K. Register, R. Ohrel, R. Ohrel

Overview

Nearly all aquatic life needs oxygen to survive. Because of its importance to estuarine ecosystems, oxygen is commonly measured by volunteer monitoring programs. When monitoring oxygen, volunteers usually measure dissolved oxygen and biochemical oxygen demand.

Dissolved oxygen concentrations indicate how well aerated the water is, and vary according to a number of factors, including season, time of day, temperature, and salinity. Biochemical oxygen demand measures the amount of oxygen consumed in the water by chemical and biological processes.

This chapter discusses the role of dissolved oxygen and biochemical oxygen demand in the estuarine environment. It provides steps for measuring these water quality variables. Finally, a case study is provided.

Why Monitor Oxygen?

Of all the parameters that characterize an estuary, the level of oxygen in the water is one of the best indicators of the estuary's health. An estuary with little or no oxygen cannot support healthy levels of animal or plant life.

Unlike many of the problems plaguing estuaries, the consequences of a rapid decline in oxygen set in quickly and animals must move to areas with higher levels of oxygen or perish. This immediate impact makes measuring the level of oxygen an important means of assessing water quality. ■

DISSOLVED OXYGEN (DO)

Oxygen enters estuarine waters from the atmosphere and through aquatic plant photosynthesis. Currents and wind-generated waves boost the amount of oxygen in the water by putting more water in contact with the atmosphere.

Dissolved Oxygen in the Estuarine Ecosystem

DO is one of the most important factors controlling the presence or absence of estuarine species. It is crucial for most animals and plants except for a small minority that can survive under conditions with little or no oxygen. Animals and plants require oxygen for respiration—a process critical for basic metabolic processes.

In addition to its use in respiration, oxygen is needed to aid in decomposition. An integral part of an estuary's ecological cycle is the breakdown of organic matter. Like animal and plant respiration, this process consumes oxygen. Decomposition of large quantities of organic matter by bacteria can severely deplete the water of oxygen and make it uninhabitable for many species.

An overload of nutrients from wastewater treatment plants or runoff from various land uses also adds to the problem. Nutrients fuel the overgrowth of phytoplankton, known as a bloom. The phytoplankton ultimately die, fall to the bottom, decompose, and use up oxygen in the deep waters of the estuary. Although nutrients from human activities are a major cause of depleted oxygen, low oxygen conditions may also naturally occur in estuaries relatively unaffected by humans. Generally, however, the severity of low DO and the length of time that low oxygen conditions persist in these areas are less extreme.

DO and nutrients can be connected in another way. When oxygen is low, nutrients bound to bottom sediments can be released into the water column, thereby permitting more plankton growth and eventually more oxygen depletion. Other pollutants may also be released from sediments under low oxygen conditions, potentially causing problems for the estuarine ecosystem.

Oxygen availability to aquatic organisms is complicated by the fact that its solubility in water is generally poor. Salt water absorbs even less oxygen than fresh water (e.g., seawater at 10°C can hold a maximum dissolved oxygen concentration of 9.0 mg/l, while fresh water at the same temperature can hold 11.3 mg/l). Warm water also holds less oxygen than cold water (e.g., seawater can hold a dissolved oxygen concentration of 9.0 mg/l at 10°C, but that concentration drops to 7.3 mg/l when the temperature increases to 20°C). Therefore, warm estuarine water can contain very little dissolved oxygen, and this can have severe consequences for aquatic organisms.

Levels of Dissolved Oxygen

Although we may think of water as homogeneous and unchanging, its chemical constitution

does, in fact, vary over time. Oxygen levels, in particular, may change sharply in a matter of hours. DO concentrations are affected by physical, chemical, and biological factors (Figure 9-1), making it difficult to assess the significance of any single DO value.

At the surface of an estuary, the water at midday is often close to oxygen saturation due both to mixing with air and the production of oxygen by plant photosynthesis (an activity driven by sunlight). As night falls, photosynthesis ceases and plants consume available oxygen, forcing DO levels at the surface to decline. Cloudy weather may also cause surface water DO levels to drop since reduced sunlight slows photosynthesis.

DO levels in an estuary can fluctuate greatly with depth, especially during certain times of the year. Temperature differences between the surface and deeper parts of the estuary may be quite distinct during the warmer months. Vertical **stratification** in estuarine waters (warmer, fresher water over colder, saltier water) during the late spring to summer period is quite effective in blocking the transfer of oxygen between the upper and lower layers (see Figure 9-1). In a well-stratified estuary, very little oxygen may reach lower depths and the deep water may remain at a fairly constant low level of DO. Changing seasons or storms, however, can cause the stratification to disintegrate, allowing oxygen-rich surface water to mix with the oxygen-poor deep water. This period of mixing is known as an **overturn**.

When DO declines below threshold levels, which vary depending upon the species, mobile animals must move to waters with higher DO; immobile species often perish. Most animals and plants can grow and reproduce unimpaired when DO levels exceed 5 mg/l. When levels drop to 3-5 mg/l, however, living organisms often become stressed. If levels fall below 3 mg/l, a condition known as **hypoxia**, many species will move elsewhere and immobile species may die. A second condition, known as **anoxia**, occurs when the water becomes totally depleted of oxygen (below 0.5 mg/l) and results in the death of any organism that requires oxygen for survival. Figure 9-2 summarizes DO thresholds in estuarine waters. ■

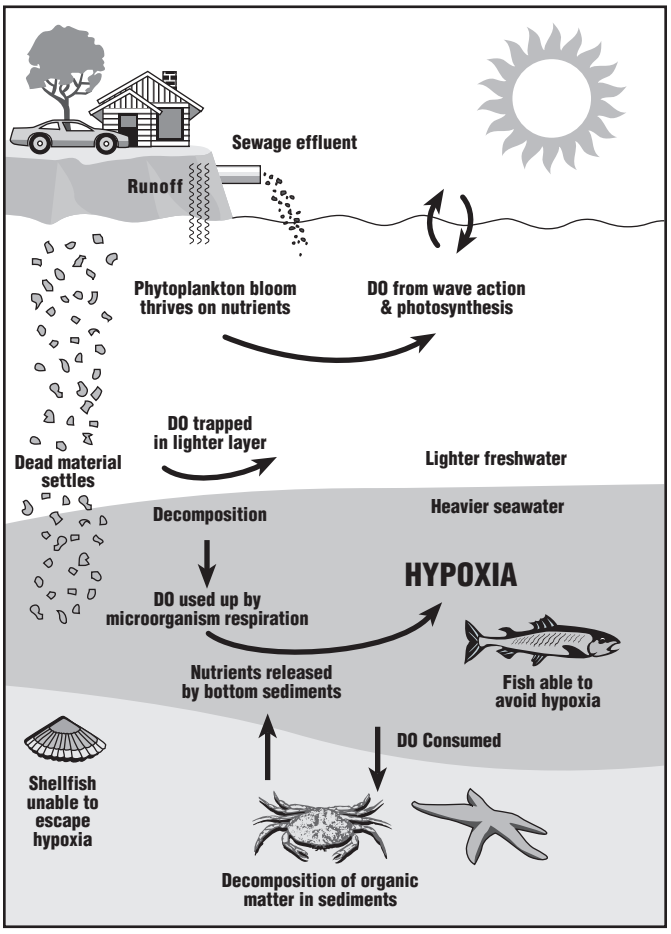


Figure 9-1. Physical, chemical, and biological processes that affect dissolved oxygen concentrations in estuaries. *(Redrawn from USEPA, 1998.)*

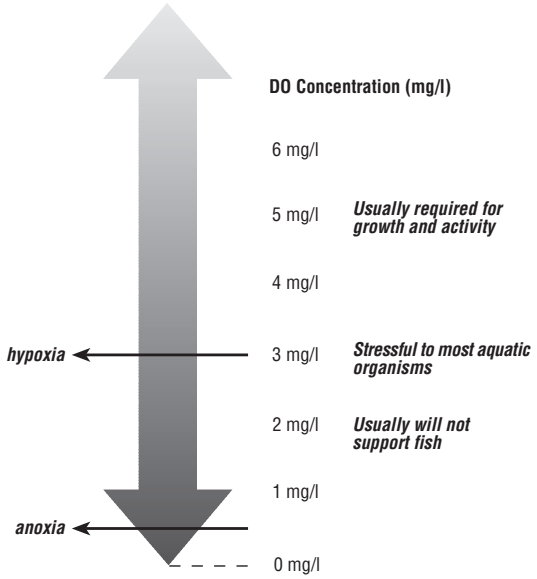


Figure 9-2. Dissolved oxygen in the water. A minimum DO concentration of 5 mg/l is usually necessary to fully support aquatic life.

Sampling Considerations

Chapter 6 summarized several factors that should be considered when determining monitoring sites, where to monitor in the water column, and when to monitor. In addition to the considerations in Chapter 6, a few additional ones specific to oxygen monitoring are presented here.

When to Sample

In estuarine systems, sampling for DO throughout the year is preferable to establish a clear picture of water quality. If year-round sampling is not possible, taking samples from the beginning of spring well into autumn will provide a program with the most significant data. Warm weather conditions bring on hypoxia and anoxia, which pose serious problems for the estuary's plants and animals. Because these conditions are rare during winter, cold weather data can serve as a baseline of information.

Sampling once a week is generally sufficient to capture the variability of DO in the estuary. Since DO may fluctuate throughout the day, **volunteers should sample at about the same time of day** each week. This way, they are less likely to record data that largely capture daily fluctuations. Some programs suggest that volunteers sample in the morning near dawn as well as mid-afternoon to capture the daily high and low DO values.

In some areas, especially large tidal swings can work to weaken the stratification in the estuary. Tidal effects, then, could be a consideration when collecting and analyzing DO data.

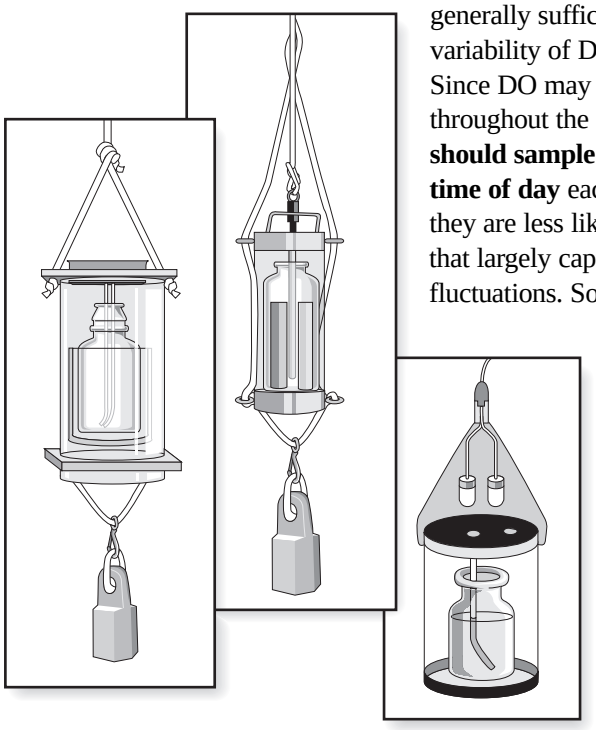


Figure 9-3. Dissolved oxygen samplers. Many of these instruments may also be used to collect samples for the analysis of other water quality variables.

Where to Sample

As mentioned previously, estuary stratification can have an impact on DO levels at different depths. Stratification is especially evident during the summer months, when warm fresh water overlies colder, saltier water. Very little mixing occurs between the layers, forming a boundary to mixing.

Because DO levels vary with depth—especially during the summer—volunteer groups may wish to collect samples at different depths. Van Dorn and Kemmerer samplers (see Chapter 7) are commonly used to collect these kinds of samples. In addition, there are several water samplers designed primarily for collecting DO samples at different depths (Figure 9-3). Appendix C provides a list of equipment suppliers.

Choosing a Sampling Method

Citizen programs may elect to use either a DO electronic meter or one of the several available DO test kits (Table 9-1). If the volunteer group wants its data to be used by state or federal agencies, it is wise to confer with the appropriate agency beforehand to determine an acceptable monitoring method.

Meters

The electronic meter measures DO based on the rate of molecular oxygen diffusion across a membrane. The results from a DO meter are extremely accurate, providing the unit is well-maintained, calibrated, and the membrane is handled in accordance with the manufacturer's instructions before each use. To properly calibrate some DO meters, knowledge of the sampling site's salinity is necessary.

The DO probe may be placed directly into

Table 9-1. Summary of dissolved oxygen monitoring methods. Depending on the method used, DO measurements may be made in the field or in a laboratory *(USEPA, 1997)*.

Method	Location of Measurement	Comments
Meter	Field	• The meter must be properly calibrated, accounting for salinity. • The meter is fragile; handle it carefully.
Test kit (Winkler titration)	Field or Lab	• If measured in lab, the sample is fixed in the field and titrated in the lab. • Lab measurement must take place within 8 hours of sample collection.

the estuary for a reading or into a water sample drawn out by bucket for a surface measurement. Depending on the length of its cable, a meter may allow monitors to get DO readings directly from various depths. Some meters allow volunteers to take both DO and temperature readings simultaneously.

Though easy to use, a reliable DO meter will likely cost more than $1,000. It also uses batteries, which last a long time but must be disposed of properly. To offset upfront and maintenance costs, monitoring groups might consider sharing equipment (Stancioff, 1996).

Because of the expense, a volunteer program might be able to afford only one meter. Consequently, only one team of monitors can measure DO and they will have to do it at all sites. Dissolved oxygen meters may be useful for programs in which many measurements are needed at only a few sites, volunteers sample at several sites by boat, or volunteers plan on running DO profiles (many measurements taken at different depths at one site).

Test Kits

If volunteers are sampling at several widely scattered sites, one of the many DO kits on the market may be more cost-effective. These kits rely on the Winkler titration method or one of its modifications. The modifications reduce the effect of materials in the water, such as organic matter, which may cause inaccurate results.

The kits are inexpensive, generally ranging from $30 to $200, depending on the method of titration they use. While inexpensive upfront, the kits require reagent refills as the reagents are used up or degrade over time. Reagents cannot be reused. Unused reagents and waste generated during the performance of tests must be disposed of properly (see Chapter 7). Volunteers must also take appropriate safety precautions when using the reagents, which can be harmful if used improperly.

Kits provide good results if monitors adhere strictly to established sampling protocols. Aerating the water sample, allowing it to sit in sunlight or unfixed (see box, page 9-6, for an explanation of fixing), and titrating too hastily can all introduce error into DO results.

For convenience, the volunteer monitors may keep their kits at home and take them to the sampling site each week. The program manager must provide the monitors with fresh chemicals as needed. Periodically, the manager should check the kit to make sure that each volunteer is properly maintaining and storing the kit's components. At the start of the monitoring program, and periodically thereafter if possible, the program manager should directly compare kit measurements to those from a standard Winkler titration conducted in a laboratory. ■

Titration

Titration is an analytical procedure used to measure the quantity of a substance in a water sample by generating a known chemical reaction. In the process, a reagent is incrementally added to a measured volume of the sample until reaching an obvious **endpoint**, such as a distinct change in color (Figure 9-4).

The volunteer on the left is titrating a water sample, while the other volunteer is "fixing" another sample (photo by K. Register).

Volunteers can use titration to assess the quantity of dissolved oxygen at a sampling site. This procedure, known as the Winkler titration, uses iodine as a substitute for the oxygen dissolved in a "fixed" sample of water. A **fixed sample** is one in which the water has been chemically rendered stable or unalterable, meaning that atmospheric oxygen will no longer affect the test result. Iodine stains the sample yellow-brown. Then, a chemical called sodium thiosulfate reacts with the free iodine in the water to form another chemical, sodium iodide. When the reaction is complete, the sample turns clear. This color change is called the endpoint.

Since the color change is often swift and can occur between one drop of reagent and the next, a starch indicator should be added to the solution to exaggerate the color change. The starch keeps the sample blue until all the free iodine is gone, at which time the sample immediately turns colorless. The amount of sodium thiosulfate used to turn the sample clear translates directly into the amount of dissolved oxygen present in the original water sample.

Figure 9-4. Titration of a reagent into a water sample.

Reminder!

To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

Not all quality control procedures are appropriate for all water quality analyses. Blanks and standards are not usually used for Winkler DO titrations, due to problems with contamination by oxygen from the air. To check the accuracy of the procedure, one has at least two options:

- *Create an oxygen-saturated sample by shaking and pouring water back and forth through the air, then titrate the sample and compare the results to published tables of oxygen solubility versus temperature (salinity must be known to determine oxygen solubility).*
- *Use a standard solution of potassium bi-iodate to check the accuracy of the titrant (standard solutions can be ordered from chemical supply companies—see Appendix C). The amount of titrant required to make the sample colorless should equal the amount of potassium bi-iodate added to the sample, $\pm$0.1 ml.*

(Excerpted and adapted from Mattson, 1992.)

How to Monitor Dissolved Oxygen

General procedures for collecting and analyzing dissolved oxygen samples are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

STEP 1: Check equipment.

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

If using the Winkler method

- large clean bucket with rope (if taking surface sample or if unable to collect sample directly in DO bottles);
- Kemmerer, Van Dorn, DO sampler, or homemade sampler (if taking a full DO profile);
- fully stocked dissolved oxygen kit with instructions;
- extra DO bottles;
- equipment for measuring temperature and salinity (necessary to calculate percent saturation—see page 9-12); and
- enough reagents for the number of sites to be tested.

If using a meter and probe

- calibrated DO meter and probe with operating manual (the meter must be calibrated according to the manufacturer's instructions);
- extra membranes and electrolyte solution for the probe;
- extra batteries for the meter;
- extra O-rings for the membrane;
- extension pole; and
- equipment for measuring temperature and salinity (necessary to calculate percent saturation—see page 9-12), if temperature and salinity cannot be measured by the meter.

STEP 2: Collect the sample.

This task is necessary if the volunteer is using a DO kit or if a sample is being drawn for a DO meter (rather than placing the DO probe directly in the estuary). Chapter 7 reviews general information about collecting a water sample.

Although the task of collecting a bottle of water seems relatively easy, volunteers must follow strict guidelines to prevent contamination of the sample. The citizen monitor must take care during collection of the water; jostling or swirling the sample can result in aeration and cause erroneous data. Using a bucket to collect the sample increases the risk of introducing oxygen to the sample. It is preferable to use a standard DO sampling bottle rather than a simple bucket since a washed and capped bottle is less likely to become contaminated than an open container.

Reminder!

The water sample must be collected in such a way that you can cap the bottle while it is still submerged. That means you must be able to reach into the water with both arms and the water must be deeper than the sample bottle.

If using a bucket

- Rinse the sample bucket with estuary water twice before sampling. Rinse and empty the bucket away from the collection area.
- Drop the bucket over the side of the dock, pier, or boat and allow water from just under the surface to gently fill the container until it is about two-thirds full. There should be no air bubbles in the bucket.
- Lift the bucket carefully to the working platform.
- If using a DO kit, rinse two DO bottles twice each with estuary water before filling them from the sample bucket. Then, submerge each capped bottle in the bucket, remove the lid, and slowly fill. Avoid agitating the water in the bucket to minimize the introduction of oxygen to the sample.
- While the bottle is still under water, tap its side to loosen any air bubbles before capping and lifting the bottle from the bucket.
- Check the sample for bubbles by turning the bottle upside-down and tapping. If you see any bubbles, repeat the filling steps.

Figure 9-5. Taking a water sample for DO analysis. Point the bottle against the tide or current and fill gradually. Cap the bottle under water when full, ensuring that there are no air bubbles in the bottle *(USEPA, 1997).*

If collecting samples directly in bottles

- Rinse two DO bottles twice each with estuary water away from the collection area before filling them with the sample.
- Make sure you are positioned downcurrent of the bottle.
- Submerge each capped bottle in the water, facing into the current.
- Remove the lid, and slowly fill (Figure 9-5). Avoid agitating the water to minimize the introduction of oxygen to the sample.
- While the bottle is still under water, tap its side to loosen any air bubbles before capping and lifting the bottle from the water.
- Check the sample for bubbles by turning the bottle upside-down and tapping. If you see any bubbles, repeat the filling steps.

If collecting samples from other samplers

- Follow the manufacturer's instructions.
- Make sure that no air bubbles are introduced into the sample.
- The sampler should have a mechanism for allowing the DO bottle to fill from the bottom to the top.

If using a test kit, take the water temperature by setting the thermometer in the bucket and allow it to stabilize while preparing for the DO test. Most meters will have a thermometer included. The bucket of water used for measuring DO can also be used for many of the other water quality tests.

Temperature and salinity should also be measured to calibrate a DO meter or if the volunteer group wishes to calculate percent saturation (see box, page 9-12).

STEP 3: *Measure DO.*

Many citizen monitoring programs use the "azide modification" of the Winkler titration to measure DO. This test removes interference due to nitrites—a common problem in estuarine waters.

If using the Winkler method

Gloves should be worn when doing this test.

Part One: "Fix" the sample immediately

- Proceed with the DO test for both sample bottles by carefully following the manufacturer's instructions. Allow some of the sample to overflow during these steps; this overflow assures that no atmospheric oxygen enters the bottled contents. After the sample is fixed, exposure to air will not affect the oxygen content of the sample. Be careful not to introduce air into the sample while adding the reagents. Simply drop the reagents into the test sample, cap carefully, and mix gently.
- Once the sample has been fixed in this manner, it is not necessary to perform the titration procedure immediately. Thus, several samples can be collected and "fixed" in the field, then carried back to a testing station or laboratory where the titration procedure is to be performed. The titration portion of the test should be carried out within 8 hours. In the meantime, keep the sample refrigerated and in the dark.

Part Two: Titrating the sample

- Continue with the titration of both samples, again following specific instructions included with the kit or provided by the program manager.
- Carefully measure the amount of fixed sample used in titration; this step is critical to the accuracy of the results. The bottom of the meniscus should rest on top of the white line on the titration test tube. (A **meniscus** is the curved upper surface of a liquid column that is concave when the containing walls are wetted by the liquid—see Figure 9-6.)
- Fill the syringe in the test kit, following instructions.
- Insert the syringe into the hole on top of the test tube and add 1 drop of sodium thiosulfate to the test tube; swirl the test tube to mix. Add another drop of the sodium thiosulfate and swirl the tube. Continue this titration process one drop at a time until the yellow-brown solution in the test tube turns a pale yellow. Then pull the syringe out of the hole (with the remaining sodium thiosulfate) and put it aside for a moment.

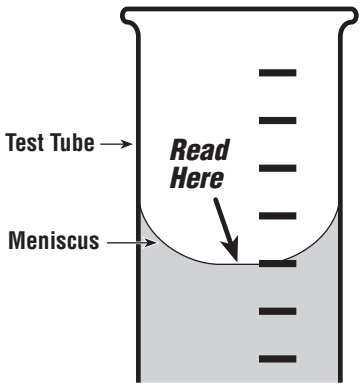


Figure 9-6. Measurements should be made at the bottom of the meniscus.

- Add starch solution to the test tube through the hole on top of the lid, according to directions. Swirl the tube to mix. The solution should turn from light yellow to dark blue.
- Now put the syringe back into the hole on the test tube. Continue the titration process with the remaining sodium thiosulfate, until the test tube solution turns from blue to clear. Do not add any more sodium thiosulfate than is necessary to produce the color change. Be sure to swirl the test tube after each drop.
- Using the scale on the side of the syringe, read the total number of units of sodium thiosulfate used in the experiment. Each milliliter of thiosulfate used is equivalent to 1 mg/l DO.
- Each volunteer should carry out all steps on two samples to minimize the possibility of error. The two samples can either be titrated from the one bottle of fixed sample solution or, for better quality assurance, from two water samples fixed in the field.

- If the discrepancy between the two DO concentrations is significant, the volunteer should run a third titration. The program's quality assurance project plan should define what difference is considered "significant." Some monitoring programs stipulate that a third sample must be analyzed if the DO concentrations of the first two samples differ by more than 0.6 mg/l.

NOTE: Samples with high levels of DO are brown, while low DO samples are generally pale yellow before the starch indicator is added. A few minutes after reaching the colorless endpoint, the sample may turn blue once again. This color reversion is not cause for concern—it is simply proof of a precise titration.

Helpful Hint

If volunteers are to collect and fix two water samples at each of their monitoring sites, be sure to provide each monitor with the appropriate number of DO bottles (e.g., 4 bottles for 2 monitoring sites, etc.). The bottles can be permanently marked with site location names. Volunteers will collect and fix the samples in the field, then titrate the samples within 8 hours. After the DO bottles have been emptied and cleaned, they are ready for the next monitoring session.

If using a meter and probe

- Make sure the unit is calibrated according to the manufacturer's instructions. Knowledge of salinity is needed to properly calibrate most meters (Green, 1998).
- After inserting the DO probe into the bucket or placing it over the side of the boat or pier, allow the probe to stabilize for at least 90 seconds before taking a reading.
- With some meters, you should manually stir the probe without disturbing the water to get an accurate measurement.

STEP 4: *Clean up and submit data.*

If using the Winkler titration method, make sure to thoroughly rinse all glassware in the kit and tightly screw on the caps to the reagent bottles. Check to ensure that each bottle contains sufficient reagents for the next DO analysis. Properly dispose of wastes generated during the performance of tests (see Chapter 7).

If using a laboratory to analyze the samples, deliver the fixed samples and field data sheets to the lab as soon as possible, as the sample analysis must be done within 8 hours.

Make sure that the data sheet is complete and accurate. Volunteers should make a copy of the completed data sheet before forwarding it to the project manager in case the original data sheet becomes lost. ■

Case Study: Dissolved Oxygen Monitoring in New Jersey

In New Jersey, the Alliance for a Living Ocean coordinates the Barnegat Bay Watch Monitoring Program. Dissolved oxygen testing is one of the more complicated monitoring activities undertaken by program volunteers.

The volunteer monitors use a modified Winkler titration test kit that is user-friendly and has a good degree of accuracy. With each test kit, the monitors receive a test procedure sheet and a monitor's testing manual. Often, monitors tape a simplified version of the test procedures to the inside of their test kits.

The program provides several tips to minimize any confusion about the test procedure:

- Because the test kit uses five reagents, monitors are encouraged to label the reagent bottles as #1, #2, etc.
- It is suggested that the bottles be arranged in numeric order in the test kit. This simplifies looking for the next reagent.
- Solutions 1, 2, 3, and 5 are each added 8 drops at a time. (Solution #4 is added one drop at a time.) The monitors can mark these reagent bottles with the words "8 drops." When the monitors' hands are wet or the wind is blowing, it is much easier to read the label on a bottle than an instruction sheet.

Many monitors conduct tests from their boats in the Barnegat Bay. These monitors are encouraged to "fix" the water sample by adding the first three reagents, and then return to land. Once on shore, volunteers can resume the test, which includes filling a titration tube to exactly 20 ml and titrating Solution #4 one drop at a time. In this manner, inaccuracies caused by a rocking boat are avoided.

Monitors are reminded to remove all air bubbles from the water sample by tapping the sample bottle while it is submerged. Monitors also double-check for air bubbles in the sample and the titration plunger before beginning a test. Air bubbles in the plunger are avoided by depressing the plunger before drawing up the titration solution. These practices greatly reduce data error.

The program suggests that volunteers perform the dissolved oxygen test several times at home or in the laboratory before going out in the field. Through practice, they can become familiar with the order of reagents and what the water sample should look like at each step.

For More Information:

Alliance for a Living Ocean
P.O. Box 95
Ship Bottom, NJ 08008
Phone: 609-492-0222
Fax: 609-492-6216
E-mail: livingocean@worldnet.att.net

DO Saturation and Percent Saturation

DO saturation, or potential DO level, refers to the highest DO concentration possible under the environmental limits of temperature, salinity (or chlorinity), and atmospheric pressure. As salinity or chlorinity increases, the amount of oxygen that water can hold decreases substantially. For example, at 20°C, 100% DO saturation for fresh water (for which salinity and chlorinity are zero) is 9.09 mg/l. At the same temperature, 100% saturation for water with 36 parts per thousand (ppt) salinity is 7.34 mg/l.

Table 9-2 summarizes DO saturation levels for different salinities and temperatures at sea level. Tables showing saturation levels in waters of various chlorinity can be found in APHA (1998).

Percent saturation is the amount of oxygen in the water relative to the water's potential DO saturation. It is calculated as follows:

$$\text{Percent saturation} = \frac{\text{measured DO}}{\text{DO saturation}} \times 100$$

(Excerpted and adapted from Green, 1998.)

Temperature °C	Oxygen Saturation Concentration (mg/l)				
	Salinity: 0 ppt	9 ppt	18 ppt	27 ppt	36 ppt
0.0	14.6	13.7	12.9	12.1	11.4
1.0	14.2	13.4	12.5	11.8	11.1
2.0	13.8	13.0	12.2	11.5	10.8
3.0	13.5	12.7	11.9	11.2	10.5
4.0	13.1	12.3	11.6	10.9	10.3
5.0	12.8	12.0	11.3	10.6	10.0
6.0	12.4	11.7	11.0	10.4	9.8
7.0	12.1	11.4	10.8	10.2	9.6
8.0	11.8	11.2	10.5	9.9	9.4
9.0	11.6	10.9	10.3	9.7	9.2
10.0	11.3	10.6	10.0	9.5	9.0
11.0	11.0	10.4	9.8	9.3	8.8
12.0	10.8	10.2	9.6	9.1	8.6
13.0	10.5	10.0	9.4	8.9	8.4
14.0	10.3	9.7	9.2	8.7	8.2
15.0	10.1	9.5	9.0	8.5	8.1
16.0	9.9	9.3	8.8	8.4	7.9
17.0	9.7	9.2	8.7	8.2	7.8
18.0	9.5	9.0	8.5	8.0	7.6
19.0	9.3	8.8	8.3	7.9	7.5
20.0	9.1	8.6	8.2	7.7	7.3
21.0	8.9	8.4	8.0	7.6	7.2
22.0	8.7	8.3	7.9	7.5	7.1
23.0	8.6	8.1	7.7	7.3	7.0
24.0	8.4	8.0	7.6	7.2	6.8
25.0	8.3	7.8	7.4	7.1	6.7
26.0	8.1	7.7	7.3	7.0	6.6
27.0	8.0	7.6	7.2	6.8	6.5
28.0	7.8	7.4	7.1	6.7	6.4
29.0	7.7	7.3	7.0	6.6	6.3
30.0	7.6	7.2	6.8	6.5	6.2
31.0	7.4	7.1	6.7	6.4	6.1
32.0	7.3	7.0	6.6	6.3	6.0
33.0	7.2	6.8	6.5	6.2	5.9
34.0	7.1	6.7	6.4	6.1	5.8
35.0	7.0	6.6	6.3	6.0	5.7

Table 9-2. Dissolved oxygen saturation concentrations (mg/l) in waters of various salinity (ppt) and temperature (°C) at sea level *(adapted from Campbell and Wildberger, 1992, and APHA, 1998).* Readers are referred to APHA (1998) for DO saturation concentrations using chlorinity instead of salinity (salinity = 1.80655 x chlorinity).

Common Questions About DO Testing

Should I pour off any of the water in my sample bottle before I add the reagents?

No. Pouring off some of the water allows space for an air bubble to be trapped when the bottle is capped. When you shake the bottle, this oxygen mixes with the sample and causes erroneously high results. It's OK for some liquid to overflow as you add the fixing reagents. (If you are concerned about spillage, put the bottle on a paper towel.)

How should I hold the dropper bottles to dispense the reagents?

Hold the dropper bottles completely upside down (i.e., vertical). This ensures a uniform drop size.

What is meant by saying that the sample is "fixed"?

After the first three reagents are added, the sample is fixed; this means that contact with atmospheric oxygen will no longer affect the test result because all the dissolved oxygen in the sample has reacted with the added reagents. The final titration actually measures iodine instead of oxygen. Fixed samples may be stored up to 8 hours, if kept refrigerated and in the dark.

What if I spill some of the acid as I am fixing the sample?

As part of the fixing process, acid crystals or liquid are added to the sample. The addition of the acid will dissolve the flocculate. You can spill a few acid crystals and not have to start over—but you should be sure to clean up the spill (see Chapter 7). If a few grains of acid do not go into the solution and all the flocculate is dissolved, you may continue the titration.

Sometimes after I add the acid, some brown "dots" remain. Is this OK?

The brown particles should be dissolved before you continue the test. Try shaking the sample bottle again. If this doesn't work, add one more drop of acid. You may occasionally find that organic material or sediment in the sample will not dissolve. This will not affect the test results.

What if my sample is colorless after it's fixed?

This means there is no dissolved oxygen in the sample. If this happens, you might want to test a sample that you know contains oxygen to make sure that your kit is functioning properly. One way to do this is to intentionally introduce an air bubble into the water sample, shake well, then fix the sample. You should see a yellow color.

When filling the syringe with the thiosulfate reagent, how far back should I pull the barrel?

The point of the black neoprene tip should be set right at zero. This is extremely important.

What if my syringe runs out of the sodium thiosulfate titrant?

In colder water, the amount of DO may be above 10 mg/l, so you will have to refill the syringe. For accurate results, fill to 0 mark and add the amount titrated from second syringe-full to the 10 from the first syringe-full.

How much starch solution should I add?

When and how much starch solution is added is not critical to the test. The important thing is that the sample turns blue.

(Excerpted and adapted from Green, 1997, and Ellett, 1993.)

BIOCHEMICAL OXYGEN DEMAND (BOD)

Biochemical oxygen demand measures the amount of oxygen that microorganisms consume while decomposing organic matter; it also measures the chemical oxidation of inorganic matter (i.e., the extraction of oxygen from water via chemical reaction). The rate of oxygen consumption in an estuary is affected by a number of variables, including temperature, the presence of certain kinds of microorganisms, and the type of organic and inorganic material in the water.

The Role of Biochemical Oxygen Demand in the Estuarine Ecosystem

BOD directly affects the amount of dissolved oxygen in estuaries. The greater the BOD, the more rapidly oxygen is depleted. This means less oxygen is available to aquatic organisms. The consequences of high BOD are the same as those for low dissolved oxygen: many aquatic organisms become stressed, suffocate, and die. Examples of BOD levels are provided in Table 9-3. Sampling locations with traditionally high BOD are often good candidates for more frequent DO sampling.

Table 9-3. Significant BOD Levels *(from Campbell and Wildberger, 1992).*

Type of Water	BOD (mg/l)
unpolluted, natural water	<5
raw sewage	150-300
wastewater treatment plant effluent	8-150*

**Allowable level for individual treatment plant specified in discharge permit*

Sources of BOD include leaves and woody debris; dead plants and animals; animal waste; effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants; failing septic systems; and urban stormwater runoff. Although some waters are naturally organic-rich, a high BOD often indicates polluted or eutrophic waters. ■

Sampling Considerations

BOD is affected by the same factors that affect DO. Chlorine can also affect BOD measurements by inhibiting or killing the microorganisms that decompose the organic and inorganic matter in a sample. In some water samples, chlorine will dissipate within 1-2 hours of being exposed to light. Such exposure often happens during sample handling or transport. However, if you are sampling in heavily chlorinated waters, such as those below the effluent discharge point from a wastewater treatment plant, it may be necessary to neutralize the chlorine with sodium thiosulfate (see APHA, 1998). ■

How to Measure Biochemical Oxygen Demand

The standard BOD test is a simple means of measuring the uptake of oxygen in a sample over a predetermined period of time. Citizens can easily collect the required water samples as they monitor the water for other variables. The BOD test does, however, demand a several-day period of water storage in the dark to obtain results. Test for BOD using the following steps:

- Collect two water samples from the same place in the water column (surface or at depth) using the water sampling protocol described earlier for DO. Each bottle should be labeled clearly so that the samples will not be confused. Make sure there is no contact between the sample water and the air.
- Immediately measure the first sample for DO using either a DO meter or DO kit. Record the time of sample collection and the water temperature. Place the second sample in a standard BOD bottle. The bottle should be black to prevent photosynthesis. You can wrap a clear bottle with black electrician's tape, aluminum foil, or black plastic if you do not have a black or brown glass bottle.
- Incubate the bottle of untested sample water at 20°C and in total darkness (to prevent photosynthesis). After 5 days of incubation, use the same method of testing to measure the quantity of DO in the second sample. Because of the 5-day incubation, the test should be conducted in a laboratory.
- The BOD is expressed in milligrams per liter of DO using the following equation:

BOD = DO (mg/l) of 1st bottle – DO of 2nd bottle

This represents the amount of oxygen consumed by microorganisms to break down the organic matter present in the sample bottle during the incubation period.

Sometimes by the end of the 5-day incubation period, the DO level is zero. This is especially true for monitoring sites with a lot of organic pollution (e.g., downstream of wastewater discharges). Since it is not known when the zero point was reached, it is not possible to tell what the BOD level is. In this case, it is necessary to collect another sample and dilute it by a factor that results in a final DO level of at least 2 mg/l. Special dilution water containing the nutrients necessary for bacterial growth should be used for the dilutions. Some supply houses carry premeasured nutrient "pillows" to simplify the process. APHA (1998) describes in detail how to dilute a sample and conduct the BOD analysis.

It takes some experimentation to determine the appropriate dilution factor for a particular sampling site. The final result is the difference in DO between the first measurement and the second after multiplying the second result by the dilution factor. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Other references:

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.

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

Ellett, K. 1993. *Chesapeake Bay Citizen Monitoring Program Manual*. Alliance for the Chesapeake Bay. Richmond, VA. 57 pp.

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.

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

Stancioff, E. 1996. *Clean Water: A Guide to Water Quality Monitoring for Volunteer Monitors of Coastal Waters.* Maine/New Hampshire Sea Grant Marine Advisory Program and University of Maine Cooperative Extension. Orono, ME. 73 pp.

U.S. Environmental Protection Agency (USEPA). 1998. *Condition of the Mid-Atlantic Estuaries*. EPA 600-R-98-147. November. Office of Research and Development, Washington, DC. 50 pp.

Chapter 10

Nutrients

Nutrients—especially nitrogen and phosphorus—are key water quality parameters in estuaries. Nutrient concentrations vary according to surrounding land use, season, and geology. Because nitrogen and phosphorus play such important roles in the estuarine ecosystem, it is not surprising that volunteer groups very commonly monitor these two nutrients.

Photos (l to r): K. Register, R. Ohrel, The Ocean Conservancy, E. Ely

Overview

Nutrients—especially nitrogen and phosphorus—are key water quality parameters in estuaries. Depending on their chemical forms (or species), nitrogen and phosphorus can have significant direct or indirect impacts on plant growth, oxygen concentrations, water clarity, and sedimentation rates, just to name a few. Nitrogen's primary role in organisms is protein and DNA synthesis; plants also use this substance in photosynthesis. Phosphorus is critical for metabolic processes, which involve the transfer of energy. Because nitrogen and phosphorus play such important roles in the estuarine ecosystem, it is not surprising that volunteer groups very commonly monitor these two nutrients.

Nutrient concentrations vary according to surrounding land use, season, and geology. This chapter discusses factors that the volunteer monitor should consider when establishing a nutrient monitoring program. Sample monitoring instruments and techniques are described. Finally, an additional monitoring opportunity for volunteers—atmospheric deposition—is introduced.

Why Monitor Nutrients?

Nutrients are chemical substances used for maintenance and growth that are critical for survival. Plants require a number of nutrients—carbon, nitrogen, phosphorus, oxygen, silica, magnesium, potassium, calcium, iron, zinc, and copper—to grow, reproduce, and ward off disease. Of these nutrients, nitrogen and phosphorus are of particular concern in estuaries for two reasons:

- they are two of the most important nutrients essential for the growth of aquatic plants; and
- the amount of these nutrients being delivered to estuaries has increased significantly.

Eutrophication is a condition in which high nutrient concentrations stimulate excessive algal blooms, which then deplete oxygen as they decompose (Figure 10-1). The organic production can also lead to sediment accumulation. Because of the potential impacts of nutrients, citizen monitoring programs often focus on nitrogen and phosphorus as indicators of estuarine health.

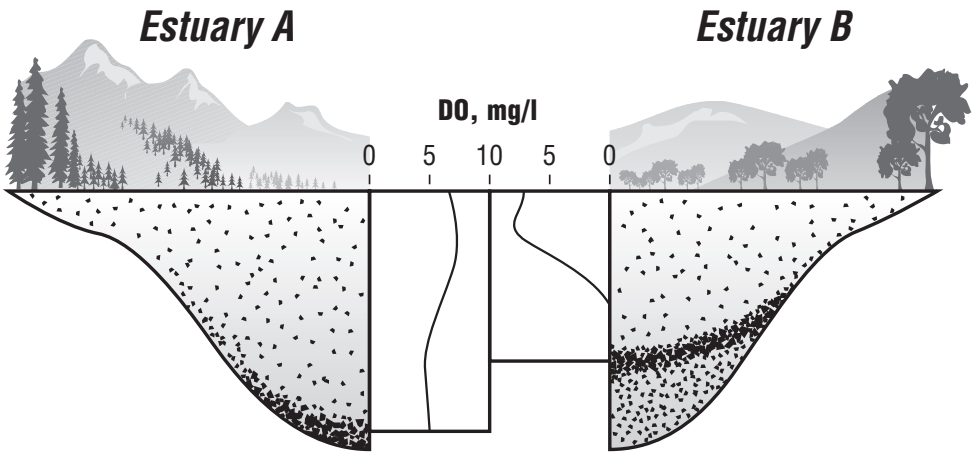


Figure 10-1. Eutrophication. Estuary B receives more nutrient loads than Estuary A. As a result, Estuary B experiences more plant production and organic material accumulation. Dissolved oxygen levels are also lower in Estuary B, especially in deeper water, due to the decomposition of organic matter. *(Adapted from Cole, 1994.)*

Nutrient Sources

Nitrogen and phosphorus enter estuaries from several natural and human-made sources (Figure 10-2). Natural sources of nitrogen and phosphorus in the estuary include:

- fresh water that runs over geologic formations rich in phosphate or nitrate;
- decomposing organic matter and wildlife waste; and
- the extraction of nitrogen gas from the atmosphere by some bacteria and blue-green algae (known as nitrogen fixation).

There are three major manmade or anthropogenic sources of nutrients: atmospheric deposition, surface water, and groundwater. Atmospheric sources include fossil fuel burning by power plants and automobiles. Nutrients from these sources may fall to the land or estuary either directly or along with precipitation. Surface water inputs include point and nonpoint source discharges: effluent from wastewater treatment plants, urban stormwater runoff, lawn and agricultural fertilizer runoff, industrial discharges, and livestock wastes. Groundwater sources are primarily underwater seepage from agricultural fields and failing septic systems.

The Role of Nutrients in the Estuarine Ecosystem

Figures 10-3 and 10-4 illustrate the nitrogen and phosphorus cycles, respectively. Although nutrients are essential for the growth and survival of an estuary's plants, an excess of nitrogen and phosphorus may trigger a string of events that seasonally deplete dissolved

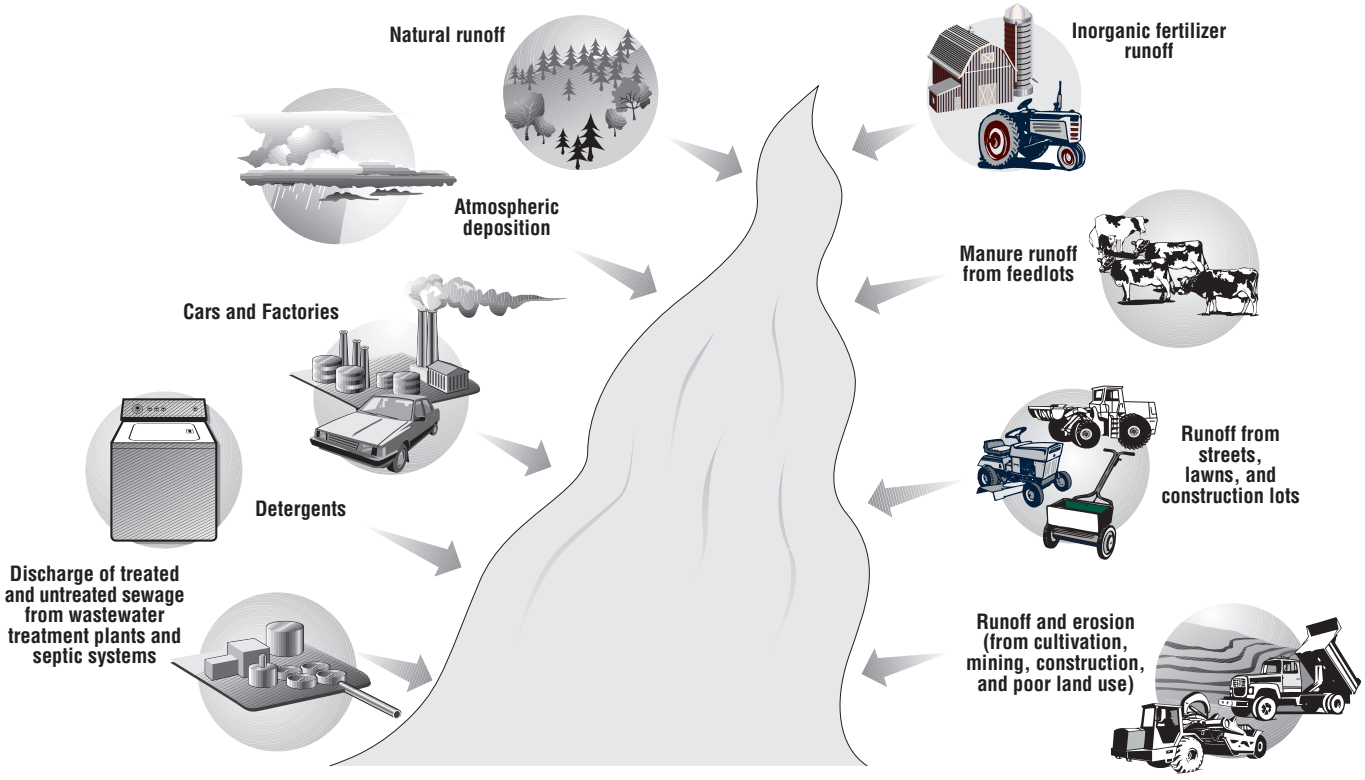


Figure 10-2. Typical nutrient sources to an estuary.

oxygen (DO) in the water (see Chapter 9). As stated earlier, an overabundance of such nutrients can lead to uncontrolled growth of phytoplankton (minute floating plants) or algae—these are often referred to as blooms.

Water clouded by thick patches of these tiny plants does not allow sunlight to penetrate to the bottom. Submerged aquatic vegetation (see Chapter 18) requires light for photosynthesis; if the plants' fronds (leaves) are covered or if the water is too cloudy during much of the growing season, these plants will die.

When algae and phytoplankton die, they are decomposed by oxygen-consuming bacteria. Especially slow-moving waterbodies with insufficient mixing may become **hypoxic** (low in oxygen). Under the worst conditions, the bottom waters of an estuary turn **anoxic** (without oxygen). Excessive nutrient concentrations have been linked to hypoxic conditions in over 50 percent of U.S. estuaries. Even coastal ocean areas, such as the Gulf of Mexico, have been impacted, endangering economically and ecologically important fisheries (USGS, 1999).

High nutrient concentrations have also been linked to harmful or nuisance phytoplankton blooms—such as "red tides" and "brown tides"—some of which produce harmful toxins (see Chapter 19). Nutrients are also believed to be one cause for the growth of the potentially toxic dinoflagellate *Pfiesteria*, found in estuaries along Atlantic coasts (USGS, 1999). These events may result in fish and shellfish kills and be harmful to human health.

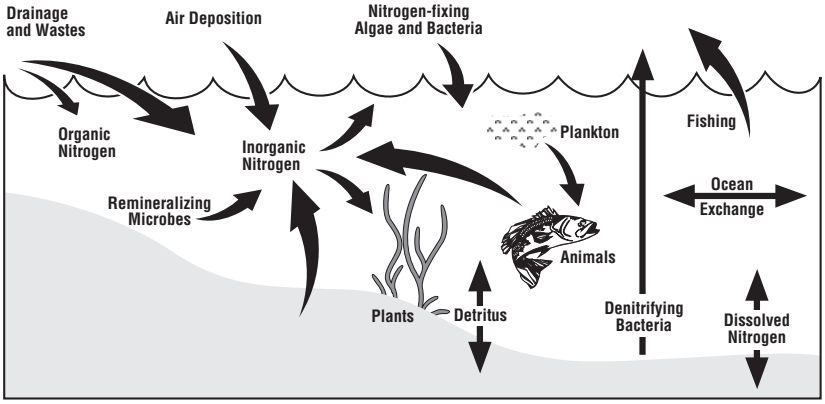


Figure 10-3. The nitrogen cycle *(adapted from USEPA, 1987).*

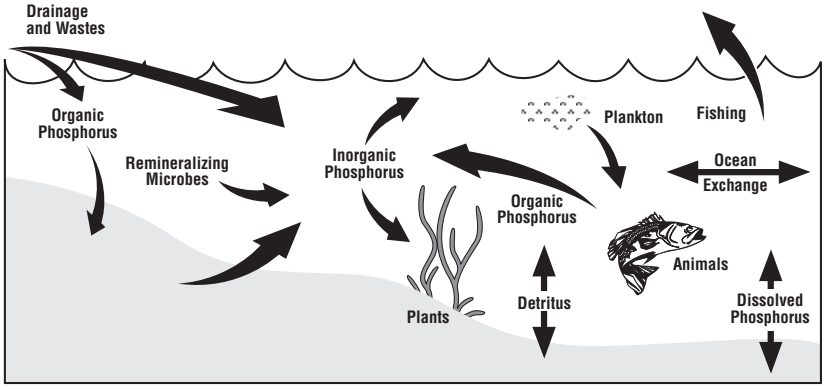


Figure 10-4. The phosphorus cycle *(adapted from USEPA, 1987).*

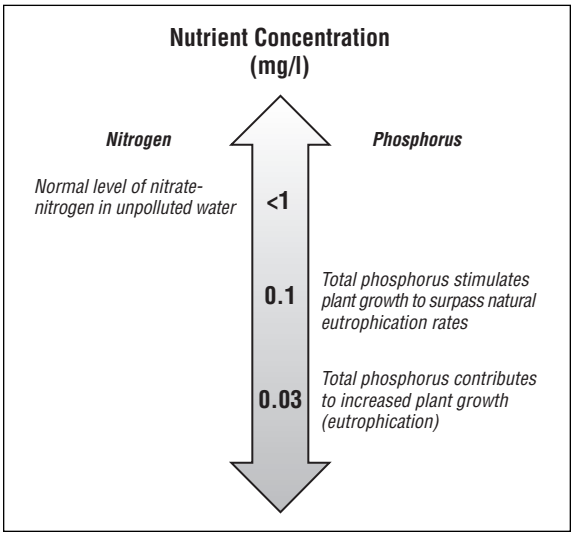


Figure 10-5. Significant levels of nutrients in aquatic systems *(Campbell and Wildberger, 1992).*

Levels of Nutrients

Nutrient concentrations are always in flux, responding to changes in:

- precipitation and amount of runoff;
- fertilizer or manure application rates;
- estuary flushing rates;
- water temperature;
- biological activity in the estuary; and/or
- the status of other water quality parameters.

Figure 10-5 shows significant levels for nutrients in estuarine waters.

Nutrient concentrations are usually greatest during spring and early summer, when fertilizer use and water flow from tributaries and irrigation activities are high.

High nutrient concentrations can also be detected during seasonal low-flow conditions (USGS, 1999). During winter low-flow periods, for example, the lack of land and aquatic plant uptake combined with contributions from groundwater can result in high nitrogen levels. Nutrient levels downstream from urban areas may also be high during low-flow periods. At these times, contributions from point sources can be greater relative to streamflow, and dilution is less (USGS, 1999).

Nutrient levels also vary among watersheds. Natural features (e.g., geology and soils) and land management practices (e.g., drainage and irrigation) can affect the movement of nitrogen and phosphorus over land, creating local and regional effects on estuarine water quality (USGS, 1999).

Tidal stage may also cause fluctuations in nutrient levels, but many volunteer programs have found that "chasing the tides" does not yield enough additional information to make the effort worthwhile. ■

Sampling Considerations

Chapter 6 summarized several factors that should be considered when identifying monitoring sites, where to monitor in the water column, and when to monitor. In addition to the considerations in Chapter 6, a few additional ones specific to nutrient monitoring are presented here.

When to Sample

In setting up a nutrient monitoring plan, the program manager should ensure that the effort will continue for several seasons. Since the workings of an estuary are complex, a mere year or two of nutrient data is insufficient to capture the variability of the system. In fact, a couple of years of unusual data may be quite misleading and tell a story very different from the long-term situation (note the variability in Figure 10-6).

Volunteers should sample nutrients on a weekly basis, although biweekly sampling will still yield valuable information. However, sampling at a small number of sites every week or two cannot possibly capture the constantly changing water quality of an entire estuary. The key to effective nutrient monitoring is to sample at a sufficiently frequent interval and at enough representative sites so that the data will account for most of the inherent variability within the system. In temperate climates, some programs have eliminated wintertime measurements when aquatic plants are dormant and the effects of nutrients are not so marked. A few measurements during the winter, however, will provide a baseline of nutrient levels that can be compared to the rest of the year's data.

Where to Sample

If the monitoring program is designed to pinpoint trouble spots in the estuary, the program manager should cluster monitoring sites where point and nonpoint sources of nutrients appear to enter the water. Such sites might include an area near the discharge pipe of a wastewater treatment plant or adjacent to an agricultural area where fertilizers are applied or livestock congregate.

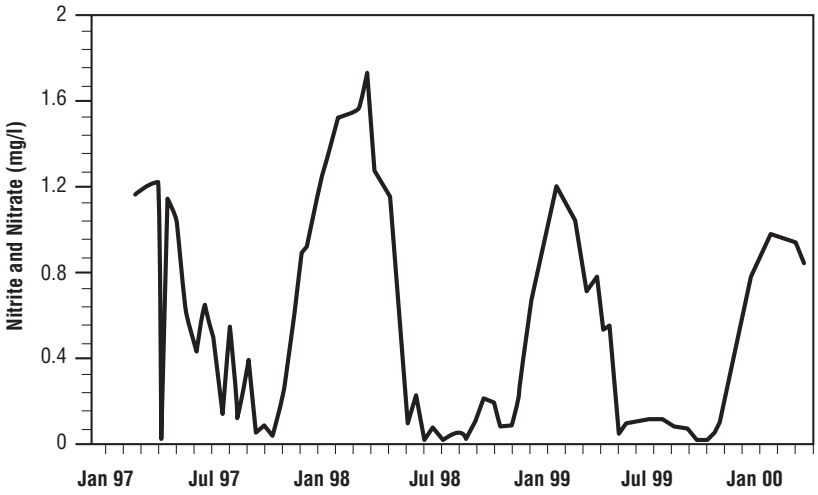


Figure 10-6. Seasonal fluctuations of nitrite and nitrate—two forms of nitrogen—in a typical mid-Atlantic estuary.

Because nutrient levels often vary with depth, especially during the summer when the estuary is well-stratified, volunteer groups may wish to collect samples at different depths. Van Dorn and Kemmerer samplers (see Chapter 7) are commonly used to collect these kinds of samples. In addition, there are several water samplers designed primarily for collecting samples at different depths. Appendix C provides a list of equipment suppliers.

Special Consideration: The Different Forms of Nutrients

Nitrogen and phosphorus come in many different chemical forms, or **species**, which are determined by a number of environmental conditions. Measuring each nutrient species can help identify its source into the estuary. Therefore, volunteer efforts to measure different nutrient species can provide significant information to resource managers.

Table 10-1. Examples of nitrogen species and notes about potential sources *(adapted from Phinney, 1999).*

Nitrogen Species	***Notes About Possible Species Sources***
Nitrate (NO_3^-), Nitrite (NO_2^-) and NO_x ("nox")	• Make up 70 percent of total nitrogen inputs from groundwater to smaller watersheds in the Chesapeake Bay • Make up approximately 15 percent of total nitrogen found in agricultural fertilizers • NO_2^- is generally a short-lived nitrogen species that is measured in low oxygen environments • NO_x from fossil fuel burning makes up at least 25 percent of atmospheric nitrogen inputs into coastal waters (Paerl and Whiteall, 1999)
Ammonium (NH_4^+) and unionized ammonia (NH_3)	• Make up 5.8 percent of total nitrogen in lawn fertilizer • Make up 20 percent of total nitrogen in agricultural fertilizers • Primary nitrogen component from animal feedlot operations (AFOs)
Urea (an organic form of nitrogen)	• Makes up 12 percent of total nitrogen in lawn fertilizer • Makes up 38-45 percent of total nitrogen in agricultural fertilizers

Nitrogen Forms and Impacts

Although nitrogen makes up about 80 percent of the earth's atmosphere, it is inaccessible to most terrestrial and aquatic organisms. Some types of bacteria and blue-green algae, however, can "fix" nitrogen gas, converting it to an inorganic nitrogen form—thereby making it available to other organisms.

In the estuary, nitrogen exists in a variety of chemical (e.g., ammonium, nitrate, and nitrite) and particulate and dissolved organic forms (e.g., living and dead organisms). Table 10-1 summarizes information about different nitrogen species and their connection to surrounding land activities.

The quantity and form of nitrogen in the water can also closely relate to dissolved oxygen levels. Bacteria are able to convert nitrogen into different nitrogen species and gain energy from the process. Through **nitrification**, some bacteria transform ammonium into nitrite and then to nitrate. This biological process consumes oxygen. When nitrification is inhibited by low dissolved oxygen conditions, ammonia or nitrite forms of nitrogen may accumulate.

Through **denitrification**, bacteria convert nitrate to nitrite and then to nitrogen gas. This process occurs under anoxic conditions and helps rid the system of excess nitrogen.

Nitrate and urea are highly soluble in water, a characteristic which facilitates their transport to the estuary by runoff. Ammonium is also soluble in water; it can be transformed to ammonia in low oxygen environments and escape to the atmosphere. All of these nitrogen species promote phytoplankton, algae, and bacterial blooms (Phinney, 1999). Certain nitrogen species can have other adverse impacts. At high concentrations, nitrates are toxic to eelgrass, and ammonia is toxic to fish (Maine DEP, 1996).

Phosphorus Forms and Impacts

Phosphorus also exists in the water in several forms: organic phosphate, orthophosphate (inorganic, dissolved phosphorus), total phosphorus (dissolved and particulate), and polyphosphate (from detergents). Orthophosphate in the water comes from fertilizers and is the form commonly measured. Organic phosphate results from plant and animal waste. Decomposition of dead plants and animals also adds organic phosphorus to the water. In general, excess phosphates can enter an estuary from water treatment plants, sewage, soils, agricultural fields, animal feedlot operations, and lawns.

Many phosphorus species attach to soil particles and are, therefore, transported to the estuary with eroded soil. Especially high phosphorus loads are often delivered during periods of high runoff from storms or irrigation activities.

Under oxygenated conditions, phosphate will

form chemical complexes with minerals such as iron, aluminum, and manganese and fall to the bottom sediments. In cases when this nutrient is found mostly in sediments, water column concentrations may not provide a full picture of nutrient loads and impacts. If the bottom water in an estuary has no oxygen, however, phosphate bound to the sediments is released back into the water. This release can fuel yet another round of phytoplankton blooms.

Choosing a Sampling Method

A dilemma arises for program managers when deciding upon the appropriate method for measuring nutrient levels in an estuary. On one hand, kits for nitrogen and phosphorus can be imprecise; on the other, submitting prepared samples for lab analysis is costly and time consuming. Program managers frequently arrange to have a college or professional lab donate its time and facilities to the volunteer effort.

If the data are intended to supplement state or federal efforts, it is wise to confer with the agency beforehand to determine an acceptable monitoring method. Whatever sampling method is chosen, program managers should periodically compare the citizen monitoring data to duplicate samples analyzed by another method under laboratory conditions.

The following sections provide an overview of possible nutrient analysis methods, along with each method's advantages and pitfalls.

Test Kits

Several companies manufacture kits for analyzing the various forms of nitrogen and phosphorus. While the kits are not precise or accurate when nutrient levels are low, the manager may choose to use them when deemed appropriate given the program's data objectives. The kits rely on a color comparison in which the volunteer matches the color of a prepared water sample to one in a set of provided standards. The subjectivity of each volunteer's decision as well as ambient light levels will influence the results to some degree.

Kits are suitable for identifying major nutrient sources, such as wastewater and animal feedlots, where levels are generally higher than the surface water in the estuary. Areas where concentrations routinely exceed concentrations of 1 mg/l are good candidates for kit analysis.

While the kits are generally easy to use, many state and federal agencies will reject nutrient data derived from their use because of their imprecision and subjective nature. In some cases, data that are collected from the use of kits may be helpful as a screening tool.

Spectrophotometer

A spectrophotometer measures the quantity of a chemical based on its characteristic absorption spectrum. This is accomplished by comparing the collected sample to a reference sample, also called a **standard**. Spectrophotometers are generally quite accurate although the instruments are expensive to purchase and maintain. Programs with ample funds for equipment may want to consider purchasing this reliable instrument, which costs from $1,000 to $6,000. Because reagents and standards are required, the volunteer program will have an added expense of a few hundred dollars.

The instrument requires proper maintenance and precise calibration; therefore, the program manager or someone familiar with this equipment must oversee its care and use.

Colorimeter

A colorimeter compares the intensity of color between the sample and a standard in order to measure the quantity of a compound in the sample solution.

Cheaper than a spectrophotometer, electric colorimeters offer citizen programs a reasonably priced alternative. They are quite accurate, fairly easy to use, and can provide direct meter readout. Colorimeters range in price from $250 to $2,000.

Like the spectrophotometer, this instrument can be used for forms of both nitrogen and

phosphorus. The colorimeter is a more affordable alternative for those programs that prefer a method less costly than the spectrophotometer and more accurate than the kits.

Similar to a spectrophotometer, a colorimeter requires standard maintenance and reagents, which must be purchased on a regular basis. The colorimeter provides accurate data only when properly maintained and precisely calibrated by a professional.

Laboratory Analysis

Analysis of nutrients by a professional laboratory is by far the most accurate means of obtaining nutrient data. Most laboratories institute strict quality assurance and quality control methods to ensure consistently reliable results. A college or professional lab may offer its services free of charge to the volunteer program.

If the program decides to use lab analysis, it must ensure that its volunteers adhere to strict guidelines while collecting samples. Sloppy field collection techniques will result in poor data no matter how sophisticated the lab may be. ■

Reminder!
To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

How to Monitor Nutrients

General procedures for collecting and analyzing samples for nutrients are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7. A visual assessment of phytoplankton density is particularly recommended to aid nutrient data interpretation—nutrient concentrations in a water sample may be low because phytoplankton are utilizing the nutrients.

STEP 1: Check equipment.

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site when sampling for nutrients:

Procedure A—Equipment for test kit analysis

- fully stocked nitrogen and phosphorus kits, with instructions for use;
- clean polypropylene sample bottles or scintillation vials (60 ml) (see Chapter 7 for details on cleaning reusable sampling containers);
- water sampler (if collecting samples from other than the surface); and
- appropriate type of equipment and water for making sample dilutions.

Procedure B—Equipment for preparing sample for laboratory analysis

- clean polypropylene sample bottles or scintillation vials (60 mg/l) (see Chapter 7 for details on cleaning reusable sampling containers);
- filter assembly and supporting equipment (many laboratories require filtered samples);
- water sampler (if collecting samples from other than the surface);
- ice cooler with ice packs to keep samples cool and in darkness; and
- properly labeled preservation chemicals.

Sampling Hint:

If using a boat to reach the sampling location, make sure that it is securely anchored. It is best not to bring up the anchor until the sampling is completed since mud (with associated nutrients) may become stirred into the water.

STEP 2: *Collect the water sample.*

Volunteers must follow strict guidelines to prevent contamination of the sample. For example, it is preferable to use a standard sampling bottle rather than a simple bucket since a washed and capped bottle is less likely to become contaminated than an open container.

Chapter 7 reviews general information about collecting a water sample using a bottle or Whirl-pak bag. Volunteers using bottles should be sure to:

- Rinse the bottle by pushing it into the water in a forward motion, holding the container by the bottom. This technique will keep water contaminated by skin oils and dirt from entering the mouth. Fill the bottle a quarter full and swish the water around the inside, making sure to cover all inside surfaces. Pour out the water on the down-current side of the boat and away from the actual sampling site. Rinse the cap as well.
- After rinsing, push the bottle back into the water in the same manner to collect a sample for analysis.
- Fill the bottle to the shoulder, leaving an airspace. Cap the bottle.
- If the samples are not to be measured that day, they should be preserved according to the requirements specified by the test kit manufacturer, laboratory conducting the analysis, water quality agency, etc. The preservation technique may vary according to the type of nutrient and the method by which it is measured.
- Store the container in a cold, dark ice chest to minimize bacterial activity and phytoplankton growth.
- Filtered samples may require a polypropylene syringe and filter that can be screwed on. Bottle rinsing should be done with filtered water before the final sample is added.

NOTE: Volunteers using test kits may prefer to place the kit's test tube or bottle directly into the water to collect the sample. Eyedroppers are helpful in filling the test tube to the marked line.

STEP 3: *Measure nutrients or prepare sample for laboratory analysis.*

Procedure A—Elements of test kit analysis

- Conduct the test as soon as possible after collecting the water sample. As the sample sits, organisms living in the water will use up nutrients, changing the nutrient concentrations in the water.
- Before starting the analysis, double-check that the bottles, test tube or sample bottle, and any other equipment that will come in contact with the sample are clean. Reagents should be maintained at about 20°C to yield the best results.
- Make sure the sample water is well mixed.

- Follow the protocol for each nutrient type as outlined in the instructions accompanying the kit.
- Immediately record the results on the data sheet.

Procedure B—Prepare sample for laboratory analysis

Volunteers may need to filter the sample, depending on the nutrient species being analyzed. This activity removes the particulate nutrient fraction from the dissolved fraction. Individual laboratories may require different filtering techniques; therefore, volunteer groups should consult with their laboratory to determine how samples should be filtered.

STEP 4: *Clean up and send off data.*

Volunteers should thoroughly clean all equipment, whether using the test kit or the lab preparation method. Follow laboratory or test kit instructions for cleaning. Allow the equipment to air dry before storing it. If volunteers used the filtration technique, they should detach the filter unit from the syringe, unscrew it, and clean all parts. The paper filter can be thrown away.

Properly dispose of wastes generated during the performance of tests (see Chapter 7).

Make sure that the data sheet is complete and accurate. Volunteers should make a copy of the completed data sheet before sending it to the project manager in case the original data sheet becomes lost.

After preserving the samples, follow laboratory guidelines for packing and shipping them to the analytical lab. This step should be done as soon as possible.

Warning!

The interpretation of nutrient concentration data must be done with care. While high nutrient levels suggest the potential for explosive algal growth, low levels do not necessarily mean the estuary is receiving less nutrient input. Large quantities of nutrients may flow into the estuary and be quickly taken up by phytoplankton. Zooplankton, in turn, graze upon the phytoplankton. Phosphorus may also bind with minerals in the sediment, which settle to the bottom, but may be reintroduced to the water column under low oxygen conditions.

In this scenario, although water nutrient concentration is low, the quantity of nutrients tied up in sediment and biomass (living matter) is high. Chlorophyll analysis is needed to quantify the phytoplankton biomass and interpret the low nutrient concentrations.

Special Topic: Atmospheric Deposition of Nutrients

Over the past 30 years, scientists have collected a large amount of convincing information demonstrating that air pollutants can be deposited on land and water, sometimes at great distances from their original sources. Atmospheric deposition, then, can be an important contributor to declining estuarine water quality.

What Is Atmospheric Deposition and How Does It Occur?

Nitrogen pollutants released into the air are carried by wind away from their place of origin. These pollutants come from manmade sources such as fossil fuel burning, industrial processes, cars and other forms of transportation, fertilizer, and the volatilization of animal wastes. Air deposition can also come from natural sources of emissions.

Atmospheric deposition occurs when pollutants in the air fall on the land or water. Pollution deposited in snow, fog, or rain is called **wet deposition**, while the deposition of pollutants as dry particles or gases is called **dry deposition**. Air pollution can be deposited into waterbodies either directly from the air onto the surface of the water or through indirect deposition, where the pollutants settle on the land and are then carried into a waterbody by runoff.

How Much Water Pollution from Nutrients Is Atmospheric?

Nitrogen is one of the most common air deposition pollutants, especially in the eastern United States. Since 1940, human activity has doubled the rate of nitrogen cycling through the global atmosphere, and the rate is accelerating (Vitousek et al., 1997). Depending on the waterbody and watershed being considered, it is estimated that roughly a quarter of the nitrogen in an estuary comes from air sources (Paerl and Whiteall, 1999). Table 10-2 shows estimated nitrogen sources in the Chesapeake Bay watershed.

Table 10-2. Estimated sources of nitrogen in the Chesapeake Bay *(Alliance for the Chesapeake Bay, 1997).*

Waterborne point sources (e.g., industry, sewage treatment plants, etc.)	25%
Runoff from land* (e.g., farms, lawns, city streets, golf courses, etc.)	50%
Air sources* (e.g., electric power plants, vehicles, municipal waste combustors, etc.)	25%

**This estimate of air sources includes indirect air deposition that reaches the bay as runoff from forests, streets, farmland, and anywhere else it is deposited.*

In the Chesapeake Bay region, it is estimated that 37 percent of the nitrogen entering the bay from air sources comes from electric utilities; 35 percent from cars and trucks; 6 percent from industry and other large sources of fossil fuel-fired boilers; and 21 percent from other sources such as ships, airplanes, lawnmowers, construction equipment, and trains (Alliance for the Chesapeake Bay, 1997).

Some other estuaries have also attempted to estimate how much of the nitrogen in their water comes from air sources, including both direct and indirect deposition (see Table 10-3).

Table 10-3. Amount and percentage of nitrogen entering the estuarine systems due to atmospheric deposition *(NEP Web site).*

Bay or Estuary	Million Tons of Nitrogen	% of Total Nitrogen
Albemarle-Pamlico Sounds	9	38-44
Delaware Bay	8	15
Delaware Inland Bays*	-	21
Long Island Sound	12	20
Massachusetts Bays*	-	5-27
Narragansett Bay*	0.6	12
Sarasota Bay*	-	2
Tampa Bay*	1.1	28

** Indicates measurement of direct deposition to water surface only.*

What Can Volunteers Do?

Presently, atmospheric deposition monitoring by volunteers is in its early stages. One potential procedure that may interest volunteer groups is a passive sampler that measures ammonia concentrations (Greening, 1999). The samplers are small disks that are set out for several days (up to one week), collected, and then sent to a laboratory for analysis. The procedure is still being developed and refined.

Another way volunteers can assist with atmospheric deposition monitoring is to measure rainfall. Rainfall measurements in watershed sub-basins are critical in determining the contribution of wet deposition to estuarine nutrient concentrations. Precipitation monitoring can also be instrumental in determining potential causes for other pollutants (e.g., sediments).

Steps for Monitoring Precipitation

- Place a rain gauge in an open area away from interference from overhead obstructions and more than one meter above the ground (see Chapter 7). Avoid obstructions making angles greater than 45^{o} from the top of the gauge.
- Check the gauge after each rainfall, record the amount of precipitation and the time of measurement, and then empty the gauge. If the gauge sits after a rainfall, evaporation can falsify the measurement.
- Make sure that the data sheet is complete and accurate. Volunteers should make a copy of the completed data sheet before sending it to the project manager in case the original data sheet becomes lost. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

U.S. Environmental Protection Agency. Web site: http://www.epa.gov/owow/oceans/airdep/index.html

Other references:

Alliance for the Chesapeake Bay. 1997. *Air Pollution and the Chesapeake Bay.* White Paper of the Alliance for the Chesapeake Bay. 16 pp.

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.

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

Cole, G. A. 1994. *Textbook of Limnology.* 4th ed. Waveland Press, Prospect Heights, IL.

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

Ellett, K. 1993. *Chesapeake Bay Citizen Monitoring Program Manual*. Alliance for the Chesapeake Bay. Richmond, VA. 57 pp.

Greening, H. 1999. "Atmospheric Deposition Monitoring." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Mobile, AL: March 17-19, 1999.

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

Kerr, M., L. Green, M. Raposa, C. Deacutis, V. Lee, and A. Gold. 1992. *Rhode Island Volunteer Monitoring Water Quality Protocol Manual.* URI Coastal Resources Center, RI Sea Grant, and URI Cooperative Extension. 38 pp.

LaMotte Chemical Products Company. Undated. *Laboratory Manual for Marine Science Studies.* Educational Products Division, Chestertown, MD. 41 pp.

Maine Department of Environmental Protection (DEP). May 1996. *A Citizen's Guide to Coastal Watershed Surveys.* 78 pp.

Paerl, H. W., and D. R. Whiteall. 1999. "Anthropogenically-Derived Atmospheric Nitrogen Deposition, Marine Eutrophication and Harmful Algal Bloom Expansion: Is There a Link?" *Ambio* 28(4): 307-311.

Phinney, J. 1999. "Nurients and Toxics." In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Stancioff, E. November 1996. *Clean Water: A Guide to Water Quality Monitoring for Volunteer Monitors of Coastal Waters.* Maine/New Hampshire Sea Grant Marine Advisory Program and Univ. of Maine Cooperative Extension. Orono, ME. 73 pp.

U.S. Geological Survey (USGS). 1999. *The Quality of Our Nation's Waters-Nutrients and Pesticides.* USGS Circular 1225. 82 pp.

Vitousek, P.M., J. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger, and G.D. Tillman. 1997. "Human Alteration of the Global Nitrogen Cycle: Causes and Consequences." *Issues in Ecology*. No. 1, Spring 1997. Ecological Society of America, 15 pp.

Web sites:

Air Deposition

National Estuary Program (NEP): http://www.epa.gov/owow/estuaries/airdep.htm

Chapter 11

pH and Alkalinity



Every estuary is part of the carbon cycle. Carbon moves from the atmosphere into plant and animal tissue, and into water bodies. Alkalinity, acidity, carbon dioxide (CO_2), pH, total inorganic carbon, and hardness are all related and are part of the inorganic carbon complex. There are fascinating interrelationships among these factors. For example, the amount of carbon dioxide in the water affects (and is affected by) the pH and photosynthesis.

Photos (l to r): G. Carver, K. Register, R. Ohrel

Overview

This chapter discusses two additional chemical parameters of estuaries that are monitored to increase our understanding of the water's health: pH and alkalinity. Since the pH of water is critical to the survival of most aquatic plants and animals, monitoring pH values is an important part of nearly every water quality monitoring program. The testing is quick and easy and can establish a valuable baseline of information so that unanticipated water quality changes can be better understood.

Testing water samples for total alkalinity measures the capacity of the water to neutralize acids. This test is important in determining the estuary's ability to neutralize acidic pollution from rainfall or wastewater.

Every estuary is part of the carbon cycle. Carbon moves from the atmosphere into plant and animal tissue, and into water bodies. Alkalinity, acidity, carbon dioxide (CO_2), pH, total inorganic carbon, and hardness are all related and are part of the inorganic carbon complex. There are fascinating interrelationships among these factors. For example, the amount of carbon dioxide in the water affects (and is affected by) the pH and photosynthesis.

Why Monitor pH and Alkalinity?

Routine monitoring of a waterbody should provide baseline information about normal pH and alkalinity values. Unanticipated decreases in pH could be indications of acid rain, runoff from acidic soils, or contamination by agricultural chemicals. Values of pH outside the expected range of 5.0 to 10.0 should be considered as indications of industrial pollution or some cataclysmic event. Likewise, a long-term database on alkalinity values provides researchers with the ability to detect trends in the chemical makeup of estuary waters. ■

pH

pH is a measure of how acidic or basic (alkaline) a solution is. It measures the hydrogen ion (H^+) activity in a solution, and is expressed as a negative logarithm. The pH measurements are given on a scale of 0.0 to 14.0 (Figure 11-1). Pure water has a pH of 7.0 and is **neutral**; water measuring under 7.0 is **acidic**; and that above 7.0 is **alkaline** or **basic**. Most estuarine organisms prefer conditions with pH values ranging from about 6.5 to 8.5.

Values of pH are based on the logarithmic scale, meaning that for each 1.0 change of pH, acidity or alkalinity changes by a factor of ten; that is, a pH of 5.0 is ten times more acidic than 6.0 and 100 times more acidic than 7.0. When the hydrogen and hydroxyl ions are present in equal number (the neutral point), the pH of the solution is 7.

The Role of pH in the Estuarine Ecosystem

Water's pH is affected by the minerals dissolved in the water, aerosols and dust from the air, and human-made wastes as well as by plants and animals through photosynthesis and respiration. Human activities that cause significant, short-term fluctuations in pH or long-term acidification of a waterbody are exceedingly harmful. For instance, algal blooms that are often initiated by an overload of nutrients can cause pH to fluctuate dramatically over a few-hour period, greatly stressing local organisms. Acid precipitation in the upper freshwater reaches of an estuary can diminish the survival rate of eggs deposited there by spawning fish.

Several other factors also determine the pH of the water, including:

- bacterial activity;
- water turbulence;
- chemical constituents in runoff flowing into the waterbody;
- sewage overflows; and
- impacts from other human activities both in and outside the drainage basin (e.g., acid drainage from coal mines, accidental spills, and acid precipitation).

Estuarine pH levels generally average from 7.0 to 7.5 in the fresher sections, to between 8.0 and 8.6 in the more saline areas. The slightly alkaline pH of seawater is due to the natural buffering from carbonate and bicarbonate dissolved in the water.

The pH of water is critical to the survival of most aquatic plants and animals. Many species have trouble surviving if pH levels drop under 5.0 or rise above 9.0. Changes in pH can alter other aspects of the water's chemistry, usually to the detriment of native species. Even small shifts in the water's pH can affect the solubility of some metals such as iron and copper. Such changes can influence aquatic life indirectly; if the pH levels are lowered, toxic metals in the estuary's sediment can be resuspended in the water column. This can have impacts on many aquatic species. See Chapter 12 for more information on toxins. ■

Sampling Considerations

Chapter 6 summarized several factors that should be considered when determining monitoring sites, where to monitor, and when to monitor. In addition to the considerations in Chapter 6, a few additional ones specific to monitoring pH are presented here.

When to Sample

It is well-established that levels of pH fluctuate throughout the day and season, and a single pH measure during the day may not draw a very accurate picture of long-term pH conditions in the estuary. Photosynthesis by aquatic plants removes carbon dioxide from the water; this significantly increases pH. A pH reading taken at dawn in an area with many aquatic plants will be different from a reading taken six hours later when the plants are photosynthesizing. Likewise, in waters with plant life (including planktonic algae), an increase in pH can be expected during the growing season. For these reasons, it is important to monitor pH values at the same time of day if you wish to compare your data with previous readings. It is also important to monitor pH values over a long period of time to provide useful data. The actual time to measure pH will depend on local conditions and the monitoring goals of the volunteer program.

Choosing a Sampling Method

The pH test is one of the most common analyses done in volunteer estuary monitoring programs. In general, citizen programs use one of two methods to measure pH: (1) the colorimetric method or (2) electronic meters. Both require that measurements be taken in the field, since the pH of a water sample can change quickly due to biological and chemical processes.

Color comparator (also called "colorimetric") field kits are easy to use, inexpensive, and sufficiently accurate to satisfy the needs of most programs. The colorimetric method can also be used with an electronic colorimeter. If very precise measures are required, more expensive electronic pH meters provide extremely accurate readings. Test paper strips to obtain pH are *unsuitable* for use in estuarine waters since they do not provide consistent measurements in salt water. The following sections describe the use of the two common methods.

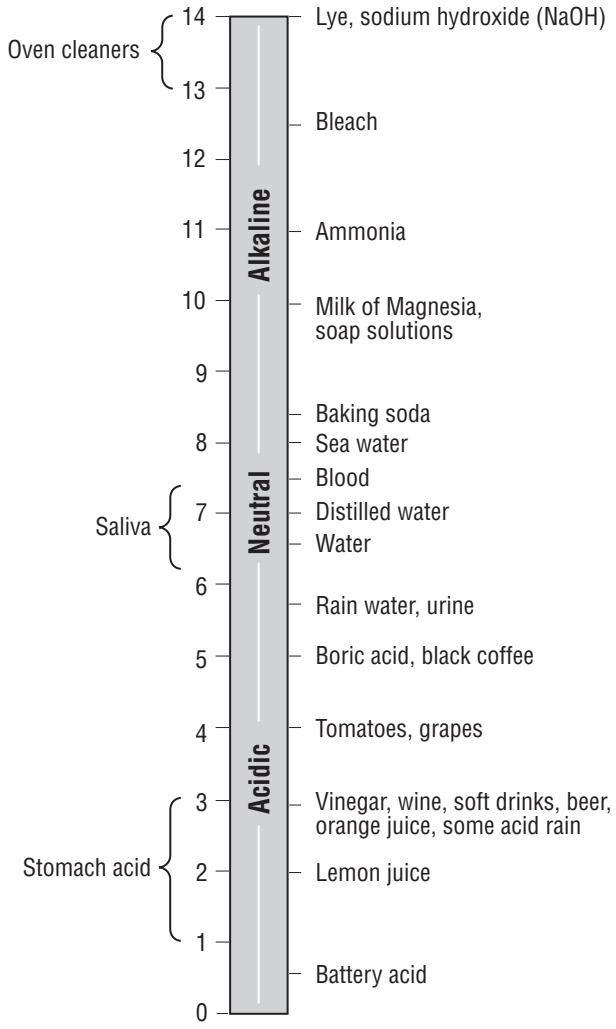


Figure 11-1. pH range scale.

Colorimetric Method

Colorimetric means "to measure color." In a colorimetric test method, reagents are added to a water sample, and a reaction occurs which produces a color. The color can be measured visually or electronically. This method is not suitable for water containing colored materials such as dissolved organic compounds or excessive algae. For water samples that are colored, a meter is suggested.

Visual Method to Measure Color

Field kits cover a range of pH values. They cost between $15 and $50, depending on the range of pH values to be tested. These kits come with several color standards built into a plastic housing unit or printed on a card. After adding reagents according to the instructions, the volunteer compares the color in the test tube

with the standards to determine the pH value. If the general pH values of the estuary are known, pick a kit that includes these values within its range of sensitivity. Some programs prefer to use a wide-range kit that covers pH values from 3.0 to 10.0 until the measured range of values for that waterbody has been established. After determining the actual range over several seasons, switch to a narrower range kit for greater accuracy. Make sure kits have been checked against pH standards.

Electronic Method to Measure Color

An electronic colorimeter measures the amount of light that travels through the reacted sample and converts the measurement to an analog or digital reading (LaMotte, 1999). A reagent is added to the water sample in a test tube, which is then inserted into the colorimeter for analysis. Usually electronic colorimeters are capable of testing multiple water quality parameters.

pH Meters

Although more expensive than the colorimetric field kits, pH meters give extremely accurate readings of a wide range of pH values. The more economical pH testers cost about $40. Some more expensive meters ($75 - $750) also will display the water temperature, and some meters have cables so that you can obtain readings throughout the water column. Unlike the colorimetric method, meters can be used even if the water is clouded or colored. ■

Helpful Hint:
If your water quality monitoring program plans to collect data on alkalinity, pH meters with built-in temperature sensors are required rather than the colorimetric kits.

pH Calibration Standards

Whether you use a field kit, pH meter, or colorimeter unit, calibration standards (also called "buffer solutions") are employed to ensure that your equipment is accurate. The standards most commonly used are pH 4.00 (or 4.01), pH 7.00, and pH 10.00. They are available in liquid or powder form (the powder is added to demineralized or deionized water). These pH standards cost from $5 to $25 each, depending on the quantity of calibrations you will be conducting.

Following is information regarding buffers:

- Because buffer pH values change with temperature, the buffer solutions should be at room temperature when you calibrate the meter. Usually you can calibrate your pH equipment at home, a few hours before using it. Check manufacturer's instructions.
- Do not use a buffer after its expiration date.
- Always cap the buffers during storage to prevent contamination.
- Do not reuse buffer solutions!

How to Measure pH Values

General procedures for measuring pH are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5)**.

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

Reminder!
To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- pH colorimetric field kit; or
- pH meter with built-in temperature sensor; or
- colorimeter unit with reagents.

STEP 2: *Collect the sample.*

If you are using the colorimetric method to measure pH, you can fill the test tube by lowering it into the water. If using a meter, you can sometimes put the meter directly in the water—you don't need to collect a sample. But if monitoring from a dock or boat, you will need to collect a water sample using screw-cap bottles, Whirl-pak bags, or water samplers. Refer to Chapter 7 for details.

Volunteer using a color comparator, or colorimetric field kit (photo by K. Register).

STEP 3: *Measure pH values.*

Colorimetric Method

The colorimetric methods (both visual and electronic meter) use indicators that change color according to the pH of the solution. Follow the directions in your colorimetric kit.

Since the test tube for the colorimetric tests is small, a clean eyedropper is useful as you fill the tube with the correct amount of sample water. With colorimetric kits, you add a chemical or two (reagents) to your water sample, and compare the resulting color of the water sample to the color standards of known pH values. With the field kits, which use visual assessments, it is helpful to place white paper in the background of the tube to emphasize any color differences, especially if the sample's color is faint. Record the pH value of the standard that most closely matches the color of the sample. If the sample hue is between two standards, check your program's quality assurance project plan (QAPP) (see Chapter 5). Some QAPPs require you to average the values of the two closest standards, and record this number as the pH. Other plans require you to select the closest value, and do not allow you to average the values.

pH Meter

Consistent calibration of equipment will ensure that high quality data are collected. The pH meter should be calibrated prior to sample analysis and after every 25 samples according to the instructions in the meter manual. Use two pH standard buffer solutions (see the box, "pH Calibration Standards," page 11-4). After calibration, place the electrode into the water sample and record the pH. The glass electrode on these meters must be carefully rinsed with deionized water after each use to ensure accurate results in the future.

STEP 4: *Clean up and send off data.*

Volunteers should thoroughly clean all equipment.

Make sure that the data sheet is complete, legible, and accurate, and that it accounts for all samples. Volunteers should make a copy of the completed data sheet before sending it to the designated person or agency in case the original data sheet becomes lost. ■

TOTAL ALKALINITY

Alkalinity (also known as "buffer capacity") is a measure of the capacity of water to neutralize acids. Alkaline compounds such as bicarbonates, carbonates, and hydroxides, remove hydrogen ions and lower the acidity of the water (thereby increasing pH). They usually do this by combining with the hydrogen ions to make new compounds.

Alkalinity is influenced by rocks and soils, salts, certain plant activities, and certain industrial wastewater discharges. Some water can test on the acid side of the pH scale and still rank high in alkalinity! This means that, while the water might be acidic, it still has a capacity to buffer, or neutralize, acids.

Total alkalinity is measured by measuring the amount of acid (e.g., sulfuric acid) needed to bring the sample to a pH of 4.2. At this pH, all the alkaline compounds in the sample are "used up." The result is reported as milligrams per liter of calcium carbonate (mg/l $CaCO_3$).

The Role of Alkalinity in the Estuarine Ecosystem

Measuring alkalinity is important in determining the estuary's ability to neutralize acidic pollution from rainfall or wastewater. Without this acid-neutralizing capacity, any acid added to a body of water would cause an immediate change in pH. This buffering capacity of water, or its ability to resist pH change, is critical to aquatic life. The estuary's capacity to neutralize acids will vary between the freshwater reaches of the estuary and the portions with higher salinity.

Total Alkalinity Levels in Estuaries

Total alkalinity of seawater averages 116 mg/l and is greater than fresh water, which can have a total alkalinity of 30 to 90 mg/l, depending on the watershed. The brackish waters of an estuary will have total alkalinity between these values. ■

Sampling Considerations

Choosing a Sampling Method

For total alkalinity, a double endpoint titration using a pH meter and a digital titrator is recommended. This can be done in the field or in the lab. If you plan to analyze alkalinity in the field, it is recommended that you use a digital titrator. Another method for analyzing alkalinity uses a buret. For volunteer programs, using a digital titrator is recommended over the buret, because digital titrators are portable, economical, take less time, and have easy-to-read endpoints (results).

Digital Titrator

This method involves **titration,** the addition of small, precise quantities of sulfuric acid (the reagent) to the sample until the sample reaches a certain pH (the **endpoint**). The amount of acid used corresponds to the total alkalinity of the sample.

Digital titrators have counters that display numbers. A plunger is forced into a cartridge containing the reagent by turning a knob on the titrator. As the knob turns, the counter changes in proportion to the amount of reagent used. Alkalinity is then calculated based on the amount used. Digital titrators cost approximately $100; the reagents (chemicals) to conduct total alkalinity tests cost about $36. Additionally, alkalinity standards are needed for accuracy checks (see the box, "Alkalinity Calibration Standards," page 11-9). ■

Reminder!

To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

How to Measure Alkalinity

General procedures for measuring alkalinity are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

The alkalinity method described below (using a digital titrator) was developed by the Acid Rain Monitoring Project of the University of Massachusetts Water Resources Research Center (River Watch Network, 1992).

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- digital titrator;
- 100-ml graduated cylinder;
- 250-ml beaker;
- pH meter with built-in temperature sensor;

- reagent (sulfuric acid titration cartridge, 0.16 N);
- standard alkalinity ampules, 0.500 N, for accuracy check; and
- bottle with deionized water to rinse pH meter electrode.

STEP 2: *Collect the sample.*

If you plan to analyze a water sample in the lab for alkalinity, then follow these collection and storage steps:

- Use 100 ml plastic or glass bottles.
- Label the bottle with site name, date, time, data collector, and analysis to be performed.
- Wearing gloves, plunge the bottle into the water. Fill the bottle completely and cap tightly.
- Avoid excessive agitation and prolonged exposure to air.
- Place the bottle in the cooler. Samples should be analyzed as soon as possible, but can be stored at least 24 hours by cooling to 4°C (39°F) or below. NOTE: Samples should be warmed to room temperature before analyzing (Hach, 1997).

STEP 3: *Measure total alkalinity.*

Alkalinity is usually measured using sulfuric acid with a digital titrator. Follow the steps below in the field or lab. Remember to wear latex or rubber gloves.

Add sulfuric acid to the water sample in measured amounts until the three main alkaline compounds (bicarbonate, carbonate, and hydroxide) are converted to carbonic acid. At pH 10, hydroxide (if present) reacts to form water. At pH 8.3, carbonate is converted to bicarbonate. At pH 4.5, all carbonate and bicarbonate are converted to carbonic acid. Below this pH, the water is unable to neutralize the sulfuric acid and there is a linear relationship between the amount of sulfuric acid added to the sample and the change in the pH of the sample. So, more sulfuric acid is added to the sample to reduce the pH by exactly 0.3 pH units (which corresponds to an exact doubling of the pH) to a pH of 4.2. However, the exact pH at which the conversion of these bases might have happened, or total alkalinity, is still unknown.

Arriving at total alkalinity requires an equation (given below) to extrapolate back to the amount of sulfuric acid that was added to actually convert all the bases to carbonic acid. A multiplier (0.1) then converts this to total alkalinity as mg/l of calcium carbonate ($CaCO_3$). To determine the alkalinity of your sample, follow these steps:

- Samples should be warmed to room temperature before analyzing.
- Insert a clean delivery tube into the 0.16N sulfuric acid titration cartridge and attach the cartridge to the titrator body.
- Hold the titrator, with the cartridge tip pointing up, over a sink or waste bottle. Turn the delivery knob to eject air and a few drops of titrant. Reset the counter to 0 and wipe the tip.
- Measure the pH of the sample using a pH meter. If it is less than 4.5, skip to step 3a, page 11-9.
- Insert the delivery tube into the beaker containing the sample. Turn the delivery knob while magnetically stirring the beaker until the pH meter reads 4.5. Record the number of digits used to achieve this pH. Do not reset the counter.
- Continue titrating to a pH of 4.2 and record the number of digits.
- Apply the following equation:

  Alkalinity (as mg/l $CaCO_3$) = (2a - b) x 0.1

  Where:

  a = digits of titrant to reach pH 4.5

  b = digits of titrant to reach pH 4.2 (including digits required to get to pH 4.5)

  0.1 = digit multiplier for a 0.16 titration cartridge and a 100 ml sample

Example:

Initial pH of sample is 6.5.

It takes 108 turns to get to a pH of 4.5.

It takes another 5 turns to get to pH 4.2, for a total of 113 turns.

Alkalinity = [(2 x 108) - 113] x 0.1
= 10.3 mg/l

- Record alkalinity as mg/l $CaCO_3$ on the data sheet.
- Rinse the beaker with distilled water before the next sample.

STEP 3a:

If the pH of your water sample, prior to titration, is less than 4.5, proceed as follows:

- Insert the delivery tube into the beaker containing the sample.
- Turn the delivery knob while swirling the beaker until the pH meter reads exactly 0.3 pH units less than the initial pH of the sample.
- Record the number of digits used to achieve this pH.
- Apply the equation as before, but a = 0 and b = the number of digits required to reduce the initial pH exactly 0.3 pH units.

Example:

Initial pH of sample is 4.3.

Titrate to a pH of 0.3 units less than the initial pH; in this case, 4.0.

It takes 10 digits to get to 4.0.

Enter this in the 4.2 column on the data sheet and note that the pH endpoint is 4.0.

Alkalinity = (0 - 10) x 0.1
= -1.0

- Record alkalinity as mg/l $CaCO_3$ on the data sheet.
- Rinse the beaker with distilled water before the next sample.

Note on Data Sheet for Alkalinity

Data sheets should be specialized depending on which methods your program uses to measure each parameter—and this is true for alkalinity, too. With the method described in this manual, your worksheet should include places for volunteers to record the results of the various steps described.

Alkalinity Calibration Standards

You will need to do an accuracy check on your alkalinity test equipment before the first field sample is titrated, again about halfway through the field samples, and at the final field sample. For this, you will need an alkalinity standard. Often, these come in pre-measured glass ampules. To use, break off the tip of the glass ampule and pour the liquid into a beaker. Then, follow the directions found under "Step 4: Perform an accuracy check." The price for the alkalinity standards is about $23 for 20 2-ml ampules.

STEP 4: *Perform an accuracy check.*

This accuracy check should be performed on the first field sample titrated, again about halfway through the field samples, and at the final field sample. Check the pH meter against pH 7.00 and 4.00 buffers after every 10 samples.

- Snap the neck off an alkalinity ampule standard, 0.500 N; or, if using a standard solution from a bottle, pour a few milliliters of the standard into a clean beaker.
- Pipet 0.1 ml of the standard to the titrated sample (see above). Resume titration back to the pH 4.2 endpoint. Record the number of digits needed.
- Repeat using two more additions of 0.1 ml of standard. Titrate to the pH 4.2 after each addition. Each 0.1 ml addition of standard should require 250 additional digits of 0.16 N titrant.

STEP 5: *Return the field data sheets and/or samples to the lab.*

Volunteers should thoroughly clean all equipment and transport the samples to the designated lab. Alkalinity samples must be analyzed within 24 hours of their collection. If the samples cannot be analyzed in the field, keep the samples on ice and take them to the lab or drop-off point as soon as possible.

Make sure that the data sheets are complete, legible, and accurate, and that they account for all samples. Volunteers should make a copy of the completed data sheets before sending them to the designated person or agency in case the original data sheet becomes lost. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

Ellett, K. 1993. *Chesapeake Bay Citizen Monitoring Program Manual*. Alliance for the Chesapeake Bay. Richmond, VA. 57 pp.

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

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

LaMotte Chemical Products Company. Undated. *Laboratory Manual for Marine Science Studies.* LaMotte Educational Products Division, Chestertown, MD. 41 pp.

River Watch Network. 1992. *Total Alkalinity and pH Field and Laboratory Procedures.* (Based on University of Massachusetts Acid Rain Monitoring Project.)

Other references:

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.

Godfrey, P. J. 1988. *Acid Rain in Massachusetts.* University of Massachusetts Water Resources Research Center. Amherst, MA.

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Chapter 12

Toxins

Testing for toxins requires specialized equipment and expertise beyond the means of most volunteer monitoring programs. Nonetheless, it is important to understand the sources of toxins and the role they play in estuaries. Volunteers can provide valuable assistance with research projects by providing local knowledge of a watershed and potential sources of toxic compounds and by collecting fish and invertebrates for laboratory analysis.

Photos (l to r): G. Carver, R. Ohrel, R. Ohrel

Overview

Since industrialization in the late 1940s and 1950s, the amount of contaminants and toxic substances put into estuaries has greatly increased. These contaminants include heavy metals (such as mercury, lead, cadmium, zinc, chromium, and copper) and synthetic (manmade) organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides (e.g., dichlorodiphenyltrichloroethane—DDT), and human sewage. Many of these toxins such as PCBs and DDT do not degrade for hundreds of years and can concentrate in the sediment and in the tissues of local aquatic animals. Sources of toxins into estuaries include industrial discharges; runoff from lawns, streets, and farmlands; and discharges from sewage treatment plants. The estuary's own sediment can also serve as a source, as sediment contains years of toxic deposits. Other toxic substances are deposited into estuaries from the atmosphere. Mercury vapor and lead particles from industrial sources enter estuaries from the atmosphere as rain, snow, or dry particles. All toxins can affect an estuary's biological structure and populations. Humans, in turn, can be harmed by consuming bottom-dwelling organisms such as shellfish that are exposed to contaminated sediment as well as through exposure to contaminated water.

Testing for many of these toxins requires specialized equipment and expertise beyond the means of most volunteer monitoring programs. Nonetheless, it is important to understand the sources of toxins and the role they play in estuaries. Volunteers can provide valuable assistance with research projects by providing local knowledge of a watershed and potential sources of toxic compounds and by collecting fish and invertebrates for laboratory analysis.

This chapter reviews some of the toxic substances found in our nation's estuarine ecosystems, especially heavy metals, pesticides, PCBs, and PAHs, and introduces some testing techniques for toxins.

Toxins in Estuaries

There are two general classes of toxic pollutants found in estuaries—metals and organic compounds. Toxic metals include mercury, lead, cadmium, chromium, and copper. Some of these metals (e.g., copper) are required in small concentrations for metabolic processes but are toxic at higher levels. Organic compounds of interest include PAHs and several synthetic ones that are no longer produced, such as PCBs and DDT (USEPA, 1996). Other organic toxins of concern are biotoxins that are produced by harmful algal blooms (see Chapter 19). This chapter focuses on the more traditional organic compounds.

Sources of toxic substances include surface water from municipal and industrial discharges, runoff (e.g., from lawns, streets, and farmlands), and atmospheric deposition.

Lifespan of Toxins

How long pollutants remain in estuaries depends on the nature of the compound. Some pollutants bind to particles and settle, while others remain water soluble. Another factor is the flushing rate within the estuary. Many pollutants, including DDT and PCBs, have been banned in the United States since the 1970s, but are very chemically stable and persist in benthic sediment long after the pollution source has abated. ■

Toxicity

Toxins can affect the animals in an estuarine ecosystem through acute or chronic toxicity. Organisms suffer **acute toxicity** when exposure levels result in death within 96 hours. Lethal doses differ for each toxin and species, and are influenced by the potency and concentration of the toxin. **Chronic toxicity**—also referred to as sub-lethal toxicity—does not result in death (at exposures of at least 96 hours), but can cause impairment to aquatic animals, organ damage and failure, gastro-intestinal damage, and can affect growth and reproduction.

Why Monitor Toxins?

Monitoring for the presence of toxins provides information on possible effects to an estuary's community structure and populations. Human health is another important reason for monitoring. Bottom-dwelling organisms, like shellfish, can accumulate these metals and chemicals in their tissues, making them a potential risk to human health when consumed. When high concentrations of chemical contaminants are found in local fish and wildlife, state officials issue consumption advisories for the general population as well as for sensitive subpopulations such as pregnant women. Advisories include recommendations to limit or avoid consumption of certain fish and wildlife species from specific bodies of water. ■

Accumulation and Amplification of Toxins—Definitions

Biological accumulation (bioaccumulation)—The uptake and storage of chemicals (e.g., DDT, PCBs) from the environment by animals and plants. Uptake can occur through feeding or direct absorption from water or sediments.

Biological amplification (also called bioamplification, biomagnification or bioconcentration)—The concentration of a substance as it "moves up" the food chain from one consumer to another (Figure 12-1). The concentration of chemical contaminants (e.g., DDT, PCBs, methyl mercury) progressively increases from the bottom of the food chain (e.g., phyto-plankton, zooplankton) to the top of the food chain (e.g., fish-eating birds such as cormorants).

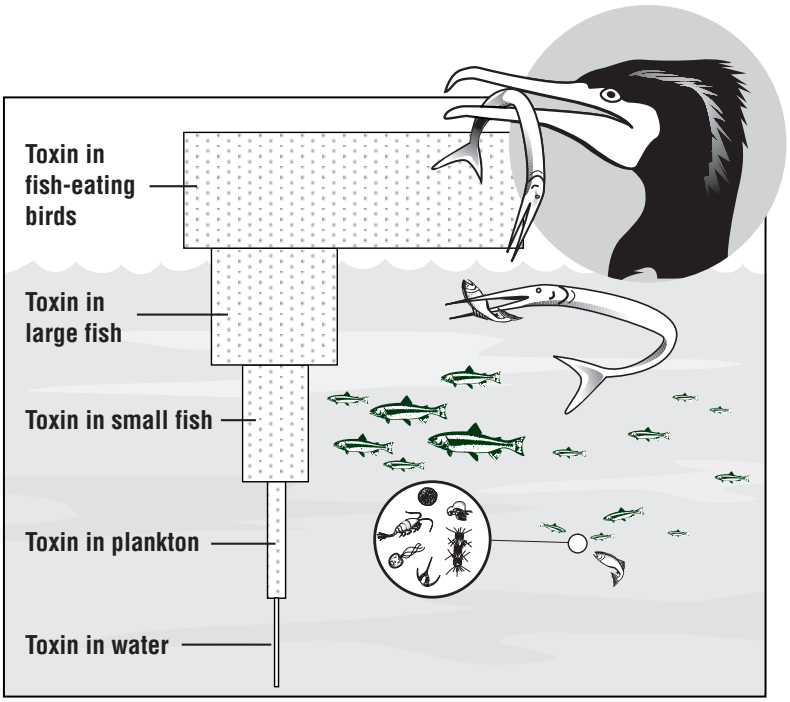


Figure 12-1. Biological amplification. Chemical concentrations progressively increase from lower to upper levels of the food chain.

The Role of Toxins in the Estuary Ecosystem

Though there are many toxic substances found in our nation's estuarine ecosystems, the categories of biggest concern are: heavy metals, pesticides, PCBs, and PAHs (USEPA, 1996).

Heavy Metals

Some toxic metals, such as copper and zinc, are needed in trace amounts for metabolism but are toxic in higher levels. Others, such as mercury, lead, chromium, and cadmium, have no known metabolic function. Their presence may prompt state officials to restrict water use, close shellfish waters, or issue fish consumption advisories. Generally, the three metals most closely monitored are mercury, copper, and lead because of their adverse effects on human health.

Mercury

Mercury is distributed throughout the environment from natural sources and from human activities. Sources of mercury from human activities (also called **anthropogenic sources**) include solid waste incineration and coal combustion facilities for electricity. Together, they contribute approximately 87 percent of the emissions of mercury in the United States. Other sources of mercury include municipal wastewater treatment plants and mining and industrial sources, such as smelting, pulp mills, paper mills, leather tanning, electroplating, chemical manufacturing, and cement production. In addition, mercury is deposited in surface waters through runoff from its natural occurrence in rocks and soils as well as from

Toxins in the water can make estuaries and other waterbodies unsafe for fishing or swimming (photo by R. Ohrel).

atmospheric deposition of volatile compounds from wetlands (USEPA, 1999c).

Methylmercury is the chemical form or "species" that bioaccumulates in the tissue of animals and bioamplifies in food chains. Mercury poisoning through consumption of methylmercury-contaminated food results in such adverse central nervous system effects as impairment to peripheral vision and mental capabilities, loss of feeling, and—at high doses—seizures, severe neurological impairment, and death. Methylmercury has also been shown to be a developmental toxicant, causing subtle to severe neurological effects in children.

Methylmercury makes up 90-100 percent of the mercury found in most adult fish. It binds to proteins and is found primarily in fish muscle (fillets). Concentrations of total mercury in fish are approximately 10,000 to 100,000 times higher than the concentrations of total mercury found in the surrounding waters.

Mercury contamination is one of the leading reasons that fish consumption advisories are issued in the United States. These advisories inform the public that concentrations of mercury have been found in local fish at levels of public health concern. State advisories recommend either limiting or avoiding consumption of certain fish from specific waterbodies (USEPA, 1999c).

Lead

Lead is used by the ton in products such as batteries, ammunition, solder, pipes, and in building construction. Lead poisoning is associated with kidney damage, anemia, and damage to the central nervous system. Of greatest concern are the dangers of lead poisoning to children, who can suffer permanent physical and mental impairments.

Cadmium

Cadmium is another heavy metal of concern because it can cause kidney and bone damage to people who suffer long-term chronic exposure to it. Sources of cadmium into the environment from human activities are mainly from the mining, extraction, and processing of copper, lead, and zinc. Other sources can include solid waste incineration, reprocessing of galvanized metal, and sewage sludge. Cadmium can also be found in some batteries, fertilizers, tires, and many industrial processes.

Copper

Copper is an essential nutrient, required by the body in very small amounts. However, the U.S. Environmental Protection Agency has found copper to potentially cause stomach and intestinal distress, liver and kidney damage, and anemia, depending on the level and term of exposure. Persons with certain diseases may be more sensitive than others to the effects of copper contamination.

Copper releases to land and water are primarily from smelting industries. Municipal incineration may also produce copper. Copper is also widely used in household plumbing materials.

Chromium

Depending on the level and term of exposure, chromium has the potential to cause skin irritation, ulcers, dermatitis, or damage to liver, kidney, circulatory, and nerve tissues.

Though widely distributed in soils and plants, chromium is rare in natural waters. The two largest sources of chromium emission in the atmosphere are chemical manufacturing industries and natural gas, oil, and coal combustion. Chromium may also reach waterways via:

- road dust;
- cement-producing plants;
- the wearing down of asbestos brake linings from automobiles or similar asbestos sources;

- municipal refuse and sewage sludge incineration;
- automotive catalytic converter exhaust;
- emissions from cooling towers that use chromium compounds as rust inhibitors;
- waste waters from electroplating, leather tanning, and textile industries; and
- solid wastes from chemical manufacture.

Pesticides

Another major category of toxins in estuaries is pesticides. Most of them will break down into nontoxic chemicals within a few days of application. Others are banned because they can persist for decades. Pesticides are developed to eliminate pests such as weeds (herbicides), insects (insecticides), rodents (rodenticides), fungi (fungicides), and other organisms that are considered undesirable.

Two of the more persistent pesticides are DDT and its breakdown product and closely related compound, DDD (dichlorodiphenyldichloroethane). They are both in a class of pesticides called organochlorines. These pesticides destroy living cells and affect the nervous system of organisms. DDT is a highly toxic, broad-spectrum poison that is capable of killing many different species. It was used extensively in the 1940s, 1950s, and 1960s because it was cheap to produce, effective, and not harmful to humans. For these reasons, it continues to be used in developing countries to eradicate the mosquito that transmits malaria. DDT was banned in the U.S. in 1972 because of its effects on wildlife, but it continues to be measured in sediment and in aquatic animals. In fact, buried sediments may be a large and continuing source of DDT compounds due to mixing processes such as flooding, dredging activities, and the disturbing of sediment by animals (called **bioturbation**), as well as other mechanisms.

Polychlorinated Biphenyls (PCBs) and Polycyclic Aromatic Hydrocarbons (PAHs)

PCBs are another class of banned synthetic organic chemicals comprising 209 individual chlorinated biphenyl compounds. Similar to DDT, PCBs are resistant to biological and chemical degradation and can persist in the environment for decades. There are no known natural sources of PCBs. Millions of metric tons of PCBs were used as solvents and in the electronic industry as insulators for transformers. Most PCBs are soluble in fats; therefore, they accumulate in the tissues of animals. Once incorporated into an animal's fat, PCBs will stay there and cannot be excreted. They are rapidly accumulated by aquatic organisms, becoming amplified in the food chain when animals eat PCB-contaminated organisms. PCB concentrations in fish at the top of the food chain can be 2,000 to more than a million times higher than the concentrations found in the surrounding waters (USEPA, 1999d).

While the manufacture and use of PCBs have been banned in the U.S. since 1976, the sediment of many estuaries can have high levels of PCB contamination, and PCBs can continue to enter estuaries from leaking shoreside landfills or from improper disposal. PCBs in the sediment can reenter the water column though natural processes and dredging activities. Although PCBs are declining in the environment, health concerns are still warranted.

Recent findings indicate that susceptible populations (e.g., certain ethnic groups, sport anglers, the elderly, pregnant women, children, fetuses, and nursing infants) continue to be exposed to PCBs via fish and wildlife consumption (USEPA, 1999d).

Exposure to PCB compounds involves different levels of harmful risks. There is much interest in determining if PCBs are **endocrine disrupters**—chemicals that can mimic, block, or otherwise disrupt the body's hormones. Some have been shown to act as

hormone disrupters in wildlife and possibly in laboratory animals. Human health studies indicate that eating fish containing PCBs can lead to significant health consequences including:

- reproductive dysfunction;
- deficiencies in neurobehavioral and developmental behavior, especially in newborns and school-aged children;
- other systemic effects (e.g., liver disease, diabetes, effects on the thyroid and immune systems); and
- increased cancer risks (e.g., non-Hodgkin's lymphoma) (USEPA, 1999d).

Polycyclic aromatic hydrocarbons, PAHs, are the byproducts of oil burning. They are carcinogenic (cancer causing) and mutagenic (change cell growth). They are also produced by burning coal and wood. They enter estuaries from leaking gas storage tanks, road runoff, sewage plants, industrial and municipal discharges, oil spills, and bilge water discharges. Creosote applied to wharf pilings also contains PAHs.

Other Notable Toxins

In addition to the toxins discussed above, there are many others that enter estuaries and affect their wildlife. Some of these include:

Dioxin

Dioxin, a byproduct of bleaching paper with chlorine, is associated with birth defects in humans. Chlorine combines with lignins (natural binders of wood fiber) to produce dioxin.

Tributyltin (TBT)

TBT, an antifouling paint additive used on boats and in marinas, is a fat-loving compound (lipophilic) that accumulates in the tissue of animals, and amplifies in the food chain. Contributions of TBT arise almost exclusively from anti-fouling bottom paints that are applied to boat hulls to retard the growth of barnacles and other fouling organisms. The greatest release of trace metals occurs when the paint is fresh or after hull cleaning when new layers of paint are exposed. Over the last few years, increasing regulation and controls have attempted to reduce emissions from this source to estuary waters. For example, TBT can no longer be used on small craft, but is used on ocean-bound tankers. Nonetheless, while the use of TBT is restricted, it is still in use and accumulates in harbor sediments.

Household chemicals, paints, cleaning chemicals, etc.

There are tens of thousands of chemicals used in industrial processes and in our homes. Little is known about their effects on aquatic life, how concentrated they are in estuaries, how long they persist in aquatic environments, or their interaction with each other. ■

Some Toxins Are from Biological Processes

Excessive algae growth can result in brown and red tides and other harmful blooms. Harmful algal blooms excrete biotoxins that can be hazardous to shellfish, fish, and humans. See Chapter 19 for more information.

Sampling Considerations

Toxic metal and organic pollutants are found in low concentrations in water—on the order of parts-per-billion and parts-per-trillion levels. But concentrations in the sediment are higher and range in the parts-per-million and parts-per-billion levels. Because of these low levels, collecting water and sediment samples for toxin analysis involves a high degree of rigor and training to limit inadvertent contamination of the sample. Sources of contamination include the polyethylene bottle, as well as the handling of the bottle. **Unless there is a clear justification and rigorous oversight, volunteer monitoring programs are discouraged from collecting samples for toxin analysis**. However, it is important that volunteer programs understand the general process of sampling for toxins and testing their impact.

Testing for the presence of toxic substances (metals and toxic chemical compounds) in estuary water and sediment usually requires a laboratory with expensive equipment, such as a mass spectrometer, high performance liquid chromatography, or atomic absorption spectrophotometer. Some toxins are in minute quantities and require a concentration step, such as organic extractions, to be analyzed.

One method scientists use to analyze the effects of a toxic substance on living organisms is called a **bioassay**, or biological assay. A bioassay is a controlled experiment using a change in biological activity as a qualitative or quantitative means of analyzing a material response to a pollutant. Depending on the test, microorganisms, planktonic animals, or live fish can be used as test organisms.

Scientists also look for biochemical indicators of contaminants by studying animals called biomarkers. They look for DNA damage in blood cells and the presence of stress proteins, which are produced in response to a wide variety of contaminants, including trace metals and organic pollutants. Volunteers may be able to assist with collecting fish and invertebrates to be used in the chemical analysis of tissue, or under a very high degree of training assist with the collection of sediment and water samples to be tested for toxicity. In some cases, volunteers collect shellfish and send them to a laboratory for tissue analysis. See Chapter 19 for more information.

Volunteer water quality monitoring programs interested in monitoring for toxins are recommended to work with a local college or laboratory which has the necessary equipment and knowledge. Any such study should carefully follow established protocols for analysis and testing (see, for example, APHA, 1998).

Volunteers can also assist with a field survey to identify potential sources of toxins in an estuary. See Chapter 7 for more information on field observations.

It should be noted that conventional toxicity tests and chemical analyses are rarely sufficient to identify the cause or sources of toxicity. Multiple contaminants are usually present in a toxic sample, and many of the contaminants may be at elevated concentrations. There are other important factors that influence toxicity, such as sediment organic carbon content or the size of sand grains.

Field test kits are available for some of the heavy metals and other pollutants that can be used in preliminary measurements. For example, one kit measures copper in estuaries that may exist as a soluble salt or as suspended solids. Test kits are also available for zinc, chlorine, chromate, iron, chloride, silica, and cyanide. Field test kits vary greatly in their detectable range and cost between $15 and $450. ■

Atmospheric Deposition of Toxins

Pollutants released into the air can be introduced to the estuary through atmospheric deposition (photo by R. Ohrel).

Over the past 30 years, scientists have collected a large amount of convincing information demonstrating that air pollutants can be deposited on land and water—sometimes at great distances from their original sources—and can contribute to declining estuarine water quality. This is called **atmospheric deposition**. Pollutants released into the air are carried by wind patterns away from their place of origin. These pollutants come from manmade or natural sources of emissions. For example, up to 25% of the mercury emitted worldwide is released naturally as part of the global mercury cycle.

Presently, atmospheric deposition monitoring by volunteers is in its early stages. In the future, there may be a role for volunteers to monitor the amount of toxins that are deposited from the atmosphere into estuaries. See Chapter 10 for more information on atmospheric deposition. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

Miller, G.T. 1999. *Environmental Science*. Wadsworth Publishing Company. Belmont, CA.

Southern California Coastal Water Research Project. 1999. FY 1999/2000 Research Plan.

U.S. Environmental Protection Agency (USEPA). 1996. *Environmental Indicators of Water Quality in the United States.* EPA 841-R-96-002. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1998. *Estuaries and Your Coastal Watershed.* EPA-842-F-98-009. Office of Water, Washington, DC. Web site: http://www.epa.gov/owowwtr1/oceans/factsheets/fact5.html.

U.S. Environmental Protection Agency (USEPA). 1999a. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories.* Vol. 2, 3rd ed. "Risk Assessment and Fish Consumption Limits." EPA 823-B-99-008. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999b. *Fact Sheet: Update: National Listing of Fish and Wildlife Advisories.* EPA-823-F-99-005. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999c. *Fact Sheet: Mercury Update: Impact on Fish Advisories*. EPA-823-F-99-016. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999d. *Fact Sheet: Public Health Implications of Exposure to Polychlorinated Biphenyls (PCBs).* EPA-823-F-99-019. Office of Water, Washington, DC.

Other references:

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.

Maine Coastal Program. 1998. *The Estuary Book.* State Planning Office, 38 State House Station, Augusta, ME 04333.

National Safety Council's Environmental Center. 1998. *Coastal Challenges: A Guide to Coastal and Marine Issues*. Prepared in conjunction with Coastal America. Web site: http://www.nsc.org/ehc/guidebks/coasttoc.htm

Web sites:

Restore America's Estuaries: http://www.estuaries.org/estuarywhat.html.

Atmospheric Deposition

National Estuary Program (NEP): http://www.epa.gov/owow/estuaries/airdep.htm

Unit Two

Physical Measures

Temperature • Salinity • Turbidity and Total Solids • Marine Debris

Photos (l to r): U.S. Environmental Protection Agency, R. Ohrel, S. Schultz, P. Bergstrom

Chapter 13

Temperature

Water temperature is closely connected to many biological and chemical processes in the estuary. For this reason, and because it is easily measured, temperature is commonly monitored by volunteer groups using thermometers or meters.

Photos (l to r): R. Ohrel, R. Ohrel, Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab, U.S. Environmental Protection Agency

Overview

Water temperature is closely connected to many biological and chemical processes in the estuary. For this reason, and because it is easily measured, temperature is commonly monitored by volunteer groups using thermometers or meters.

This chapter explains the significance and variability of estuarine water temperature and provides steps for collecting temperature data.

Why Monitor Temperature?

Temperature, probably the most easily measured parameter, is a critical factor influencing several aspects of the estuarine ecosystem. It influences biological activity and many chemical variables in the estuary.

The Role of Temperature in the Estuarine Ecosystem

Temperature plays many roles in the estuary. As water temperature increases, for example, the capacity of water to hold dissolved oxygen becomes lower. Water temperature also influences the rate of plant photosynthesis, the metabolic rates of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, and diseases (USEPA, 1997).

Many species regulate the timing of important events, such as reproduction and migration, according to specific water temperatures. Optimal temperatures (which vary with the species and their life stage) allow organisms to function at maximum efficiency. The slow change of temperature that comes with the seasons permits organisms to acclimate, whereas rapid shifts may adversely affect plants and animals. Temperature shifts of more than 1°-2°C can cause thermal stress and shock (Campbell and Wildberger, 1992). Long-term temperature changes can affect the overall distribution and abundance of estuarine organisms.

Throughout the winter, temperatures remain fairly constant from top to bottom. In spring and summer, the uppermost layer of an estuary grows warmer and mixing between this surface water and the cooler bottom water slows. As air temperatures cool through the autumn, the surface water becomes increasingly cold and increases in density. The surface water mass ultimately sinks when its density becomes greater than that of the underlying water mass. As the surface water moves down, mixing occurs and nutrients from the bottom are redistributed toward the surface. This introduction of nutrients to surface waters fuels phytoplankton growth (see Chapters 10 and 19).

Temperature is not generally constant from the water surface to the bottom. An estuary's water temperature is a function of:

- depth;
- season;
- amount of mixing due to wind, storms, and tides;
- degree of stratification (layering) in the estuary;
- temperature of water flowing in from the tributaries; and
- human influences (e.g., release of urban stormwater, warm water discharged from power plants). ■

Sampling Considerations

Where to Sample

Because temperatures change according to the many variables listed above, it is often helpful to measure water temperature throughout the water column and at different surface locations. By collecting samples at different depths, thermal layers within the estuary can be determined. This information, in turn, can be useful for analyzing other environmental parameters.

HELPFUL HINT

Temperature can only be measured at the monitoring site. If samples are to be taken to a laboratory for analysis, temperature should first be measured in the field.

When to Sample

As with other water quality variables, temperature should be measured at the same location and time of day each time volunteers collect data.

Choosing a Sampling Method

Water temperature is measured with a thermometer or meter. Alcohol-filled thermometers are less hazardous, when broken, than mercury-filled thermometers, making them the better option. Under field conditions, using a thermometer armored in plastic or metal will minimize breakage problems.

Some meters used to measure other parameters, such as pH or dissolved oxygen, also measure temperature and can be used instead of a thermometer.

Volunteer monitors usually take a single temperature reading while they collect other water quality data at their monitoring sites. While the single reading is useful, it does not fully provide details about daily trends. Temperature data loggers, which record data at regular intervals (usually hourly), could be deployed at selected monitoring sites. These instruments are able to continuously record data for up to months at a time. The data can then be downloaded directly into a computer database. As the costs of data loggers decline, they may become attractive options for volunteer programs. ■

Thermometer Accuracy

To assure accuracy, check the thermometer against a National Institute of Standards and Technology (NIST) certified thermometer at least once a year.

Confirm the thermometer's accuracy in several samples of water of varying temperatures. Your county health department or the state department of environmental protection may lend an NIST thermometer to the program for these important periodic checks.

Reminder!

To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

How to Monitor Temperature

General procedures for measuring temperature are presented in this section for guidance only. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

STEP 1: *Check equipment.*

Check to make sure that no separation has occurred in the thermometer liquid before each use.

If you are using a thermometer and not measuring directly in the water, bring a large (at least 2-gallon) clear container that can hold the sample. This will facilitate thermometer reading.

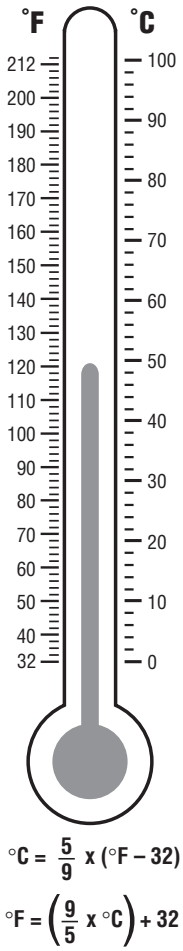


Figure 13-1. Temperature conversion scale.

STEP 2: *Measure air temperature.*

Chapter 7 specifies air temperature as one of the general observations that should be made at each monitoring site. Air temperature can be measured with the same thermometer or meter used for reading water temperature. Prior to measuring water temperature, allow the thermometer or meter to equalize with the ambient or surrounding air temperature for three to five minutes. Make sure the thermometer is out of direct sunlight to avoid a false high reading. **Record the air temperature on the data sheet before measuring the water temperature.**

STEP 3: *Measure water temperature.*

The following section describes two procedures to measure water temperature. If measuring temperature in shallow water or at the surface, follow Procedure A. If measuring temperature from a collected water sample, follow Procedure B.

Procedure A—Measuring temperature directly in shallow water or at the water surface:

- Place the thermometer or meter probe in the water at least 4 inches below the surface or halfway to the bottom (if in very shallow water).
- If using a thermometer, wait until it reaches a stable temperature (3-5 minutes). If using a meter, allow it to reach a stable reading.
- If possible, read the temperature with the thermometer bulb beneath the water surface. Otherwise, quickly remove the thermometer and read the temperature.
- Record the temperature on the field data sheet, using the scale (°C or °F) required by the program (Figure 13-1).
- If the meter probe has a long cable, you may measure temperature at different depths.

Procedure B—Measuring temperature from a collected water sample:

- Make sure the sample holds at least two gallons so that the water remains unaffected by the temperature of the thermometer and the air. The volunteer can use this same sample for many other typical water quality monitoring tests.
- Quickly immerse the thermometer or meter in the water sample.
- If using a thermometer, wait until it reaches a stable temperature (3-5 minutes). If using a meter, allow it to reach a stable reading.
- If possible, read the temperature with the thermometer bulb beneath the water surface. Otherwise, quickly remove the thermometer and read the temperature.
- Record the temperature on the field data sheet, using the scale (°C or °F) required by the program (Figure 13-1).

STEP 4: *Clean up and send off data.*

Thoroughly clean all equipment for proper storage.

Make sure the data sheets are complete and accurate. Volunteers should make a copy of the completed data sheets before turning them in to the laboratory, program manager, or designated drop-off point. ■

References and Further Reading

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.

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

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Chapter 14

Salinity

Because of its importance to estuarine ecosystems, salinity (the amount of dissolved salts in water) is commonly measured by volunteer monitoring programs.

Photos (l to r): U.S. Environmental Protection Agency, R. Ohrel, The Ocean Conservancy, P. Bergstrom

Overview

Because of its importance to estuarine ecosystems, salinity (the amount of dissolved salts in water) is commonly measured by volunteer monitoring programs. This chapter discusses the role of salinity in the estuarine environment and provides steps for measuring this water quality variable.

About Salinity

Salinity is simply a measure of the amount of salts dissolved in water. An estuary usually exhibits a gradual change in salinity throughout its length, as fresh water entering the estuary from tributaries mixes with seawater moving in from the ocean (Figure 14-1). Salinity is usually expressed in parts per thousand (ppt) or ‰.

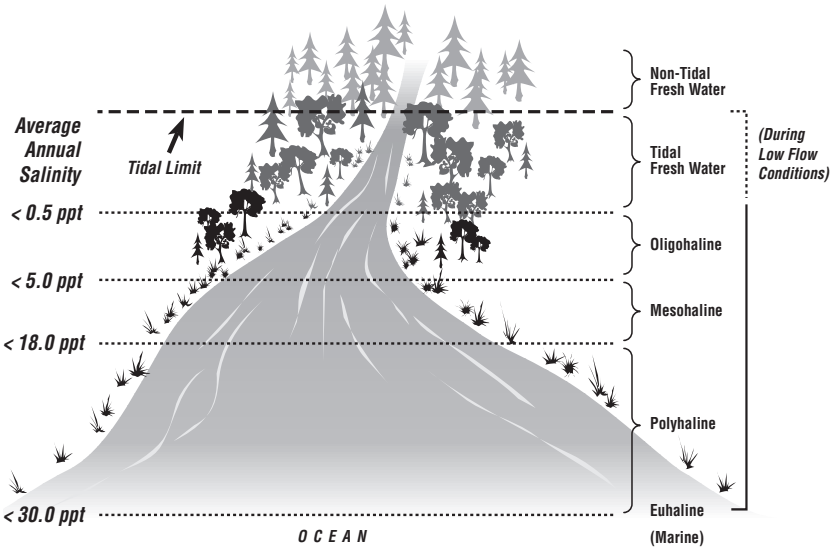


Figure 14-1. Estuarine salinity slowly increases as one moves away from freshwater sources and toward the ocean.

The fresh water from rivers has a salinity of 0.5 ppt or less. Within the estuary, salinity levels are referred to as oligohaline (0.5-5.0 ppt), mesohaline (5.0-18.0 ppt), or polyhaline (18.0-30.0 ppt). Near the connection with the open sea, estuarine waters may be euhaline, where salinity levels are the same as the ocean at more than 30.0 ppt (Mitsch and Gosselink, 1986).

Generally, salinity increases with water depth unless the estuarine water column is well mixed. Salinity, along with water temperature, is the primary factor in determining the stratification of an estuary. When fresh and salt water meet, the two do not readily mix. Warm, fresh water is less dense than cold, salty water and will overlie the wedge of seawater pushing in from the ocean. Storms, tides, and wind, however, can eliminate the layering caused by salinity and temperature differences by thoroughly mixing the two masses of water. The shape of the estuary and the volume of river flow also influence this two-layer circulation. See Chapter 2 for more information.

Role of Salinity in the Estuarine Ecosystem

Salinity levels control, to a large degree, the types of plants and animals that can live in different zones of the estuary. Freshwater species may be restricted to the upper reaches of the estuary, while marine species inhabit the estuarine mouth. Some species tolerate only intermediate levels of salinity while broadly adapted species can acclimate to any salinity ranging from fresh water to seawater.

Salinity measurements may also offer clues about estuarine areas that could become afflicted by salinity-specific diseases. In the Chesapeake and Delaware bays, for example, pathogens infecting oysters are restricted to sections that fall within certain salinity levels. Drastic changes in salinity, such as those due to drought or storms, can also greatly alter the numbers and types of animals and plants in the estuary.

Another role played by saline water in an estuary involves flocculation of particles. Flocculation is the process of particles aggregating into larger clumps. The particles that enter an estuary dissolved in the fresh water of rivers collide with the salt water, and may flocculate or clump together and increase turbidity (Figure 14-2).

Salinity is often an important factor when monitoring many key water quality variables. For example:

- Most dissolved oxygen meters require knowledge of the salinity content in order to calibrate the meter properly.
- If you are interested in converting the dissolved oxygen concentration (usually expressed as mg/l or parts per million) to

percent saturation (amount of oxygen in the water compared to the maximum it could hold at that temperature), you must take salinity into account. As salinity increases, the amount of oxygen that water can hold decreases.

- If you use a meter to measure pH, the techniques are the same whether you are testing salt or fresh water. However, if you measure with an electronic colorimeter, you must use a correction factor (available from the manufacturer) to compensate for the effects of salinity. ■

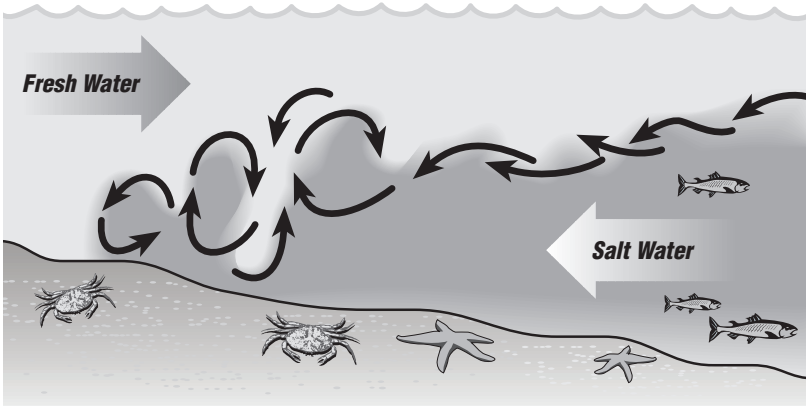


Figure 14-2. Turbidity increases when fresh water meets with salt water.

Sampling Considerations

Salinity will fluctuate with movement of the tides, dilution by precipitation, and mixing of the water by wind. There are also seasonal differences in salinity.

Season and Weather

Environmental conditions vary with the seasons, and salinity levels can reflect those variations. During wet weather periods and during the spring thaw in colder regions, more fresh water enters the estuary, so salinity is lower at these times. On the other hand, dry weather periods mean less fresh water entering the estuary, so higher salinity levels may be found. Another way the seasons influence an estuary's salinity involves the mixing of fresh water and salt water. Seasonal storms help mix estuarine waters and serve to decrease the vertical salinity and temperature gradients in the estuary.

Choosing a Sampling Method

Salinity can be measured either by physical or chemical methods. Physical methods use conductivity, density, or refractivity. The physical methods are quicker and more convenient than the chemical methods. The chemical methods determine chlorinity (the chloride concentration), which is closely related to salinity.

Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate **anions** (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum **cations** (ions that carry a positive charge). As the concentration of salts in the water increases, electrical conductivity rises—the greater the salinity, the higher the conductivity. Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and, therefore, have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is extrapolated to a standard temperature (25°C).

Conductivity is measured with a probe and a meter. Conductivity meters require temperature correction and accurate

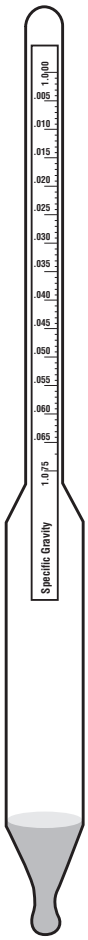


Figure 14-3. Hydrometer. Salt water is denser than fresh water and has a greater specific gravity. Volunteers can calculate salinity by measuring a water sample's specific gravity with a hydrometer.

calibration can be difficult. The cost of these meters ranges from $500 to $1,500. Voltage is applied between two electrodes in a probe immersed in the sample water. The drop in voltage caused by the resistance of the water is used to calculate the conductivity per centimeter. The meter converts the probe measurement to micromhos per centimeter and displays the result for the user.

Some conductivity meters can also be used to test for total dissolved solids and salinity. The total dissolved solids concentration in milligrams per liter (mg/l) can also be calculated by multiplying the conductivity result by a factor between 0.55 and 0.9, which is empirically determined (see APHA, 1998).

Meters should also measure temperature and automatically compensate for temperature in the conductivity reading. Conductivity can be measured in the field or the lab. In most cases, it is probably better if the samples are collected in the field and taken to a lab for testing. In this way, several teams of volunteers can collect samples simultaneously. If it is important to test in the field, meters designed for field use can be obtained for around the same cost mentioned above.

Density

As water becomes saltier, its weight increases although its volume does not measurably rise. Since salt water is denser than fresh water, this change of weight results in a greater specific gravity. The volunteer can calculate salinity by measuring a water sample's specific gravity. This is done with a hydrometer (Figure 14-3).

Hydrometers are a fairly simple and inexpensive means of obtaining salinity. Specific gravity hydrometers cost from $13 to $25 (although professional sets can cost much more), and a hydrometer jar costs about $13 to $15, although you can also use a large, clear jar that is deep enough to float the hydrometer.

Because hydrometers measure specific gravity, the presence of suspended solids can raise hydrometer readings and result in a salinity measurement that is higher than the true value. This has especially been shown in low salinity areas (Bergstrom, 1997; Bergstrom, 2002). Volunteer programs, therefore, should consider their accuracy and precision requirements before electing to use a hydrometer.

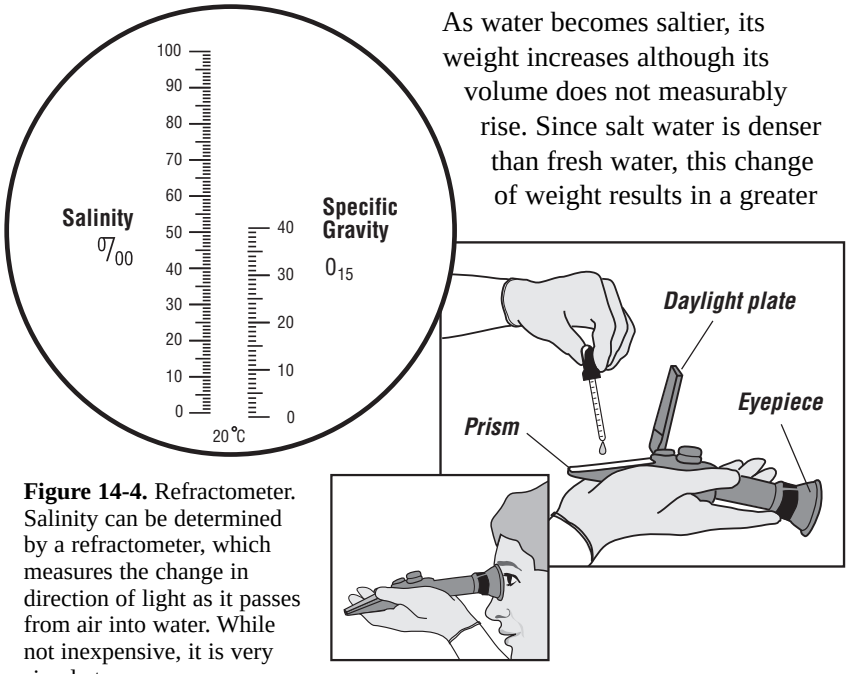


Figure 14-4. Refractometer. Salinity can be determined by a refractometer, which measures the change in direction of light as it passes from air into water. While not inexpensive, it is very simple to use.

Refractivity

Refractometers (Figure 14-4) are used to measure substances dissolved in water, using the principle of light refraction through liquids. The more dissolved solids in water, the slower light travels through it. Refractometers measure the change in the direction of light as it passes from air into water. Salinity and temperature both affect the index.

Refractometers use a scale to quantify the effect that dissolved solids in water have on light. Using a refractometer is simple. It works with ambient light, and no batteries are required. Such instruments cost from $150 to $350.

Chlorinity

Salinity is related to chlorinity, and this method calculates salinity based on the quantity of chloride ions in the sample. Salinity kits based on testing chloride ions cost about $40 for 50 tests.

The chlorinity method uses titration with

either a silver nitrate or mercuric nitrate solution. Some kits require conversion of chlorinity to salinity using a formula, while others incorporate the formula and give results directly as salinity. Whichever chloride analysis process you select, read the literature to determine if a conversion formula is needed.

This method is relatively easy to use although the color change at the endpoint is sometimes difficult to assess. A white paper placed behind the titration bottle makes determination of the endpoint an easier task. ■

REMINDER!

To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

How to Measure Salinity

General procedures for collecting and analyzing salinity samples are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

STEP 1: Check equipment.

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- hydrometer, jar, and hydrometer conversion table; or
- conductivity meter (plus standard to check accuracy of meter); or
- refractometer; or
- field kit to test for chloride.

STEP 2: Collect the sample.

If samples will be collected in the field for later measurement, follow these collection and storage steps. See Chapter 7 for information on cleaning and preparing bottles.

- Use 200 ml glass or polyethylene bottles. (NOTE: Some procedures require smaller samples. Check with your lab for their preferred volume of sample water.)
- Label the bottle with site name, date, time, data collector, and analysis to be performed.
- Wearing latex gloves, plunge the bottle into the water. Fill the bottle completely and cap tightly.
- Samples may be stored up to 7 days before analysis (Hach, 1997).

Using a hydrometer. (photo by P. Bergstrom).

STEP 3: Measure salinity.

The following section describes various methods to analyze a water sample for salinity. If analyzing salinity by using a hydrometer, follow Procedure A. If using a conductivity meter, use Procedure B. If using

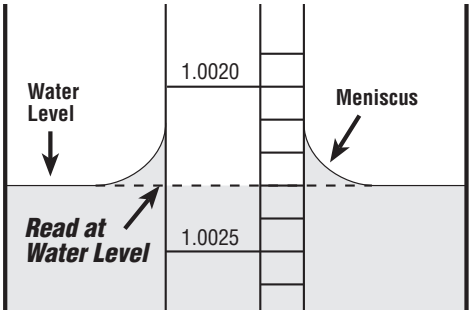


Figure 14-5. Reading the hydrometer. After letting the hydrometer stabilize, read the specific gravity at the point where the water level in the jar meets the hydrometer scale. Do not record the value where the meniscus (the upward curvature of the water where it touches the glass) intersects the hydrometer *(redrawn from LaMotte, 1993).*

a refractometer, follow Procedure C. If using a salinity kit based on testing chloride ions, follow the directions that come with the kit.

Procedure A—Measuring salinity with a hydrometer

- Put the water sample in a hydrometer jar or a large, clear jar.
- Gently lower the hydrometer into the jar along with a thermometer. Make sure the hydrometer and thermometer are not touching and that the top of the hydrometer stem (which is not in the water) is free of water drops.
- Let the hydrometer stabilize and then record the specific gravity and temperature. Read the specific gravity (to the fourth decimal place) at the point where the water level in the jar meets the hydrometer scale. Do not record the value where the meniscus (the upward curvature of the water where it touches the glass) intersects the hydrometer (see Figure 14-5).
- Record the specific gravity and the temperature on your data sheet.
- Use a hydrometer conversion table that comes with your hydrometer to determine the salinity of the sample at the recorded temperature. Record the salinity of the sample on your data sheet.

Procedure B—Measuring salinity with a conductivity meter (in field or lab)

- Prepare the conductivity meter for use according to the manufacturer's directions.
- Use a conductivity standard solution (usually potassium chloride or sodium chloride) to calibrate the meter for the range that you will be measuring. The manufacturer's directions should describe the preparation procedures for the standard solution.
- Rinse the probe with distilled or deionized water.
- Select the appropriate range on the meter, beginning with the highest range and working down. Place the probe into the sample water, and read the conductivity of the water sample on the meter's scale. If the reading is in the lower 10 percent of the range that you selected, switch to the next lower range. If the reading is above 10 percent on the scale, then record this number on your data sheet.
- If the conductivity of the sample exceeds the range of the instrument, you may dilute the sample with distilled water. Be sure to perform the dilution according to the manufacturer's directions because the dilution might not have a simple linear relationship to the conductivity.
- Rinse the probe with distilled or deionized water and repeat the fourth step above with the next water sample until finished.

Procedure C—Measuring salinity with a refractometer

- Lift the lid that protects the refractometer's specially angled lens.
- Place a few drops of your sample liquid on the angled lens, and close the lid.
- Peer through the eyepiece. Results appear along a scale within the eyepiece.
- Record the measurement on your data sheet.
- Rinse the lens with a few drops of distilled water, and pat dry, being very careful to not scratch the lens' surface.

STEP 4: *Clean up and send off data.*

Volunteers should thoroughly clean all equipment and transport the samples to the designated lab, if necessary.

Make sure that the data sheet is complete, legible, and accurate, and that it accounts for all samples. Volunteers should make a copy of the completed data sheet before sending it to the designated person or agency in case the original data sheet becomes lost. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

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

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

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003. Office of Water, Washington, DC. 211 pp.

Other references:

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.

Bergstrom, P. 1997. "Salinity by Conductivity and Hydrometer—A Method Comparison." *The Volunteer Monitor* 9(1):13-15.

Bergstrom, P. 2002. "Salinity Methods Comparison: Conductivity, Hydrometer, Refractometer." *The Volunteer Monitor* 14(1):20-21.

LaMotte Company. 1993. Hydrometer Instructions. Chestertown, MD.

Maine Coastal Program. 1998. *The Estuary Book.* State Planning Office, 38 State House Station, Augusta, ME 04333.

Mitsch, W.J., and J.G. Gosselink. 1986. *Wetlands.* Van Nostrand Reinhold, New York. 539 pp.

Chapter 15

Turbidity and Total Solids

Natural runoff, water turbulence from storms, and wave action can cause turbidity of the water. Sediment can also be disturbed by bottom-feeding animals, adding to the water's turbidity. Although we often think that clean water is clear, even unpolluted water can have suspended particles that may lessen its clarity but do not diminish its quality. Many human activities contribute to increased turbidity, as discussed in this chapter.

Photos (l to r): G. Carver, K. Register, R. Ohrel, K. Register

Overview

Measures of turbidity indicate how cloudy or muddy the water is or, alternatively, the degree of its clarity or translucence. Several types of material cause water turbidity:

- suspended soil particles (including clay, silt, and sand);
- tiny floating organisms (e.g., phytoplankton, zooplankton, and bacterioplankton); and
- small fragments of dead plants.

Natural runoff, water turbulence from storms, and wave action can cause turbidity of the water. Sediment can also be disturbed by bottom-feeding animals, adding to the water's turbidity. Although we often think that clean water is clear, even unpolluted water can have suspended particles that may lessen its clarity but do not diminish its quality. Human activities, however, exacerbate the clouding. Sediment runoff from agricultural fields, logging activities, wash from construction sites and urban areas, and shoreline erosion from heavy boat traffic and jet skis, among other problems, all contribute to high turbidity. Excessive algal growth due to the additions of nutrients into an estuary can also affect water turbidity. High levels of turbidity over long periods of time can greatly diminish the health and productivity of the estuarine ecosystem.

This chapter explains the role of turbidity in the estuarine ecosystem and describes some common steps for monitoring it. The measurement of total solids—particles suspended and dissolved in the water—is also discussed.

Why Measure Turbidity and Total Solids?

Land use decisions throughout an estuary's watershed impact water quality. Here, extensive erosion near a highway adds to the sediment entering a nearby estuary (photo by R. Ohrel).

Turbidity is a measure of water clarity: how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, and other substances. They are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand).

Total solids refer to the matter that is suspended or dissolved in water. When a water sample is evaporated, there is often a residue left in the vessel—these are the total solids. The solids in water have different attributes and sizes. The suspended particles in water can be retained on a filter with a 2 µm or smaller pore size, while dissolved solids are small enough to pass through a filter of that size.

Turbidity and total solids can be useful indicators of the effects of runoff from construction, agricultural practices, logging activity, discharges, and other sources. Regular monitoring can help detect trends that might indicate increasing (or decreasing) erosion in the estuary's watershed.

Sources of turbidity in estuary waters include:

- soil erosion from construction, forestry, or agricultural sites;
- waste discharge;
- urban runoff;
- eroding stream banks;
- stirred-up bottom sediments from flooding, dredging, boating and jet-skiing activities, or bottom-feeding animals; and
- excessive algal growth.

Turbidity and total solids often increase sharply during and immediately following a rainfall, especially in developed watersheds, which typically have relatively high proportions of impervious surfaces such as rooftops, parking lots, and roads. The flow of stormwater runoff from impervious surfaces rapidly increases stream velocity, which increases the erosion rates of streambanks and channels. Turbidity can also rise sharply during dry weather if earth-disturbing activities are occurring without erosion control practices in place.

Sedimentation, where solids settle out of the water column onto the estuary bottom, is a priority concern in many estuaries, making turbidity monitoring an important part of most volunteer estuary water quality monitoring programs. As one example, a study of Weeks Bay, Alabama, found that its watershed contributed about 22,500 tons of sediment per year to the bay as a result of agricultural field runoff (Baldwin County, 1993).

The Role of Turbidity and Total Solids in the Estuarine Ecosystem

Highly turbid water full of suspended material has many effects on the estuarine environment. If an estuary is excessively turbid over long periods, its health and productivity can be greatly diminished.

As discussed in Chapter 9, dissolved oxygen is a critical factor controlling biological activity. Highly turbid water can influence the amount of dissolved oxygen in three ways. First, turbid waters interfere with light penetration in the water, thereby reducing the amount of light reaching the bottom, making it less suitable for plant growth. Because there are fewer aquatic plants—and therefore less photosynthesis taking place—less dissolved oxygen is produced. Dissolved oxygen concentrations are also influenced by high turbidity and its relationship to water temperature. Suspended particles absorb heat, which causes water temperature to increase. Because warm water holds less dissolved oxygen than cold water,

this temperature increase causes a reduction in dissolved oxygen concentrations. High turbidity may also be caused by high levels of dead organic matter, called **detritus**. Detritus can include leaves, twigs and other plant and animal wastes. As these materials are decomposed by bacteria, oxygen can be depleted.

Some of the physical effects of excessive suspended materials include:

- clogged fish gills that inhibit the exchange of oxygen and carbon dioxide;
- reduced resistance to disease in fish;
- reduced growth rates;
- altered egg and larval development;
- fouled filter-feeding systems of animals; and
- hindered ability of aquatic predators from spotting and tracking down their prey.

Suspended materials such as sand, soil, or silt tend to settle out faster in brackish water than in fresh water. These particles settle to the estuary bottom, where they smother fish eggs and bottom-dwelling animals, and alter the habitat needed by estuary plants and animals. For example, oysters require a hard surface on which to attach and grow. Increased sedimentation in an estuary can cover the available hard surfaces such as rocks and older oyster beds, leaving oysters without the habitat that is critical to their survival. Another problem with sedimentation in an estuary is that the newly settled particles may not be the same size as the estuary's natural bottom sediment, causing shifts from fine to coarser sediments (or vice versa). This change in sediment size can greatly affect the plants and animals that have adapted to the estuary's benthic environment.

Higher concentrations of suspended solids can serve as carriers of toxins, which readily cling to suspended particles. This is particularly a concern where pesticides are being used on irrigated crops. Where solids are high, pesticide concentrations may increase well beyond those of the original application as the irrigation water travels down irrigation ditches and ultimately into estuaries. ■

Sampling Considerations

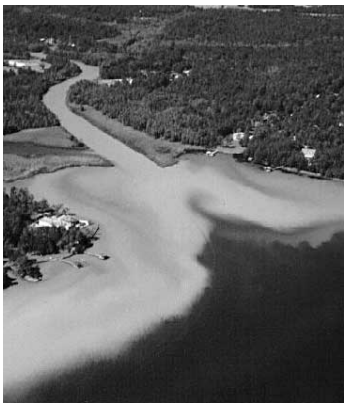
It should be remembered that turbidity is not a measurement of the amount of suspended solids present or the rate of sedimentation of an estuary—it measures only the amount of light that is scattered or absorbed by suspended particles. Some laboratories also measure "total solids" in a waterbody, which is related to turbidity. Measurement of total solids is a more direct measure of the amount of material suspended and dissolved in water.

Chapter 6 summarized several factors that should be considered when determining monitoring sites, where to monitor, and when to monitor. In addition to the considerations in Chapter 6, a few additional ones specific to monitoring turbidity are presented here.

When to Sample

In setting up a turbidity monitoring plan, the program manager should ensure that the effort will continue for several years. Since the workings of an estuary are complex, a mere year or two of turbidity data is insufficient to capture the variability of the system. In fact, a few years of unusual data may be quite misleading and tell a story very different than reality. On the other hand, volunteers can detect some sources of erosion and turbidity in just one or two monitoring sessions.

Volunteers should sample water for turbidity on a weekly or biweekly basis, year-round. The key to effective turbidity monitoring is to sample at a sufficiently frequent interval and



As stormwater enters an estuary, it often creates a plume of highly turbid water. In this photo, a plume of stormwater delivers large amounts of dissolved and suspended materials to an estuary (photo by G. Carver).

at enough representative sites so that the data will account for most of the inherent variability within the system.

Since turbidity often increases sharply during and immediately following a rainfall, volunteers may be asked to take additional turbidity readings shortly after the storm (as soon as it is safe to do so). Stormwater, as it enters an estuary, often creates a plume of highly turbid water. This is because the stormwater is carrying high levels of suspended solids due to erosion as well as sediment from roads and parking lots in the watershed. The extent of the plume can usually be seen from above, as the color of water in the plume is different from the water in the estuary's main body. Some volunteer monitoring programs include "stormwater plume tracking" as part of their turbidity data collection to assess the spatial extent of stormwater discharges (see box, this page).

Where to Sample

If the monitoring program is designed to pinpoint trouble spots in the estuary, the manager should select monitoring sites throughout the estuary, as well as cluster sites near suspected sources of turbid water into the estuary. Such sites might include an area near a discharge pipe or a river that flows into the estuary. Since rivers may have multiple trouble spots, your monitoring efforts may require several monitoring sites in the rivers and tributaries.

Choosing a Sampling Method

When deciding upon the appropriate method for measuring turbidity levels in an estuary, the program manager must consider the cost of equipment, the number and location of sites to be monitored by volunteers, and the planned uses for the collected data.

There are four commonly used methods to measure turbidity in estuary waters. Turbidity meters measure turbidity, while the Secchi disk, transparency tube, and turbidity field kits measure transparency, which is an integrated measure of light scattering and absorption. Samples can also be collected by volunteers and sent to a lab for analysis. Monitors interested in submitting data to water quality agencies should consult with the agencies to determine the preferred equipment and methods.

Secchi Disk

Most volunteer water quality monitoring programs rely on the Secchi disk because it is easy to use, inexpensive, and relatively accurate. It is also easy to make (see box, page 15-5). The Secchi disk was invented by the Italian astronomer Pietro Angelo Secchi in the 1860s. This simple weighted disk is used by volunteers to measure the water depth at which the disk just disappears from view—the Secchi depth. Most programs find that the Secchi disk gives sufficiently good clarity readings.

The Secchi disk is 20 centimeters (8 inches) in diameter and divided into alternating black and white quadrants to enhance visibility and contrast (although some disks are totally white). Secchi disks cost about $25 to $50 and can be homemade.

It is lowered by hand into the water to the depth at which it vanishes from sight. The distance to vanishing is then recorded, and then the procedure is repeated so that two readings

Stormwater Plume Tracking

As part of a turbidity monitoring program, volunteers can conduct "plume tracking" to assess the spatial extent of stormwater discharges. By monitoring for runoff characteristics (i.e., high turbidity, low salinity, etc.) near the mouth of a freshwater input to the estuary, volunteers can assess how far the stormwater plume emanating from the stream or river extends into the estuary.

An effective method to monitor a stormwater plume is to divide the plume area into a grid, and conduct sampling in each of the grid areas. Sampling should extend from the area of greatest freshwater impact, across the plume, and beyond the edge of the plume. Studying the fate of stormwater and its effects on an estuary is an important component to understanding the amount of material flowing into the estuary and where stormwater material is deposited. With this monitoring, we can begin to learn what residual effects the deposited material has on the natural function of the estuary's ecosystem. By regularly monitoring storm plumes, volunteers can collect valuable information that can help detect trends.

are obtained. The clearer the water, the greater the distance. If you are monitoring tributaries to the estuary, you may find a Secchi disk of limited use, however, because in many cases the river bottom will be visible and the disk will not reach a vanishing point.

Secchi readings will vary with the specific estuary, location in the estuary, and season. Water clouded with sediment after a storm or with high levels of phytoplankton during a warm spell will have low Secchi readings (poor water clarity). Low productivity winter waters or estuarine water located near the ocean will generally register higher Secchi depths. A significant change in Secchi depth may motivate a monitoring program to identify possible causes.

WARNING!
Beware of Secchi Line Shrinkage

Over time, a Secchi disk line may begin to shrink from regular water exposure and subsequent drying. This can lead to errors in Secchi depth measurements.

To minimize this problem, use a minimal-stretch nylon cord, a vinyl-coated braided metal-core clothesline, or other shrink-resistant line. But no matter what material you use, it is critical to calibrate Secchi disk lines regularly (e.g., every six months).

MAKING A SECCHI DISK

A Secchi disk is one of the simpler pieces of equipment required for water quality testing. Although many supply companies sell this item, volunteer programs on a tight budget can construct their own disks (Figure 15-1). Materials needed for this project are:

- 1/8” thick steel, 1/4” Plexiglas, or 1/4” to 1/2” marine plywood
- drill with 3/8” inch bit
- shrink-resistant rope or cord (e.g., minimal-stretch nylon, vinyl-coated braided metal-core clothesline)
- eyebolt (5/16”), approximately 3” to 4” long
- flat washers, lock washers, 2 nuts (5/16”)—2 of each
- attachable weights
- meter stick
- black and white flat enamel paint
- paintbrush
- marking pen

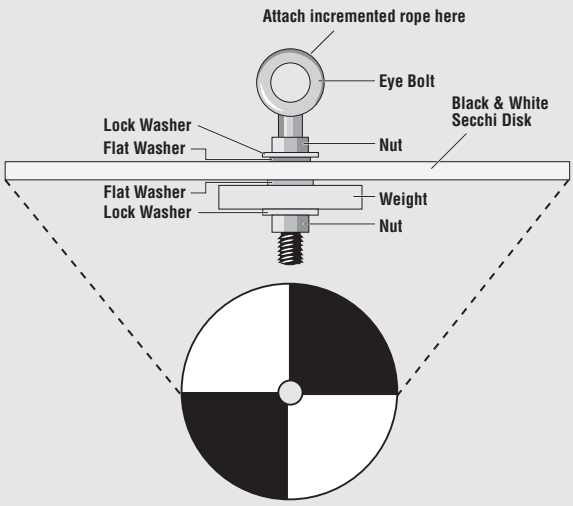


Figure 15-1. A homemade Secchi disk.

Cut the steel, Plexiglas, or plywood into a circle with a 20-centimeter (8”) diameter. Section the disk into four quarters and paint two opposing quarters white and the other two black. Paint the other side of the disk totally white.

After the paint has dried, drill a hole in the center of the disk. Put a nut onto the eyebolt followed by a lock washer and flat washer. Insert the eyebolt assembly through the hole in the disk with the white and black side facing the eye of the bolt. Place another flat washer on top of the assembly along with a sufficient number of weights (dependent on the disk material used). Add another lock washer and nut to finish the assembly.

Attach a 6-meter length of shrink-free cord or rope through the eyebolt and fasten securely. Place the meter stick alongside the rope and disk and mark the rope in 5- or 10-centimeter increments with an indelible marker or waterproof ink measuring from the top of the disk. A different color marker used at each full meter increment will facilitate reading Secchi measurements.

A volunteer uses a Secchi disk from the shady side of a dock (photo by K. Register).

Turbidity Meter

The most accurate means of assessing turbidity is with a turbidity meter, called a nephelometer. A turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample. It measures turbidity in nephelometric turbidity units or NTUs. Meters can measure turbidity over a wide range, from 0 to 1,000 NTUs. Measurements can jump into hundreds of NTUs during runoff events. Therefore, the turbidity meter to be used should be reliable over the range in which you will be working. Meters of this quality cost about $800. Many meters in this price range are designed for field or lab use.

Although turbidity meters can be used in the field, volunteers might want to collect samples and take them to a central point for turbidity measurements. This is because of the expense of the meter (most programs can afford only one and would have to pass it along from site to site, complicating logistics and increasing the risk of damage to the meter) and because the meter includes glass cells that must remain optically clear and free of scratches. At a reasonable cost, volunteers can also take turbidity samples to a lab for meter analysis.

Transparency Tube

The transparency tube (sometimes called a "turbidity tube") is a clear, narrow plastic tube marked in units (usually centimeters) with a light and dark pattern painted on the bottom. Water is poured into the tube until the pattern disappears. Volunteers then record the depth at which the pattern disappeared. Volunteer groups using transparency tubes have found tube readings to relate fairly well to lab measurements of turbidity and total suspended solids, although the transparency tube is not as precise or accurate as a meter. Also, readings in transparency tubes can be rendered inaccurate in cases of highly colored waters. A transparency reading taken from one tube cannot be compared with a reading taken from another tube of a different manufacturer, especially if the tube is homemade. Transparency tubes can be purchased from scientific supply houses for about $35 to $60.

Turbidity Field Kits

With these kits, turbidity is measured by using a standardized turbidity reagent to match the turbidity of a water sample. Drops of the turbidity reagent are added to a test tube of turbidity-free water until the water in the test tube becomes as blurred or cloudy as the water sample from the estuary, which is in an identical test tube. These field kits cost about $40.

Laboratory Analysis

Analysis of turbidity or of total solids by a professional laboratory is by far the most accurate means of obtaining this data. Most laboratories institute strict quality assurance and quality control methods to ensure consistently reliable results. A college or professional lab may offer its services free of charge to a volunteer program.

If the program decides to use lab analysis, it must ensure that its volunteers adhere to strict guidelines while collecting samples. Sloppy field collection techniques will result in poor data. ■

How to Measure Turbidity

General procedures for measuring turbidity are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Reminder!

To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- turbidity meter, turbidity standards, lint-free cloth to wipe the cells of the meter; or
- Secchi disk with weight attached and on a calibrated line; or
- transparency tube; or
- turbidity test kit.

STEP 2: *Monitor turbidity.*

The following section describes four ways to analyze a water sample for turbidity. If analyzing turbidity by Secchi disk, follow Procedure A. If using a turbidity meter, use Procedure B. If using a transparency tube, follow Procedure C. If using a turbidity field test kit, follow Procedure D.

Using a transparency tube is an easy way to measure the water transparency. It is especially useful in water that is too shallow for a Secchi disk (photo by K. Register).

Procedure A—Measuring water clarity with a Secchi disk

The key to consistent results is to train volunteers to follow standard sampling procedures and, if possible, have the same individual take the reading at the same site throughout the season. If the conditions vary from this ideal situation, record any differences on the data sheet. The line attached to the Secchi disk must be marked according to units designated by the volunteer program. Many programs require volunteers to measure to the nearest 1/10 meter. Meter intervals can be marked with waterproof ink or tagged (e.g., with duct tape) for ease of use. Do not wear sunglasses while viewing the Secchi disk in the water.

The optimal conditions for recording Secchi disk readings are:

- clear sky;
- sun directly overhead (but disk should be in shade or shadow); and
- measurements made from the protected side of a boat or dock with minimal waves or ripples.

Steps for using a Secchi disk are as follows:

- Check to make sure that the Secchi disk is securely attached to the measured line.
- Tie a wrist loop at the end of the rope so that the rope end does not accidentally drop into the water when the disk is lowered.

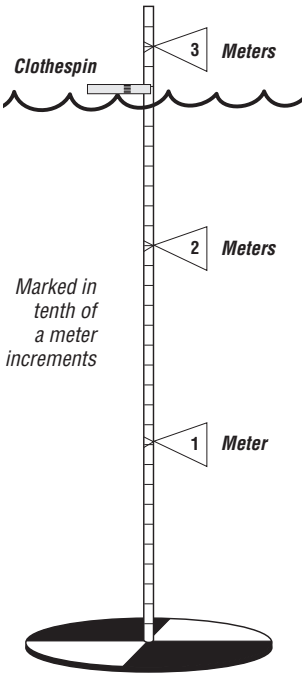


Figure 15-2. Using a Secchi disk to measure transparency. The disk is lowered until it is no longer visible. That point is the Secchi disk depth *(redrawn from USEPA, 1997).*

- Lean over the shady side of the boat or dock and lower the Secchi disk by hand into the water, keeping your back toward the sun to block glare. Make sure the disk hangs horizontally when suspended.
- Lower the disk until it disappears from view. Lower it one third of a meter and then slowly raise the disk until it just reappears. Move the disk up and down until the exact vanishing point is found. This is called the limit of visibility.
- Attach a clothespin to the line at the point where the line enters the water or, if that is not possible, note carefully where the line meets the water's surface (Figure 15-2). Raise the Secchi disk and record the depth measurement on your data sheet.
- Repeat the procedure and write the second measurement on your data sheet, as well as the average of the two depths.
- If the disk hits the bottom before dropping out of sight, note this observation and record the bottom depth.

Procedure B—Measuring water turbidity with a turbidity meter

- Prepare the sample containers.

  If factory-sealed, disposable Whirl-pak bags are used to sample, no preparation is needed. Reused sample containers (and all glassware used in this procedure) must be cleaned before the first run and after each sampling run. Follow the procedures described in Chapter 7.
- Collect the sample.

  Refer to Chapter 7 for details on how to collect water samples using screw-cap bottles or Whirl-pak bags.
- Analyze the sample.

  While monitors should consult with the instructions that come with their turbidity meter, the following procedure applies to field or lab use of most turbidity meters:

  (a) Prepare the turbidity meter for use according to the manufacturer's instructions.
  (b) Use the turbidity standards provided with the meter to calibrate it. Make sure it is reading accurately in the range in which you will be working.
  (c) Shake the sample vigorously and wait until the bubbles have disappeared. You might want to tap the sides of the bottle gently to accelerate the process.
  (d) Use a lint-free cloth to wipe the outside of the tube into which the sample will be poured. Be sure not to handle the tube below the line where the light will pass when the tube is placed in the meter. NOTE: If the tube becomes scratched, it will have to be replaced. The scratches on the glass can affect the meter's readings.
  (e) Pour the sample water into the tube. Wipe off any drops on the outside of the tube.
  (f) Set the meter for the appropriate turbidity range. Place the tube in the meter and read the turbidity measurement directly from the meter display.
  (g) Record the result on the field or lab sheet.
  (h) Repeat steps c-g for each sample.

Procedure C—Measuring water clarity with a transparency tube

Readings in transparency tubes can be rendered inaccurate in cases of highly colored waters. A transparency reading taken from one tube cannot be compared with a reading taken from another tube of a different manufacturer, especially if the tube is homemade.

- Collect the sample in a bottle or bucket at mid-depth if possible. Avoid stagnant

water and sample as far from the shoreline as is safe. Avoid collecting sediment from the bottom.

- Prepare the transparency tube by placing it on a white surface.
- Look vertically down the tube to see the black and white pattern on the bottom. Take readings in open but shaded conditions. Avoid direct sunlight by turning your back to the sun.
- Stir or swish the water in the bucket or bottle until it is homogeneous, taking care not to produce air bubbles (these will scatter light and affect the measurement).
- Slowly pour the water sample into the tube, stopping intermittently to see if the black and white pattern has disappeared. To avoid introducing air bubbles, pour the water against the inside wall of the tube.
- When you can no longer see the pattern, look at the ruler on the side of the tube, and record the number of units on your data sheet. This is the depth of the water column in the tube when the pattern just disappears.

NOTE: Some transparency tubes have a water-release valve at the bottom of the tube. With these tubes, you are required to fill the tube entirely, then open the valve while you look down the tube. As soon as you see the black and white pattern appear, close the valve, and record the depth at which you first saw the pattern.

Procedure D—Measuring water clarity with a turbidity field kit

While monitors should consult with the instructions that come with their kits, the following procedure applies to most turbidity field kits:

- The kits come with two tubes, each with a black and white pattern on the bottom. Fill one of the two turbidity tubes to the line indicated with the water to be tested. This is usually 50 ml. If you cannot see the black and white pattern on the bottom of the tube when you look down through the column, pour out half of the water until 25 ml remains in the test tube (or pour out the amount stated in your kit's instructions).
- Fill the second turbidity tube with turbidity-free water that is equal to the amount of the sample (50 or 25 ml). Distilled or tap water can be used.
- Place the tubes next to each other, and look down the tubes to note the difference in clarity. If there is a difference in clarity, go on to the next step.
- Shake the bottle of standard turbidity reagent, and add the reagent to the "clear water" tube according to the kit's instructions. Keep track of how much reagent is being added. Stir the contents of both tubes to equally distribute turbid particles. After each addition of reagent, compare the turbidity of the tubes.
- Continue to add the reagent and stir both tubes until the turbidity of both test tubes is the same.
- Record the total amount of turbidity reagent added.

STEP 3: *Clean up and send off data.*

Volunteers should thoroughly clean all equipment and transport the samples to the designated lab, if necessary. Samples submitted to a lab for analysis must be processed within 24 hours of collection. Keep samples in the dark and on ice or refrigerated.

Make sure that the data sheet is complete, legible, and accurate, and that it accounts for all samples. Volunteers should make a copy of the completed data sheet before sending it to the designated person or agency in case the original data sheet becomes lost.

How to Measure Total Solids

The measurement of total solids cannot be done in the field. Samples must be collected using clean glass, plastic bottles, or Whirl-pak bags and taken to a laboratory where the test can be run. Total solids are measured by weighing the amount of solids present in a known volume of sample. This is done by weighing an empty beaker, filling it with a known volume, evaporating the water in an oven and completely drying the residue, and then weighing the beaker with the residue. The total solids concentration is equal to the difference between the weight of the beaker with the residue and the weight of the beaker without it.

Total solids are measured in milligrams per liter (mg/l). Since the residue is so light in weight, the lab will need a balance that is sensitive to weights in the range of 0.0001 gram. Balances of this type are called analytical or Mettler balances, and they are expensive (around $3,000). The technique requires that the beakers be kept in a desiccator, which is a sealed glass vessel containing material that absorbs moisture and ensures that the weighing is not biased by water condensing on the beaker. Some desiccants change color to indicate moisture content.

Volunteers can collect samples for total solids analysis using the instructions in Chapter 7. If you are sending your samples to a lab for analysis, they must be tested within 24 hours of collection. Keep samples in the dark and on ice or refrigerated. Learn from the lab what volume of water needs to be collected. For some tests, 50 ml are needed, while other tests require 100 ml or more. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

National Estuary Program (NEP). Web site: http://www.epa.gov/owow/estuaries/about1.htm

Southern California Coastal Water Research Project, 1999/2000 Research Plan, Westminster, CA. Web site: http://www.sccwrp.org

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Other references:

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.

Association of National Estuary Programs(ANEP). 1998. *Preserving Our Heritage, Securing Our Future: A Report to the Citizensof the Nation*. Washington, DC. 49 pp.

Baldwin County (Alabama) Soil and Water Conservation District. 1993. Unpublished report on agricultural field runoff and erosion in the Weeks Bay watershed.

Mitchell, M., and W. Stapp. 1999. *Field Manual for Water Quality Monitoring.*12th ed. Kendall/ Hunt. Available from GREEN, c/o Earth Force, Inc., 1908 Mount Vernon Ave., Alexandria, VA 22301; phone: 703-299-9400; catalog # ISBN-1-6801;
Web site: http://www.earthforce.org/green/

National Safety Council's Environmental Center. 1998. *Coastal Challenges: A Guide to Coastal and Marine Issues.* Prepared in conjunction with Coastal America.
Web site: http://www.nsc.org/ehc/guidebks/coasttoc.htm.

U.S. Environmental Protection Agency (USEPA). 1991. *Volunteer Lake Monitoring: A Methods Manual.* EPA 440/4-91-002. Office of Water, Washington, DC.

White, T. 1994. "Monitoring a Watershed: Nationwide Turbidity Testing in Australia." *The Volunteer Monitor* 6(2): 22-23.

Web sites:

National Estuary Program (NEP): http://www.epa.gov/owow/estuaries/about1.htm

Environmental Protection Agency's Office of Wetlands, Oceans, & Watersheds:
http://www.epa.gov/owow/monitoring/volunteer/stream/
http://www.epa.gov/owow/monitoring/index.html

U.S. Geological Survey, Florida Bay: http://coastal.er.usgs.gov/flbay/ref.html

Chapter 16

Marine Debris

Waterbodies have historically been dumping grounds for human-made debris. Rarely can a person visit a stream, lake, river, estuary, or ocean and fail to observe some form of trash. This debris originates from many activities, but is generally categorized as coming from land-based or ocean/inland waterway-based sources. Regardless of its origin, however, marine debris impacts human health and safety; poses an entanglement or ingestion threat to wildlife; and degrades critical habitats.

All photos by The Ocean Conservancy

Overview

Waterbodies have historically been dumping grounds for human-made debris. Rarely can a person visit a stream, lake, river, estuary, or ocean and fail to observe some form of trash. This debris originates from many activities, but is generally categorized as coming from land- or ocean/inland waterway-based sources. Regardless of its origin, however, marine debris impacts human health and safety; poses an entanglement or ingestion threat to wildlife; and degrades critical habitats.

Volunteer groups may be attracted to marine debris monitoring because of the pervasiveness of the problem and the ease with which marine debris pollution can be observed. They may also choose several approaches to dealing with it. Some organizations simply remove trash from shorelines and waterways. Others take it one step further, collecting information about the types and amounts of debris found. This kind of data collection may be done with different levels of scientific rigor, depending largely on the goals of the volunteer effort.

This chapter discusses techniques for organizing a debris monitoring and cleanup program, with emphasis on data collection and data uses.

Why Monitor Marine Debris?

Marine debris is typically comprised of plastic, glass, rubber, metal, paper, wood, and cloth (photo by The Ocean Conservancy).

Once, our nation's beaches were littered only with the likes of dry seaweed strands, shells, plant stems, and stranded jellyfish. These days, the litter is more likely to include cigarette butts, grocery bags, scraps of fishing nets, pieces of foamed coffee cups, fast food containers, and beverage cans or bottles. As the coastal population has risen and society has turned from degradable natural materials to synthetic ones, the trash problem has worsened.

Of all the human-made goods produced over the past several decades, plastics are among the most persistent and pervasive. The qualities that make plastic such a versatile material for so many products can make it harmful once it is released to the environment. Constructed to be light and durable, plastics break down very slowly—some products even persisting for centuries.

Marine debris monitoring information from volunteer organizations is important in many ways. Data from monitoring efforts can be used to:

- assess debris sources;
- identify areas where public education and outreach are necessary; and
- evaluate the success of legislation enacted against littering and ocean dumping.

Marine debris monitoring and coastal cleanups serve three major functions. First, they reduce the amount of litter on shorelines in an immediate and visible way—an aspect most gratifying to the volunteers. Second, with careful planning, volunteers can document the types, quantities, and possible sources of debris. Third, the cleanup teaches the public about the problems of marine debris and how citizens can help. The sight of a littered beach transformed into a clean one makes an impression that the community will long remember and gives the volunteers a strong sense of pride in their accomplishment. Grassroots educational efforts accompanying the cleanup can help prevent future littering.

Marine Debris Sources

As our knowledge about marine debris has increased, two pathways have been shown to contribute to the problem. These sources can be divided into land-based and ocean/inland waterway-based. Land-based debris consists of waste products that have washed or blown into the water from the land. Primary sources of land-based debris include:

- sewers;
- combined sewer overflows;
- illegal dumping;
- beachgoers who leave litter on beaches;
- balloon releases;
- disposal of industrial waste products; and
- loss from coastal solid waste management landfills via wind.

Ocean/inland waterway-based debris items are accidentally or deliberately discharged at sea. Sources include:

- commercial fishing boats;
- recreational vessels;
- floating fish processing plants;
- cargo ships;
- passenger day boats and ferries;
- offshore oil platforms, rigs, and supply boats;
- military vessels;
- passenger cruise ships; and
- research vessels.

For many debris items, however, it is not so easy to identify their source—whether land or ocean/inland waterway-based.

Plastic Debris

Annex V of the International Convention for the Prevention of Pollution from Ships, commonly known as MARPOL, bans the disposal of plastic into the world's oceans and establishes limits on the disposal of other garbage. Many countries, including the United States, have agreed to this treaty. Over time, this agreement should substantially reduce the load of plastics entering the marine environment. The United States also prohibits the disposal of plastic into the nation's navigable waterways from any vessel—ranging from the largest tanker to an inner tube.

The Role of Marine Debris in the Estuarine Ecosystem

A walk along any but the most pristine coastal or estuarine shoreline will quickly reveal an astonishing array of human-made products. Beaches are natural accumulation areas for ocean- and land-based debris. Nearshore waves tend to push marine litter landward where it becomes stranded as high tide recedes. Beaches are also popular recreation areas and users often leave their trash behind.

The many marine debris sources make it one of the more widespread pollution problems threatening estuarine and coastal systems. The problem of today's litter is not merely aesthetic. Once litter gets into the estuarine environment, it seriously affects humans, wildlife, and habitats.

Human Impacts

Plastic debris (e.g., nets, fishing lines, trash bags) can snare boat propellers or clog cooling water intakes, causing substantial damage to the motor. A disabled motor can not only be costly to fix, but can leave boaters stranded in the water—a potentially dangerous situation.

Debris can also affect human health. Medical wastes menace barefoot beachgoers and pose a threat of contamination. Glass or metal shards can cause serious injuries.

Some beaches with marine debris problems face the possibility of losing money. Without regular beach cleaning—an expensive undertaking—many coastal communities risk losing tourism revenues.

Wildlife Impacts

Wildlife often fare even worse than humans. Marine debris can mean death to estuarine animals. One common cause of death by marine debris is **entanglement**. Many animals can become caught in discarded fishing nets and lines, rope, six-pack rings, balloon ribbons, grocery bags, and other floating debris.

Some animals die from marine debris **ingestion**, mistakenly eating the human-made materials. Endangered sea turtles, for example, consume floating trash bags and balloons, likely mistaking them for jellyfish—a staple in most sea turtles' diets. Several seabird species have been found to swallow plastic pieces and cigarette butts. These materials can damage the animals' digestive systems. Alternatively, animals may stop eating because their stomachs are full. Because the debris in their stomachs offers no nutritional value, the unfortunate creatures may eventually starve to death.

At least 267 marine species are known to have either become entangled in or ingested marine debris (Faris and Hart, 1995; MMC, 1997).

Wildlife entanglement is just one of the impacts of marine debris. Animals caught in debris may eventually die (photos by The Ocean Conservancy).

Habitat Impacts

Marine debris can cause problems for the estuary system. Debris coming from miles away may carry with it opportunistic plants and animals that colonize the debris' surface. These non-indigenous species can have devastating impacts for the region (see Chapter 19). Submerged debris can also cover communities such as coral reefs and smother seagrasses and bottom-dwelling species.

Levels of Marine Debris

Marine debris is pervasive throughout coastal regions. Similar to most estuarine pollution parameters, the amount of marine debris at any single moment can depend on the estuary location, its surrounding land use, the frequency of cleaning by municipal agencies, and environmental conditions, among other factors.

Each year, on the third Saturday in September, The Ocean Conservancy conducts the International Coastal Cleanup. During this activity, volunteers remove debris from shorelines and underwater sites. The volunteers also collect information about the items found. The Ocean Conservancy uses the volunteer data to evaluate the success of anti-litter and anti-dumping legislation. The data are also used to identify debris sources and public outreach possibilities.

The Ocean Conservancy compiles the information collected during the International Coastal Cleanup and generates a list of the most frequently found debris items (Table 16-1). The list provides insight to where litter prevention efforts can be concentrated. ■

Table 16-1. Most frequently found marine debris items in the United States. Data represent shoreline and underwater cleanups during the 2000 International Coastal Cleanup *(The Ocean Conservancy Web site)*.

Debris Items	Total Number Reported	Percentage of Total Collected
1. cigarette butts	1,027,303	20.25%
2. plastic pieces	337,384	6.65%
3. food bags/wrappers (plastic)	284,287	5.60%
4. foamed plastic pieces	268,945	5.30%
5. caps, lids (plastic)	255,253	5.03%
6. paper pieces	219,256	4.32%
7. glass pieces	209,531	4.13%
8. beverage cans	184,294	3.63%
9. beverage bottles (glass)	177,039	3.49%
10. straws	161,639	3.19%
11. beverage bottles (plastic)	150,129	2.96%
12. bottle caps (metal)	130,401	2.57%
Top 12 Totals	**3,405,461**	**67.12%**

Sampling Considerations and Options

Marine debris cleanup programs generally fall into two categories:

- programs that collect and remove debris; and
- programs that collect and remove debris, and record information on the numbers and types of debris found.

Any organization or individual can participate in programs that collect and remove debris from beaches and shorelines. This type of activity is designed to clean the area and raise general public awareness of marine debris pollution. Such programs can elicit a sense of pride and accomplishment in their volunteers and in the community.

Other cleanup programs go beyond simply collecting and removing debris. Some programs, such as The Ocean Conservancy's International Coastal Cleanup and National Marine Debris Monitoring Program, record data on the numbers and types of debris being found. Data collected from cleanups can be extremely important in

International Coastal Cleanup volunteers in Puerto Rico (photo by S. Sheavly, The Ocean Conservancy).

Case Study: National Marine Debris Monitoring Program

Supported by the U.S. Environmental Protection Agency (USEPA), The Ocean Conservancy coordinates the National Marine Debris Monitoring Program (NMDMP). NMDMP is a scientifically valid marine debris study utilizing volunteer groups to monitor and remove marine debris on U.S. coastal beaches. Trained volunteers conduct beach debris surveys following a strict scientific protocol and procedures.

The NMDMP was started in the spring of 1996. The goal is to establish and maintain 180 marine debris monitoring sites along the entire coastal United States, including Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. Monitoring sites are surveyed monthly by hundreds of volunteers.

The NMDMP is a five-year program designed to scientifically answer two fundamental questions regarding marine debris:

- Is the amount of debris on our coastlines decreasing?
- What are the major sources of the debris?

Information gathered by the NMDMP study will be utilized by the USEPA, National Marine Fisheries Service, National Park Service and the U.S. Coast Guard to better understand the problem of marine debris pollution.

The NMDMP data card can be found in Appendix A.

For More Information:

The Ocean Conservancy
Office of Pollution Prevention and Monitoring
1432 N. Great Neck Road, Suite 103
Virginia Beach, VA 23454
Phone: 757-496-0920
Fax: 757-496-3207
http://www.oceanconservancy.org
Email: nmdmp@oceanconservancyva.org

The National Marine Debris Monitoring Program is conducted on stretches of beach throughout the United States. Here, a volunteer coordinator measures a 500-meter monitoring site in North Carolina (photo by The Ocean Conservancy).

convincing politicians to actively solve the marine waste problem and are useful at all levels of government. The use of a data card (Appendix A) facilitates the collection of marine debris information during the cleanup activity.

Any marine debris cleanup program conducted by a volunteer group should be thoroughly planned and thought out. The following basic questions should be considered before proceeding with the activity:

- Why do we want to conduct a cleanup? What do we want to accomplish?
- Do we just want to conduct a cleanup simply to remove debris, or do we want to collect some kind of data?
- If we want to collect data, how will the data be used? What do we hope to accomplish with the data (e.g., influence legislation, monitor debris type or accumulation trends, identify debris sources, etc.)?
- What kind of data do we want to collect? (The type of data should be determined by what it is you want to accomplish.)
- Will this be a one-day event, or will it need to be repeated periodically? (Collecting meaningful data on debris may take repeated efforts.)

Choosing a Sampling Method

Marine debris monitoring is a very simple process. The sampling method selected will depend largely on the goals of the volunteer program. Sampling methods used as part of the International Coastal Cleanup and the National Marine Debris Monitoring Program (NMDMP) are briefly summarized here. Only the NMDMP method follows a scientifically valid and rigorous sampling protocol.

Method Used for International Coastal Cleanup

Volunteers fan out over a monitoring site (e.g., by foot on land, by boat, or by swimming), randomly searching for debris. Using data cards, they identify and quantify the debris items. The entire event provides a one-day "snapshot" of the types and quantities of debris occurring along shorelines and in waterways. No scientific protocol is followed during this activity.

The International Coastal Cleanup is very useful for heightening public awareness about marine debris and its prevention and provides insights into the sources and activities producing marine debris. Because it lacks scientific rigor, however, this method may not reveal information about marine debris trends.

Method Used for National Marine Debris Monitoring Program

The NMDMP is an example of a marine debris monitoring program that follows a scientific protocol for data collection.

Every 28 days, volunteers remove debris from a randomly selected and pre-measured 500-meter stretch of beach. Each 500-meter survey unit must:

- be of sandy or small gravel composition;
- have a moderate to low slope (15-45 degrees) along the width of the beach;
- receive no other routine cleaning;
- not be protected from the ocean by jetties, breakwaters, etc.;
- be accessible for monthly monitoring; and
- contain at least 500 meters of accessible length.

Not only is there scientific rigor designed into the selection of monitoring sites, but

volunteers are also trained in the proper methods for conducting a cleanup. Instead of walking randomly, volunteers must walk in a prescribed pattern (Figure 16-1) to ensure that the entire survey area is covered. Data cards are used to identify and quantify the debris items. The NMDMP also incorporates a quality assurance protocol (see Chapter 5) to guarantee the validity of the collected data.

The NMDMP utilizes only ocean beach sites; however, volunteer estuary monitoring groups may consider a similar protocol design to suit their particular data collection needs. ■

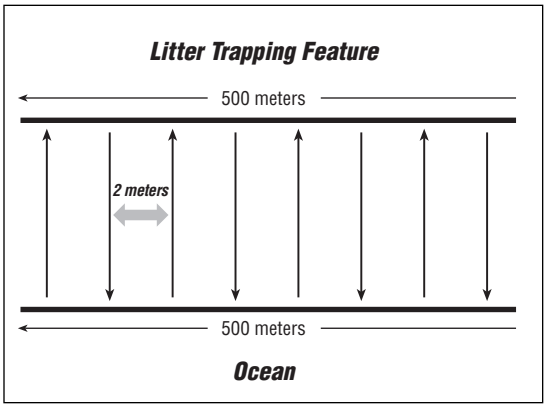


Figure 16-1. Specific walking pattern for inventorying marine debris as part of the National Marine Debris Monitoring Program (NMDMP) *(from Center for Marine Conservation, 1997).*

How to Conduct a Marine Debris Cleanup

Depending on the level of sophistication and the data needs of the program, organizing a marine debris cleanup can take minutes or months. Although getting a few people onto the local beach to pick up some trash may seem like an easy task, a successful cleanup can involve hundreds of people and demand months of organization, recruitment, and planning.

Regardless of the program objectives, a few general elements to a marine debris monitoring program are presented here for the volunteer leader. These elements are derived from The Ocean Conservancy's International Coastal Cleanup and can be divided into three categories: before the cleanup, the day of the cleanup, and immediately after the cleanup.

Helpful Hint

If you plan a marine debris cleanup during the months of September and October, your data can be included as part of your state's International Coastal Cleanup activity. Call 1-800-262-2322 or email cleanup@oceanconservancyva.org before your cleanup activity for more information.

Before the Cleanup:

STEP 1: *Identify debris collection sites that are safe and accessible to volunteers.*

- Ensure that you will have access to the site and that you have the necessary permission to be at the site.
- Verify cleanup date and time.
- Identify potential volunteer check-in site(s) that will be clearly visible and have parking available; for example, if you are conducting a waterway cleanup, it could be located next to a boat ramp or central area of a marina. You may want to post signs or posters directing people to the proper location.
- If scientific data will be collected, volunteers should be trained prior to the activity.

Volunteers in the National Marine Debris Monitoring Program collect and inventory marine debris (photo by The Ocean Conservancy).

STEP 2: *Identify site coordinators who can manage cleanup activities at each site.*

Recruit coordinators and hold a coordinators' meeting. This is your opportunity to distribute materials to the coordinators and make sure they understand everything they have to do. They should know the importance of collecting data, completing data forms, keeping track of numbers of volunteers, and working with the media. All site coordinators should visit their site before the cleanup, finalize where they will set up their check-in point, where the dumpster should be located, and where the volunteers will be sent.

Review what to do if there is a health emergency (Step 8) and what to do with dead, entangled, or injured animals (Step 9).

STEP 3: *Locate a waste hauler who will donate services to the project.*

- Contact a local waste collection company in your area. Your municipal government may help and may even waive the entrance fees at landfills or incinerators for the event.
- Identify an organization or business willing to donate trash bags.
- Plan ahead on how filled trash bags are going to be removed: (1) Will volunteers carry them back to the check-in point, or some other central location, or (2) will they leave them as they are filled, right on the beach (above the high tide mark), to be picked up by truck or other vehicle? If you chose the first option, have your volunteers start at the far end of the zone they will be cleaning and work their way back to the central location. This will decrease the distance they will have to carry full bags of debris.

STEP 4: *Plan recycling options.*

A) Contact recyclers in your area and arrange with them pickup and delivery dates and times.
   - Recycling debris should be a major emphasis of the cleanup project. Some localities may have recycling coordinators in their solid waste departments who should be able to assist you.
   - Try to remove as much other debris from the recyclable materials as possible—particularly organic matter—before sending them to be recycled.

B) Plan ahead how you will collect the recyclables. Either:
   - Have volunteers sort as they collect, working in groups of four or more (make sure to have separate bags for recyclables; using bags of different colors may aid the sorting process); or
   - Identify a special group of volunteers who will work during and after the cleanup to specifically sort the recyclables.

You can make recycling more fun by making a contest out of it: whoever has the most number of cans or bottles (or most bags, or by weight) may win a small prize or get some sort of recognition at the end of cleanup.

STEP 5: *Arrange for a scale at cleanup sites to weigh trash bags and large individual items (e.g., tires), or be sure you can get a weight from your waste hauler.*

This kind of data helps to dramatize a trash problem and is often of particular interest to the media.

There are several ways to calculate the weight of trash collected:

- Secure a scale similar to those used in seafood markets and grocery stores, or one with a hook on it for hanging bags, and weigh each bag of trash before it is thrown into a dumpster. This is the most accurate way of reporting the weight.

- Your waste hauler may be able to give you the total weight of what was hauled away (either a real weight or a good estimate by the number of filled dumpsters or roll-offs).
- Estimate the total weight by weighing a random sample of 10 filled bags of trash, calculating the average weight per bag, and multiplying that number by the total number of filled trash bags.
- Also estimate the weight of items which are too large for trash bags, including tires, large fishing nets, and building materials.

STEP 6: *Solicit volunteers and work with the media.*

A well-publicized cleanup drive can often attract large numbers of citizen volunteers. The following steps can help:

- Distribute posters and brochures.
- Contact local schools, civic organizations, chambers of commerce, environmental groups, industries, and others willing to participate in the cleanup.
- Distribute media announcements to local media and the groups listed above who may have their own newsletters or flyers.
- If you have the time, contact specific environmental reporters (print and TV/radio media) in your area who may be interested in a "before and after" type of story. Get a photographer out to shoot pictures of a cleanup site before the event to illustrate the trash problem, or supply the press with some of your own. This will help encourage participation the day of the event.

STEP 7: *Maintain a list of people who respond and express interest in the cleanup to get some indication of the number of volunteers to expect at your cleanup sites.*

This may be important in case you have too many people wanting to go to a specific site. Others can possibly be diverted to different sites that may need more participants.

Consider ahead of time how volunteers will be dispersed during the cleanup to cover your whole cleanup area. For example, some groups mark off sections of beach every 1/8 of a mile (or whatever distance is appropriate), and estimate the minimum number of volunteers that are needed for each section. Wooden stakes work well for markers, or telephone poles might be used if the cleanup occurs along a road, etc. You may want to have maps of the cleanup site available for volunteers.

Helpful Hint

One site coordinator will not be enough when 40 or more volunteers indicate they will be participating at a site. As a general rule, it takes one additional "assistant coordinator" for every 30-40 volunteers.

STEP 8: *Be prepared for health emergencies.*

- Have first aid kits available at each cleanup site or check-in location for small emergencies like cuts and scrapes. You and your site coordinators should also review what you would do if there is a major health emergency (heat exhaustion or heatstroke, broken bone, etc.). Write out a plan. Know how to get to the closest hospital or other emergency facility from your cleanup site so you can direct emergency personnel. Some communities may want to have rescue

personnel standing by, particularly for areas expecting several hundred volunteers. Additionally, volunteers suffering deep cuts or puncture wounds should check with their physician on the need for a tetanus shot.

- Try to obtain walkie-talkies, two-way radios, or cellular phones for each site coordinator. This is useful for staying in touch with each other, regardless of possible emergencies. Local cellular phone companies may donate phones for such events.

Helpful Hint

Consider contacting your local police department and marine patrol to let them know you will be having a cleanup event.

STEP 9: *Make sure volunteers know what to do with dead, entangled, or injured animals.*

- Contact your local animal/wildlife rescue facilities to let them know that a cleanup will be occurring, and ask them how to properly care for and transport any injured animals that might be found.
- Dead wildlife could simply be left; more often than not, they died naturally and some scavenger will probably take care of them.
- Entangled animals should be removed because other animals may become entangled with them.
- All entanglement and injury incidents should be reported on data cards. Consider sharing your information with local stranding networks, which often keep records of dead, injured, and entangled wildlife.

STEP 10: *Arrange for someone to take photos or videos of the event.*

- Good video footage may be useful for future public service announcements or other educational purposes.
- Label clearly all photos and slides with the photographer's name, name and location of site, and date.

STEP 11: *Contact merchants and other potential donors who can supply drinks, food, raffle prizes, or whatever else you might need.*

Many merchants will jump at the chance to be involved in a positive and non-political event. It is good public relations, and you can make it even better by remembering to mention all your donors and sponsors in press releases or conversations with the press. Donations of this type also encourage more participation.

The Day of the Cleanup:

STEP 12: *Check your equipment.*

If water quality monitoring is to be part of your cleanup activity, make sure to bring along all the proper equipment designated by the program manager (see Chapter 7 for a general list of equipment). In addition to the standard water quality sampling equipment and apparel listed in Chapter 7, the site coordinator should bring the following items to the site for each cleanup:

- plastic garbage bags to collect debris (have at least two bags for each expected volunteer);
- blank data cards;
- pencils or pens to record data;
- clipboards; and
- *Pocket Guide to Marine Debris* (The Ocean Conservancy and USEPA, 2000).

Volunteers should be told to bring:

- gloves;
- protective shoes;
- sunglasses;
- sunscreen; and
- water.

STEP 13: *Set up your check-in points.*

Be prepared before your volunteers start arriving! Have a table or area that will serve as a volunteer check-in station set up with all materials; sign-in sheets ready for volunteers; and signs, if necessary, to direct volunteers to parking, the check-in point, and where they will be cleaning (e.g., stake off sections of the site to be cleaned). Your dumpsters and recycling bins should be appropriately located.

You may want to display actual examples of the items that volunteers may be less familiar with, if you have them. This will aid with proper data collection.

STEP 14: *Coordinate volunteers at cleanup sites.*

Critical to the success of the cleanup is emphasizing that the volunteers' effort will make a difference. Distribute materials and instruct the volunteers on the following items as they arrive at the check-in point, either individually or in small groups:

- Have all volunteers sign in.
- Emphasize the importance of data collection, including information about unusual situations or observations (see Chapter 7). The International Coastal Cleanup data card serves as a nationwide standard that allows data from any beach in the United States to be compared with any other. Standardized data make the national database more useful and accurate for analysis. The Ocean Conservancy will provide these cards at no charge to beach cleanup programs (see end of this chapter for contact information).
- To facilitate data collection and sorting out the recyclable trash, encourage volunteers to work in teams of four or five. Each volunteer in the team should be given one to two trash bags—one for aluminum, one for plastic bottles, and several others for glass. They should sort as they go. One volunteer, designated the "data captain," would be responsible for recording the items picked up by the other volunteers on the data card (they can call out the items as they go). This person will quickly become familiar with the card, making the task easier.

A volunteer coordinator reviews data collection requirements for the International Coastal Cleanup (photo by The Ocean Conservancy).

- The volunteers should know what sort of debris they are likely to encounter. Accurate debris identification will make the database more valuable and will also help volunteers steer clear of potentially dangerous materials such as medical waste or toxic waste containers. It is best to treat unidentified containers with caution; 55-gallon drums and munitions should be avoided altogether. If volunteers do find suspicious materials, they should stay well away, but note their quantity and location and report this information to the program leaders. The leaders can then determine the best means of removing any potentially hazardous materials.
- Emphasize safety, stressing the importance of:
  - always wearing gloves;
  - picking up glass or metal shards with care;
  - steering clear of injured animals which may harbor disease;
  - avoiding overexposure to the sun;

  - not lifting heavy objects without assistance;
  - being aware of snakes and other animals in dunes or grasses;
  - not wading across tidal inlets (currents are often powerful and unpredictable); and
  - reporting any injuries to the program leader.
- Instruct volunteers on what to do if they find dead or entangled animals (see Step 9).
- Instruct the volunteers on what they are to do with the filled bags of trash (see Step 3).

STEP 15: *As the volunteers return, collect all data cards.*

Tell volunteers to return the cards immediately after the cleanup. It is best to have a labeled box at the check-in station where the cards can be returned. Review the cards to ensure they were properly filled out.

STEP 16: *Be sure that volunteers get their certificates, hats, t-shirts, or any other giveaways before leaving the site.*

Any awards that you choose to give out (e.g., for most recyclables, most unusual item, etc.) can be distributed at this time as well.

STEP 17: *Dispose of debris.*

Oversee sorting of the recyclable debris. Make sure the waste hauler takes all the trash away and no other materials are left behind.

Immediately After the Cleanup:

STEP 18: *Compile cleanup information.*

Sample information could include the total number of people, pounds, and miles in your cleanup, any entanglements, unusual items, number of trash bags filled, etc. If your cleanup is part of a larger event, send the data cards to the event coordinator. If feasible, make copies of the cards before sending them, in case the originals become lost.

STEP 19: *Follow up with site coordinators and key volunteers.*

This is intended to gauge the success of the materials developed for promotion of the cleanup, effectiveness of media coverage, etc. They then use this information to plan for next year's cleanup to make it even more efficient and effective. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

The Ocean Conservancy. 2002. *International Coastal Cleanup (ICC) Coordinator Handbook*.

Other references:

Center for Marine Conservation (now The Ocean Conservancy). 1997. *National Marine Debris Monitoring Program Volunteer Handbook.*

Faris, J. and K. Hart. 1995. *Seas of Debris: A Summary of the Third International Conference on Marine Debris*. NC Sea Grant College Program. UNC-SC-95-01.

Marine Mammal Commission (MMC). 1997. *Annual Report to Congress*. Bethesda, MD. 239 pp.

The Ocean Conservancy and U.S. Environmental Protection Agency (USEPA). 2001. *Pocket Guide to Marine Debris*. Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1989. *Marine Debris Bibliography*. Washington, DC. 25 pp.

U.S. Environmental Protection Agency (USEPA). 1992. *Turning the Tide on Trash: A Learning Guide on Marine Debris*. EPA 842-B-92-003. Office of Water, Washington, DC. 78 pp.

Web sites:

The Ocean Conservancy: http://www.oceanconservancy.org

U.S. Environmental Protection Agency: http://www.epa.gov/owow/oceans/debris/index.html

For information about the International Coastal Cleanup for marine debris research:

The Ocean Conservancy
Office of Pollution Prevention and Monitoring
Atlantic Regional Office
1432 N. Great Neck Road, Suite 103
Virginia Beach, VA 23454
Phone: 757-496-0920
Fax: 757-496-3207
Email: cleanup@oceanconservancyva.org

The newsletter *Coastal Connection* can be requested from:

The Ocean Conservancy
1725 DeSales, Street NW #600
Washington, DC 20036
Phone: 202-429-5609
Fax: 202-872-0619

Unit Three

Biological Measures

Bacteria: Indicators of Potential Pathogens

Submerged Aquatic Vegetation • Other Living Organisms

Photos (l to r): U.S. Environmental Protection Agency, R. Ohrel, Weeks Bay Watershed Project, R. Ohrel

Chapter 17

Bacteria: Indicators of Potential Pathogens

Direct testing for pathogens is very expensive and impractical, because pathogens are rarely found in waterbodies. Instead, monitoring for pathogens uses "indicator" species—so called because their presence indicates that fecal contamination may have occurred. The four indicators most commonly used today by both volunteer and professional monitors—total coliforms, fecal coliforms, **E. coli**, ***and enterococci—are bacteria that are normally prevalent in the intestines and feces of warm-blooded animals.***

Photos (l to r): S. Schultz, E. Ely, University of Maine Cooperative Extension, University of Maine Cooperative Extension

Overview

"Is the water safe?" This is one of the major water quality questions every user of an estuary wants to know when preparing for a day of swimming, boating, fishing, shellfishing, or other pursuit. Whether the water is safe depends in part on the presence or absence of pathogens—viruses, bacteria, and protozoans that can cause disease. Increasingly, monitoring and regulatory emphasis are focused on the potential for pathogens that may lead to waterborne diseases. Pathogens can enter a waterbody via fecal contamination as a result of inadequately treated sewage, faulty or leaky septic systems, runoff from urban areas, boat and marina waste, combined sewer overflows, and waste from pets, farm animals, and wildlife. Human illness can result from drinking or swimming in water that contains pathogens or from eating shellfish harvested from such waters.

Direct testing for pathogens is very expensive and impractical, because pathogens are rarely found in waterbodies. Instead, monitoring for pathogens uses "indicator" species—so called because their presence indicates that fecal contamination may have occurred. The four indicators most commonly used today by both volunteer and professional monitors—total coliforms, fecal coliforms, *E. coli*, and enterococci—are bacteria that are normally prevalent in the intestines and feces of warm-blooded animals, including wildlife, farm animals, pets, and humans. The indicator bacteria themselves are not usually pathogenic.

This chapter discusses factors that should be considered when establishing a volunteer monitoring program for bacteria and reviews the major bacterial indicators and the analytical methods most commonly used to test for them. Case studies provide further examples and illustrations.

Why Monitor Bacteria?

Waterfowl are among the many non-human sources of bacteria in estuaries (photo by S. Schultz).

Shellfish beds are closed when bacteria concentrations exceed established criteria (photo by R. Ohrel).

Pathogenic microorganisms (including bacteria, viruses, and protozoans) are associated with fecal waste and can cause a variety of diseases including typhoid fever, cholera, giardiasis (a parasitic infection of the small intestine), and hepatitis, either through the consumption of contaminated shellfish or ingestion of tainted water. Since these pathogens tend to be found in very low concentrations in the water, and there are many different pathogens, it is difficult to monitor them directly. Also, pathogens are shed into the waste stream inconsistently. For these reasons, direct testing for pathogens is expensive and nearly impossible.

Instead, monitoring for pathogens uses "indicator" species whose presence in the water suggests that fecal contamination may have occurred. The four indicators most commonly used today by volunteer and professional monitors—total coliforms, fecal coliforms, *E. coli*, and enterococci—are bacteria that are normally prevalent in the intestines and feces of warm-blooded animals, including:

- wildlife (e.g., deer, geese, raccoons);
- farm animals (e.g., swine, cattle, poultry);
- pets; and
- humans.

States routinely monitor shellfish harvesting areas for fecal coliform bacteria and close them to harvesting when the bacterial count exceeds an established criterion. States may also close bathing beaches if officials find sufficiently high levels of fecal coliform bacteria. In addition to bacteria, shellfish are also monitored for hazards such as viruses, parasites, natural toxins, and chemical contaminants (e.g., pesticides, mercury, PCBs). (See the U.S. Food and Drug Administration's Web site, provided at the end of this chapter, for more information.)

States monitor heavily used beach and recreation areas as well as the water overlying shellfish beds for total and fecal coliforms, but there are limits to the coverage they can provide. Volunteers can supply valuable data to assist established programs by monitoring areas where officials are not sampling, thereby augmenting a state's network of stations. State officials can use this information to screen for areas of possible contamination. Such expanded coverage helps states make beach- and shellfish-closing decisions on a more localized basis.

Fecal coliform contamination can frequently occur in conjunction with other inorganic pollutants. Runoff from a livestock area washing into an estuary, for instance, may contain not only fecal coliforms, but high levels of nutrients as well (see Chapter 10 for more information on nutrients). By including bacterial counts as one of a suite of monitoring parameters, a program manager can design a program that provides a good characterization of the chosen sites. This sort of data collection may reveal problem areas that were not previously recognized.

Volunteers can also perform fecal coliform monitoring with an eye toward regulatory compliance. For example, the program may establish monitoring sites near known or suspected bacterial discharges. Monitoring sites can be set up adjacent to the discharge, but the effluent itself can also be sampled. Program managers should be aware of the legal issues affecting this type of sampling, such as trespass laws and the violation of privacy and property rights.

Why do volunteer groups decide to do bacteria testing themselves? The first and foremost reason is that volunteers are concerned about their watershed and want the opportunity for more community involvement and ownership of the data. Cost is also a factor; unless you find a lab that will donate the analysis, charges run $10-$35 per sample, whereas some volunteer monitoring groups spend approximately $2 for each sample they process themselves.

The Role of Bacteria in the Estuarine Ecosystem

Bacteria are microscopic single-celled organisms that function as decomposers in an estuary, breaking down plant and animal remains. This activity releases nutrients previously locked up in the organic matter into the estuarine food web.

Bacteria live in water, on the surface of water, in the bottom (benthic) sediments, on detritus (dead organic material), and in and on the bodies of plants and animals. They exhibit round, spiral, rod-like, or filamentous shapes (Figure 17-1). Some bacterial organisms are mobile and many congregate into colonies. In the estuary, bacteria are often found densely packed on suspended particulate matter.

Bacteria serve as food for other organisms; they are also involved in many chemical reactions within the water. For example, certain bacteria convert ammonia to nitrite. Another species converts nitrite to nitrate. These nutrients are used by plants. Some bacteria exist only under **aerobic** (oxygenated) conditions; others live in **anaerobic** (no oxygen) environments. Some versatile bacteria can function under either condition.

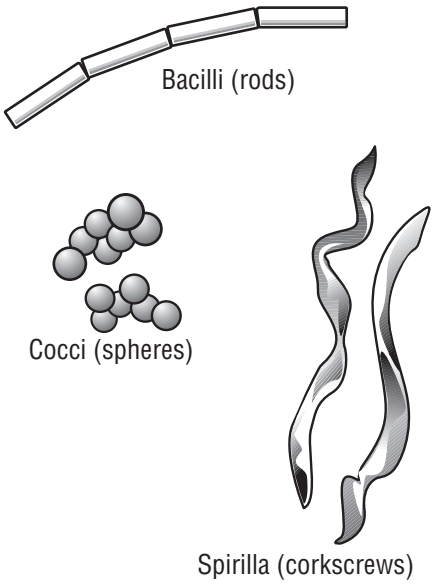
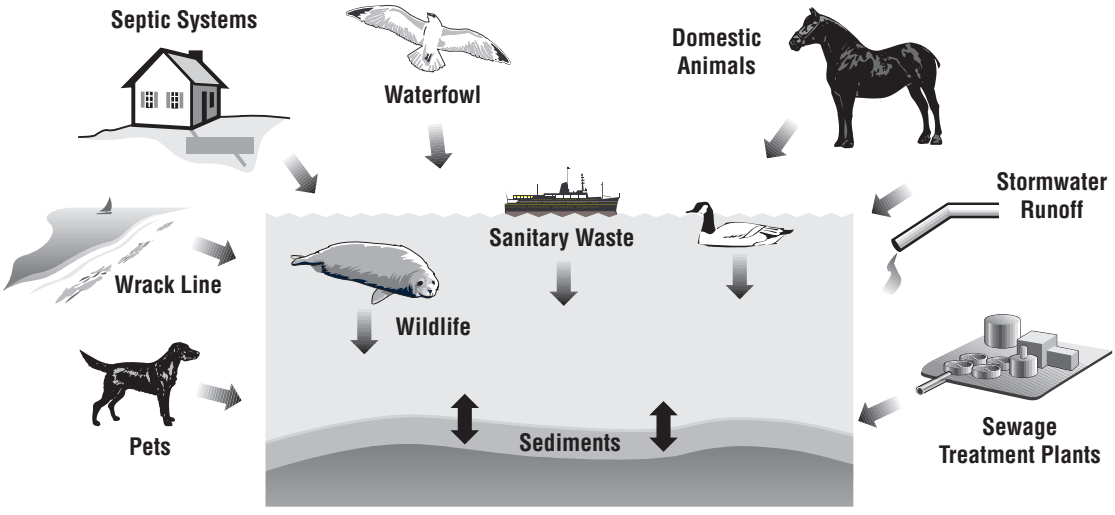


Figure 17-1. Three shapes assumed by bacteria.

Bacterial Contamination

While bacteria normally inhabit estuaries as an integral part of the food web, human activities may introduce pathogenic (disease-causing) bacteria to the system. Of greatest concern to public health is the introduction of fecal waste from humans or warm-blooded animals. Sources of fecal bacterial contamination include faulty wastewater treatment plants, livestock congregation areas, sanitary landfills, inefficient septic systems, fecal waste from pets, stormwater runoff, boat and marina waste, sewage sludge, and untreated sewage discharge. Wildlife also add bacteria to waterways, and can be the dominant source of fecal coliform bacteria in some areas (Figure 17-2). ■

Figure 17-2. Potential sources of bacteria in an estuary *(redrawn from Ely, 1997).*



BACTERIA SOURCE TRACKING

Part of interpreting fecal coliform data involves trying to understand the sources of bacteria in the estuary. If your monitoring indicates high counts of bacteria, the next step is to examine the possible sources. To begin "bacteria source tracking," volunteers should note the number of wildfowl in the area and observe the scat (excrement) of animals along the beach or shore. To establish if wild animals are large contributors of bacteria, compare bacteria counts in an area with few signs of wildlife with an area heavily populated with birds and other animals.

Also investigate whether parts of the watershed have residential areas where dog droppings can be readily found. It is recommended that monitoring programs work with local agencies to research possible sources. It is important to look at all the possible sources of bacteria (see Figure 17-2 for examples), rather than immediately assume that faulty sewage treatment or failing septic systems are the only culprits.

In addition to careful observation of possible sources and comparing bacteria counts in different apparent situations, there are other more complex methods used by laboratories to track bacteria sources. One method uses the fact that some bacteria in humans and domesticated animals have developed resistance to antibiotics. Colonies of bacteria are exposed to various antibiotics to help determine if the source of the bacteria is human, domesticated animals, or wildlife. Other methods, carried out in a few universities and laboratories, involve the analysis of bacterial DNA.

The Bacterial Indicators

In this section, the four main indicator bacteria are discussed. But before we can understand these indicators, we need to understand the criteria that were used to select them as indicators. To be an ideal assessor of fecal contamination, an indicator organism should meet as many of the following criteria as possible:

- The organism should be present whenever enteric (intestinal) pathogens are present.
- The organism should be useful for all types of water.
- The organism should have a longer survival time than the hardiest enteric pathogen.
- The organism should not grow in water.
- The organism should be found in warm-blooded animals' intestines.
- The testing method should be easy to perform.
- The density of the indicator organism should have some direct relationship to the degree of fecal pollution (Gerba, 2000).

Total Coliforms and Fecal Coliforms

Coliform bacteria live in the lower intestines of warm-blooded animals and may constitute as much as 50 percent of fecal waste. Although coliform bacteria are not usually pathogenic themselves, their presence indicates sewage contamination, perhaps accompanied by disease-causing pathogens.

Public health agencies have used total coliforms and fecal coliforms as indicators since the 1920s. **Total coliforms** are a group of closely related bacterial genera that all share a useful diagnostic feature: the ability to

metabolize (ferment) the sugar lactose, producing both acid and gas as byproducts. There are many selective growth media available that take advantage of these metabolic characteristics in traditional testing protocols.

Total coliforms are not very useful for testing recreational or shellfishing waters. Some species in this group are naturally found in plant material or soil, so their presence doesn't necessarily indicate fecal contamination. Total coliforms are useful, however, for testing treated drinking water where contamination by soil or plant material would be a concern.

A more fecal-specific indicator is the fecal coliform group, which is a subgroup of the total coliform bacteria. **Fecal coliforms** are widely used to test recreational waters and are approved as an indicator by the U.S. Food and Drug Administration's National Shellfish Sanitation Program (NSSP) for classifying shellfishing waters. However, even this group includes some species that can have a nonfecal origin (e.g., *Klebsiella pneumoniae*, which grows well in paper pulp and is sometimes found in high concentration near paper mills). Studies have found that all members of the coliform group can regrow in natural surface water depending on the water temperature and the amount of organic matter in it (Gleeson and Gray, 1997). Some warm tropical waters have sufficient organic matter for the bacteria to increase in numbers. The effluents from pulp mills, paper mills, and wastewater treatment plants may, in some cases, also provide conditions under which coliform bacteria can grow.

Even though fecal coliform bacteria have some deficiencies when it comes to being a "perfect" indicator, they are generally considered the best available indicators of contamination at the present time. Many citizen programs and state agencies use fecal coliform testing to assess potential bacterial contamination in an estuary.

One major question often asked about fecal coliforms and estuaries is: "How long do fecal coliform bacteria persist in an estuary?" The answer may vary, depending on where the bacteria are located in the estuary. For example, bacteria may survive for weeks in the sediment or in fecal pellets from wildfowl that have sunk to the bottom. During a storm or other event that disturbs the sediment, fecal coliform bacteria can become reintroduced to the water column. Fecal matter also collects in the line of seaweed and organic material (called **wrack**) that can be seen when the high tide goes out. Birds and other animals forage for food and defecate in this wrack line. When the wrack line enters the water during high tide or a storm, the fecal material and associated bacteria also enter the water.

After incubation, any fecal coliform bacteria in the water sample will have grown into a colony (when using mFC medium or broth). These are called colony forming units (cfu) (photo by University of Maine Cooperative Extension).

Escherichia Coli and Enterococci

Other commonly used indicator bacteria are ***Escherichia coli***, a single species within the fecal coliforms group, and **enterococci**, another group of bacteria found primarily in the intestinal tract of warm-blooded animals. Enterococci are unrelated to the coliforms; instead, they are a subgroup of the fecal streptococci group.

The method approved by the U.S. Environmental Protection Agency (EPA) for enterococci testing requires the use of an expensive growth medium that contains a toxic ingredient. Volunteer programs interested in monitoring for enterococci bacteria could partner with a university or lab to conduct these tests.

Other Bacteria as Indicators

In addition to the four main indicators discussed above, there are other bacteria that can also serve useful indicators of contamination. These include *Aeromonas hydrophila* (a noncoliform), which can be tested using the membrane filtration method described later in this chapter. One medium, ECA Check (made by Micrology Laboratories), identifies and quantifies *Aeromonas* as well as *E. coli* and total coliforms. Consult with suppliers for availability of medium (see Appendix C).

How Effective Are the Indicators?

Total coliforms, fecal coliforms, *E. coli*, and enterococci are easy to grow in a lab, and all will be present in large numbers if recent fecal contamination has occurred. Unfortunately, one problem with the indicators is the question of source. All the indicators can come from animals and some can also come from plants or soil. Another problem is that none of the indicators accurately reflect the potential for human health effects, though some do a better job than others. Because of these and other complications, microbiologists are still looking for better indicators. In the meantime, volunteer monitors and public health agencies alike must do their best with the presently available indicators.

In 1986, EPA issued a revision to its bacteriological ambient water quality criteria recommendations to include *E. coli* and enterococci, as they provide better correlations with swimming-associated gastrointestinal illness than fecal coliforms. As an indicator, *E. coli* has a major advantage over the fecal coliforms: it is more fecal-specific (*E. coli* occurs only in the feces of warm-blooded mammals).

Why Fecal Coliforms Are the Indicator of Choice

Even though EPA recommends enterococci or *E. coli* for testing recreational waters, many states still use fecal coliforms. This is partly for the sake of continuity, so that new data can be directly compared with historical data. Another reason fecal coliforms are the indicator of choice for many states and volunteer monitoring programs is due to economics: the EPA-approved method for testing enterococci can be more expensive than the fecal coliform test. ■

Bacterial Sampling and Equipment Considerations

Chapter 6 summarized several factors that should be considered when determining monitoring sites, where to monitor, and when to monitor. In addition to the considerations in Chapter 6, a few additional ones specific to monitoring bacteria are presented here.

Due to the costs and training associated with analyzing water samples for bacterial contamination, programs just starting up or those without adequate lab facilities should strongly consider allowing a professional, university, or other lab facility to run the bacterial analyses. Often these labs will run samples free of charge or at a reduced rate for volunteer monitoring programs.

Where to Sample

The selection of bacterial monitoring sites depends on the ultimate purpose of the data. If the data are to supplement state efforts, for example, the program should choose sites based on gaps in the state's array of monitoring stations. Areas suspected of contamination that are not routinely monitored by state officials should receive the highest priority.

If data will serve as regulatory compliance documentation, sites should cluster near dischargers believed to be in noncompliance. State health or water quality agencies can provide information on where additional data

are needed. Government managers are more likely to use the data if volunteers monitor more than one site near discharge sources.

To better understand bacterial contamination in a particular estuary, it is necessary to establish the relationship between flow into the estuary and the extent of bacterial contamination. Choose sample sites above and below the area of suspected contamination, at the effluent's entry into the estuary, and even the discharge itself to obtain a scientifically valid set of data (Figure 17-3). Bacterial data collected by volunteers can help assess the relationship between bacterial density and estuarine conditions, and help identify bacterial sources.

As previously mentioned, bacteria may survive for weeks in the sediment, or in fecal pellets which have sunk to the bottom. Bacteria in sediment can be tested by stirring up the sediment before collecting a water sample. To facilitate data analysis, volunteers should be careful to identify samples that contain sediment.

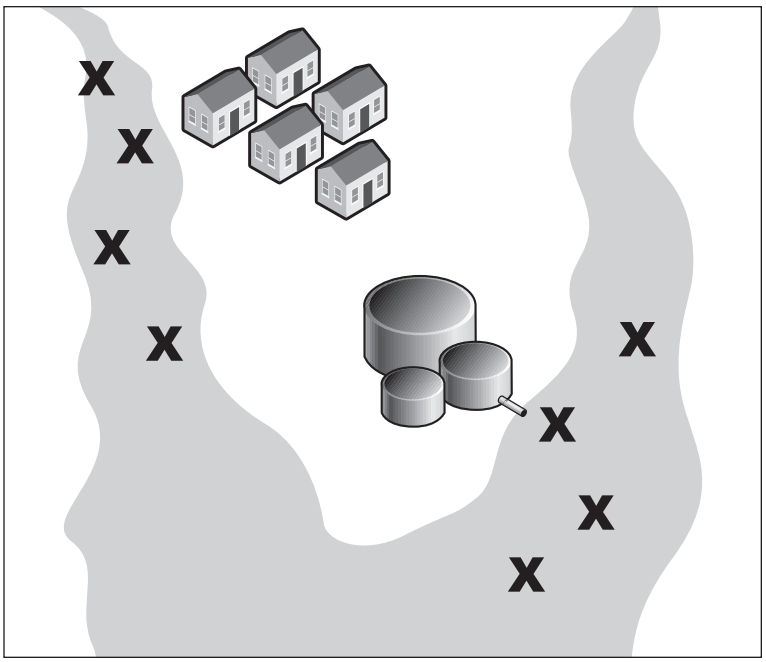


Figure 17-3. Sites to monitor for bacterial contamination.

When to Sample

Volunteers should monitor bacteria on a weekly, biweekly, or monthly basis. In addition, it may be extremely helpful to monitor during or immediately after storm events. It is important to create a monitoring schedule that is sustainable. Set reasonable goals for the frequency of monitoring given your program's number of volunteers and financial resources. In areas where volunteers sample primarily to assess the health risks in seasonal areas, such as bathing beaches, monitoring can cease or be conducted much less frequently during cold-weather months. Sampling to determine possible contamination of shellfish beds, however, should continue on a regular basis throughout the harvesting season. ■

Reminder!

To ensure consistently high quality data, appropriate quality control measures are necessary. As discussed in Chapter 5, it is very important for volunteers to carefully follow established protocols so that the resulting data are of the highest quality. With bacteria testing, two quality assurance/quality control procedures are especially critical. First, the bacteria monitoring program should require periodic split samples, in which one sample is divided equally into two or more sample containers and then analyzed by different analysts or labs. Careful handling of the water sample is also critical. Some programs have chain-of-custody forms to identify the responsible person at every step of the process. While most volunteer programs don't require these forms, the chain-of-custody can become important if the data will be used in cases where legal or corrective actions need to be taken.

In the Field: Collecting Water Samples for Bacterial Analysis

A volunteer with the Friends of the Estuary/Morro Bay NEP Volunteer Monitoring Program collects a sample in a plastic bottle for bacteria testing (photo by E. Ely).

Some citizen monitoring programs use volunteers to conduct the lab analysis of fecal coliform bacteria, and others use volunteers to collect the water samples, leaving the responsibility of sample analysis to a professional lab. In either case, the procedure for collecting the water samples requires strict adherence to quality assurance and quality control guidelines. Analysis of the sample should be done within six hours of the time when the sample was collected.

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7. In particular, they should keep alert for signs of bacteria sources (e.g., wildfowl or other wildlife, pets, nearby residences, foul smells, etc.).

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring an ice cooler (with ice packs to keep samples cool) and sterilized wide-mouth sample bottles (over 150 ml) or Whirl-pak bags.

Sampling Hint:

If using a boat to reach the sampling location, make sure that it is securely anchored. It is critical not to bring up the anchor until the sampling is completed, since mud (with associated bacteria) may become stirred into the water.

STEP 2: *Collect the sample.*

Strict adherence to protocol guidelines is critical in sampling for bacteria. Contamination from any outside source will skew the results and invalidate the data.

Volunteers must take several precautions to ensure good samples: stay clear of algal blooms, surface debris, oil slicks, and congregations of waterfowl; avoid agitating the bottom sediments; and do not allow the boat propeller to stir up the water. Wear gloves when collecting water samples.

Plastic Bottles or Whirl-pak Bags?

For collecting water samples, both plastic bottles and Whirl-pak bags meet the basic criteria of being both sterile and nontoxic. The pre-sterilized, disposable Whirl-pak bags are convenient, but plastic bottles can be washed and reused practically indefinitely, making them cheaper in the long run. In addition, the bottles are easier to work with because they stand up on a benchtop. However, they need to be sterilized in an **autoclave**, and this procedure may require the assistance of a certified lab. Volunteers should ensure that the bottles they purchase are autoclavable—some plastics are not.

(Excerpted and adapted from Miceli, 1998.)

Check to see if a current or tide is running by examining the movement of water or surface debris. If it is running, sample on the upstream side of the boat or pier.

Sampling Hint: Protect Yourself!

Volunteers should take particular care in collecting samples, especially near wastewater discharge pipes, as the effluent may contain highly pathogenic organisms. Avoid splashing water, wash hands thoroughly after water contact, and minimize the breathing of water vapor. Most importantly, all volunteers should wear gloves and protective eyeglasses or goggles.

If using a bottle

- Using a waterproof pen, label the bottle with site name, date, time, data collector, and analysis to be performed.
- Making sure to wear gloves, plunge the bottle into the water upside-down.
- Open the sample bottle below the water surface, keeping hands off the bottle mouth and the inside of the cap. Hold the lid; do not set it down as it may become contaminated.
- Reach down into the water as far as possible (at least 12-18 inches), still holding the bottle with its mouth down. Make sure you keep the bottle above the bottom so as not to disturb the sediment. In a single motion, rotate the bottle mouth so that is it facing up, and sweep the bottle up and out of the water. Make sure that the sweeping motion continues until the bottle is fully out of the water.
- Pour out enough water to leave about 1 inch of air space in the bottle so that the lab technician can shake the sample prior to analysis.
- Replace the lid, again making sure not to touch the inside of the cap or bottle rim.
- Place the bottle in the cooler. Transport samples back to the lab in a cooler regulated to between 1°- 4°C. Do not allow water that may have accumulated in the cooler from melting ice to submerge the bottles. To prevent this problem, use ice cubes packed in plastic bags, water frozen in plastic jars, or sealed ice packs.

If using a Whirl-pak bag

- Using a waterproof pen, write the following on the outside of the Whirl-pak bag: site name, date, time, data collector, and analysis to be performed.
- Tear off the perforated top of the bag.
- Making sure to wear gloves, pinch the white tabs on the top of the Whirl-pak between your fingers, and place the bag into the water.
- Open the bag below the water surface, keeping hands away from the inside of the bag.
- Fill the bag about two-thirds full, and remove from the water.
- Leave an inch or so of air space in the bag. Hold the plastic-coated wire tabs at the top of the bag with both hands, and "whirl" the bag quickly around and around in circles. This will cause the top of the bag to fold over on itself several times.
- Seal the bag by pinching the plastic-coated wire tabs together and twisting them. The bag should not leak.
- Place the bag in the cooler. Transport samples back to the lab in a cooler regulated to between 1°- 4°C. Do not allow water that may have accumulated in the cooler from melting ice to submerge the bags. To prevent this problem, use ice cubes packed in plastic bags, water frozen in plastic jars, or sealed ice packs.

A measured amount of a water sample is being removed from a Whirl-pak bag prior to testing for the presence of bacteria. The sample has been kept cold since it was collected 3 hours before. Note that the volunteer is wearing gloves (photo by K. Register).

STEP 3: *Check data sheets, and send off the sample for analysis.*

Volunteers should make sure the samples remain at the optimal temperature, adding additional ice if necessary. Recheck the data sheets for accuracy and account for all samples. Transport the samples to the designated lab. Processing of the samples should start within six hours of sample collection. Ensure that the data survey forms are complete and legible. Send the forms to the appropriate person or agency. As with all data sheets, the volunteer should make a copy in case the original becomes lost. ■

In the Lab: Analytical Methods

Membrane filtration equipment. Clockwise from left: membrane filtration apparatus; hand vacuum pump (syringe and tubing); petri plate with absorbent pad; membrane filter (photo by M. Redpath).

When testing for the presence of bacteria, laboratories generally use one of two analysis procedures: **membrane filtration (MF)** or **most probable number (MPN)**. Volunteer monitoring groups generally use the MF procedure, but may also use **presence-absence tests** or one of the simplified test methods described below. Any procedure can be used for any of the indicator bacteria, simply by varying such factors as growth media and incubation temperature. Read the summaries of each analysis procedure before deciding which is appropriate for your bacterial monitoring program.

Membrane Filtration (MF): The Classic Method for Bacteria Testing

Membrane filtration for fecal coliforms is the method most widely used by volunteer groups, who select this method because it is EPA-approved, it conforms to what many state labs use, and it is a long-established, well-recognized method. For programs that monitor shellfishing waters, MF for fecal coliforms represents a practical way to approximate the methods used by their state shellfishing lab. State shellfish labs, in accordance with NSSP mandate, use the MPN method for fecal coliforms; volunteer groups tend to use the same indicator (fecal coliforms) but not the MPN method.

Since bacteria are too tiny to count individually, MF relies on an incubation step, followed by a count of the resultant bacteria colonies. A known volume of sample water is pulled through a filter with suction from a vacuum pump. Bacteria are collected on the top of the

What Levels Are Significant?

Interpreting bacterial data can be tricky. There is a great deal of variability in the test procedure as well as in the environment, so a firm conclusion cannot be drawn based on just one sample.

Waterbodies almost always contain some level of fecal coliform bacteria; therefore, it is strongly recommended that volunteer groups do routine monitoring in dry weather so that they can know the baseline conditions for their specific sampling sites. Take samples during different weather conditions and, if possible, collect data during rain events. Consult your appropriate state agency to learn your state's standards for bacteria in surface waters.

filter, which is then placed in a petri dish on top of either solid mFC medium or an absorbent pad soaked with mFC broth.

The petri dishes are inverted and incubated for 24 hours (plus or minus 2 hours) at 44.5°C (Hach, 1997). The incubation temperature is the crux of the membrane filtration with mFC method, since the ability to grow and ferment lactose at 44.5°C is the key distinguishing feature of the fecal coliforms group. To obtain accurate counts, the temperature must be held absolutely steady (within 0.2°C): a bit too warm, and the fecal coliforms can't grow; a bit too cool, and nonfecal bacteria start growing. A good-quality waterbath incubator, while not a cheap piece of equipment, is the least expensive incubator that can provide sufficient results. Air incubators capable of maintaining the required temperature are even more expensive. Some volunteer programs have tried building their own waterbath incubators, with mixed success. Another option is to purchase a reconditioned waterbath incubator. Check the Yellow Pages or ask local laboratories to recommend companies that specialize in used and reconditioned equipment.

After incubation, it is necessary to count the number of blue-colored fecal coliform colonies. A 10- to 15-power microscope or illuminated magnifier is needed to count the colonies. Each colony has grown from a single bacterial cell, so by counting the colonies you can obtain a count of the bacteria present in the water sample. Results are reported as colony forming units (cfu)/100 ml, using the following formula:

cfu/100 ml = (coliform colonies counted x 100)/ (ml sample filtered)

In addition to using mFC medium to investigate the possible presence of fecal coliforms, the membrane filtration method can be used with other media to analyze other indicator bacteria. The medium used depends on which indicator you are looking for. Some media contain ingredients that give the target organisms a distinctive appearance, such as a color. Other media require incubation at very specific temperatures. The amount of time of incubation also varies according to the medium used.

Some volunteer monitoring groups use membrane filtration with mTEC agar, a method that provides counts for both fecal coliforms and *E. coli*. However, this procedure is extra-challenging. In addition to all the steps described above for fecal coliforms, this procedure requires the plates to be incubated at two temperatures (first 35°C and then 44.5°C), and then a special reagent is used to distinguish the *E. coli* colonies from the other fecal coliforms.

Equipment Requirements for Membrane Filtration

Unquestionably, equipment requirements present the biggest hurdle to volunteer groups who want to use an EPA-approved method. The two approved methods volunteers use—membrane filtration with mFC or with mTEC—both require an incubator, an autoclave (for sterilizing equipment), and a membrane filtration apparatus. On the other hand, once the initial investment is made, routine testing by these methods is inexpensive. Many volunteer programs arrange to use high school or university laboratories to sterilize equipment, prepare media, incubate plates, and dispose of wastes. Others set up the equipment at a central program lab.

Most Probable Number (MPN)

The traditional "most probable number" (MPN) technique (using test tubes) may not be practical for volunteer groups because it is labor-intensive, takes up significant incubator space, and requires up to four days for a final result. However, it is important for volunteer estuary monitoring groups to be aware of this method because MPN for fecal coliforms is the only method that is NSSP-approved for classifying shellfish-growing waters.

Unlike membrane filtration, which gives you a plate of colonies to count, MPN does not yield a direct count of bacteria. Instead, the water sample is added to a series of tubes that contain a liquid medium. After incubation, each tube shows either a positive or negative reaction for the target organism. In the case of fecal coliforms, for example, a positive tube is one

that shows growth and gas in lactose broth medium. A second step is required to "confirm" the positive tubes. The number of confirmed positives corresponds to a statistical probability that the sample contained a certain number—the "most probable number"—of bacteria. The accuracy of the MPN method can be increased by inoculating more tubes and by using several dilutions of the water sample.

Comparing Membrane Filtration and MPN

Professional labs mainly use the MF method of analyses, although some use the MPN method. The MF technique is good for large numbers of samples and produces results more rapidly. It should be noted that highly turbid water or water with high counts of noncoliform bacteria can limit the utility of the MF procedure. If a water sample is very turbid, the filter in the MF procedure can become clogged by sediment, algae, etc.

Presence-Absence Tests

Volunteers using membrane filtration equipment. The person on the right is using a hand-operated vacuum pump to pull rinse water through the membrane filter (photo by E. Ely).

Presence-absence (P-A) tests are the easiest method for answering the simple question of whether the target bacteria are present in the water sample. Many volunteer monitoring programs use P-A tests to determine if more extensive testing is needed. The P-A test procedure requires that a bacterial growth medium (selected based on the bacteria indicator you are interested in monitoring) be added to a water sample in a sterile, transparent test tube. The test tube is capped, and the contents are shaken until the medium is dissolved or totally mixed. The sample is then incubated for the prescribed length of time at the required temperature. After incubation, reading the results usually requires comparing the color of the sample to a standard.

For example, if using the Colilert reagent (see below) in your P-A test because you are interested in monitoring total fecal coliforms and *E. coli*, you will check the color of the sample after incubation. A yellow color confirms the presence of total coliforms. If yellow is observed, the next step is to check the sample for fluorescence by placing an ultraviolet (UV) light within five inches of the test tube. If the sample's fluorescence is greater or equal to the fluorescence of the standard, the presence of *E. coli* is confirmed. Several companies sell P-A test kits; be sure to carefully read and follow all directions before using them.

Special Note About Disposing of Bacteria Cultures:

After counting the colonies that have grown in petri dishes, you will need to safely destroy the bacteria cultures. Here are two methods:

Autoclave

Place all petri dishes in a container in an autoclave. Heat for 15 to 18 minutes at 121°C and at a pressure of 15 pounds per square inch. Throw away the petri dishes.

Bleach

Disinfection with bleach should be done in a well-ventilated area, since it can react with organic matter to produce toxic and irritating fumes. Pour a 10-25 percent bleach solution into each petri dish. Let the petri dishes stand overnight. Place all petri dishes in a sealed plastic bag and throw away.

Simplified Testing Methods

Because traditional laboratory methods are complex and can be expensive, several volunteer monitoring groups have started using simplified methods to test for total coliforms, *E. coli*, and enterococci. The

products and procedures outlined below are alternatives to the approved methods and, in some cases, can have simpler equipment requirements. New bacteria monitoring products are introduced often, so check with scientific supply houses for new options (see Appendix C).

With these simplified methods, there are a couple of important caveats to keep in mind:

- These methods are not EPA-approved for recreational waters (although Colilert is approved for drinking water) and thus are appropriate for screening only.
- None of the quick methods provides a fecal coliforms count. They only assess total coliforms, *E. coli*, or enterococci. This may be problematic for volunteer groups whose data users utilize or require fecal coliform indicators.

The big advantage of these simplified methods is that they make it possible for individual volunteer monitors to perform the tests in their own homes. Incubation is at 35°C or even at room temperature. Some of the popular simplified methods use the products listed below. See Appendix C for addresses of suppliers.

Coliscan Easygel and Coliscan-MF Membrane Filtration

Coliscan (from Micrology Labs—see Appendix C) is a product used by many volunteer monitoring programs to monitor for total coliform and *E. coli*. Coliscan comes in two pre-packaged kits: Coliscan Easygel (which is used in a plate-count method) and Coliscan-MF (which uses membrane filtration).

Both Coliscan products make use of a patented medium on which total coliform colonies other than *E. coli* appear pink and *E. coli* colonies appear purplish blue. With the Coliscan-MF Membrane Filtration Kit, water samples are processed by the membrane filtration technique and the filter is placed on the special Coliscan medium.

Coliscan Easygel is a very easy pour-plate method. It is self-contained and relatively inexpensive. You simply add the water sample (unfiltered) directly to a bottle of liquid Coliscan medium, mix it, and pour it into a special petri plate which is coated with a substance that causes the medium to gel. Easygel is appropriate only for counts higher than about 20 colony forming units per 100 milliliters (20 cfu/100 ml), since there is no filtration step to concentrate the bacteria and the maximum sample water volume is 5 ml.

After the water sample is pulled through the membrance filter (using a vacuum), the glassware above the filter is rinsed so all bacteria present in the sample will accumulate on the filter. In this laboratory, the membrane filtration process occurs under a hood for added quality control (photo by K. Register).

For both Coliscan-MF and Coliscan Easygel, the manufacturer recommends an incubation temperature of 35°C, but says that plates can also be incubated at room temperature (though growth will be slower). However, room temperature can vary with season or even day to day, making it difficult to compare results obtained at different times. Using an incubator ensures a consistent temperature.

After incubation, colonies that have formed in the petri dish are counted. Some users have found colony counting somewhat tricky with the Easygel plate because many colonies are embedded in the agar (since it is a pour plate). Nevertheless, Easygel can be an effective screening tool.

Colilert, Colilert-18, and Enterolert

Some health care agencies, pollution dischargers, and volunteer monitoring groups have adopted the use of Colilert and Enterolert test kits (all made by Idexx Laboratory—see Appendix C) as alternative methods for detecting and enumerating total coliforms, *E. coli*, and enterococci. Colilert and Colilert-18 are the media used in MPN tests to determine if total coliforms and *E. coli* are present in the water sample. **Colilert is not intended for marine waters**, but

Colilert-18 is. These kits use either multiple tubes or multiple wells, with an MPN approach, to detect the presence or absence of total coliforms and *E. coli*. As with the classic MPN method, the more tubes inoculated, the more sensitive the count. Five tubes are enough for a rough screen.

Results are read after 18 hours for Colilert-18 and after 24 hours for Colilert. Incubation is required at 35°C (plus or minus 0.5°C). With Colilert, the detection of total coliforms is based upon a color change and *E. coli* is detected when the sample fluoresces under UV light. This modified MPN test provides more information about the amount of bacteria in the water than a presence-absence test, but not as much information as an MF or MPN test.

Enterolert is used to detect enterococci in a water sample using MF, MPN, P-A, or the modified MPN procedure discussed above. Incubation is 24 hours at 41°C (plus or minus 0.5°C). ■

Case Study: Bacteria Monitoring in California

In California, several chapters of Surfrider Foundation (a nonprofit environmental organization dedicated to the protection of the world's waves, oceans, and beaches) use Colilert to monitor the surf zone. Surfrider volunteers carry out the tests in their homes or local school laboratories, using relatively inexpensive incubators. Supplies for each sample cost about $5.

Surfrider volunteers publish their results in local newspapers and present them at public meetings. Their efforts are helping to raise awareness about bacteria and nonpoint source pollution.

(Excerpted from Ely, 1998.)

Which Method and Which Medium Should You Use?

In deciding what method to use, a number of questions must be considered. Some of them are:

- How do you hope to use your data?
- Will you be testing the freshwater or saltwater portion of the estuary?
- Will you be testing water where shellfish are harvested?
- What methods does your state lab currently use?
- Do you have access to laboratory facilities?
- What kind of equipment can you afford?
- Which bacteria are used as indicators by your state?

If your budget allows, select your bacterial indicator and analysis method based on the intended use of your data. If the primary objective of the volunteer monitoring program is to evaluate water for compliance with state water quality standards, the program should use the same or similar method used by state labs. The program should keep apprised of any changes in state requirements.

On the other hand, groups that are primarily interested in raising community awareness and/or screening for high counts may find that a simpler, non-approved method is adequate for their needs. ■

Case Study: Bacteria Monitoring in Maine

The Clean Water Program of the University of Maine Cooperative Extension was established in 1988. It provides organizational and technical support to 18 citizen water quality monitoring groups (approximately 600 volunteers). The Clean Water Program works in collaboration with the Maine State Planning Office Partners in Monitoring Program, the Maine Department of Marine Resources, and the Maine Department of Environmental Protection to form the umbrella program known as the Maine Shore Stewards Program. Water quality groups study the health of estuarine water by monitoring for dissolved oxygen, temperature, pH, salinity, and fecal coliform bacteria.

Students participating in Maine's Shore Stewards Program run estuary samples for fecal coliform bacteria using the membrane filtration method (photo by University of Maine Cooperative Extension).

The primary objective of the program is to assist in determining bacterial pollution sources and to work with local and state officials to remediate those sources (Figure 17-4). The program focuses at the local community level. Labs for fecal coliform bacteria analysis are set up in local high schools or community group locations.

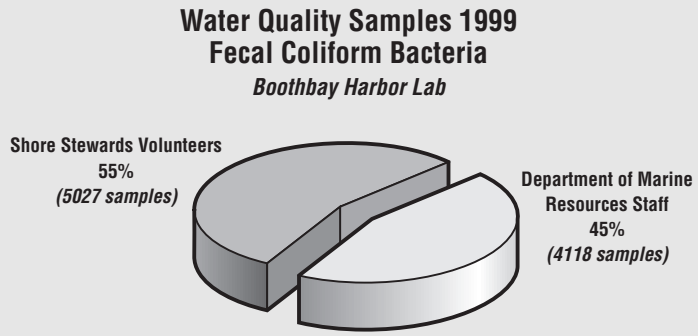


Figure 17-4. Volunteers participating in Maine's Shore Stewards Program are instrumental in supplementing state agency-collected fecal coliform data. Their efforts have helped identify the causes of many shellfish bed closures *(reprinted from Maine Department of Marine Resources).*

Through their monitoring efforts, citizen groups have discovered many bacterial sources causing shellfish bed closures, including unregulated septic storage and failing septic systems. Working with local officials and state agencies, the groups helped remedy the problems and reopen the beds. Due in large part to these monitoring efforts, 100,000 acres of clam flats in Maine have been reopened in the past five years.

Other objectives of the program are to monitor coastal swimming areas and provide baseline data. Recently, a coastal community with a failing septic system used volunteer data to determine when bacteria levels were safe for swimming. In addition, volunteer data has identified recreational boats as major bacterial sources in many communities during the summer.

The Maine Shore Stewards Program has built on the strengths of communities by providing them with water quality and marine resources education, and by assisting them with their work on environmental issues. Partly from their program participation, many high school students have been inspired to go on to study environmental science in universities and to become involved in community conservation efforts. Watershed communities have begun working together to resolve water quality problems, and hundreds of citizens have become active in environmental education and conservation efforts.

For More Information:

Maine Shore Stewards
University of Maine Cooperative Extension
235 Jefferson Street
P.O. Box 309
Waldoboro, ME 04572
Phone: 207-832-0343
Fax: 207-832-0377
http://www.ume.maine.edu/ssteward

Bacteria Testing Q & A

Bacteria testing is a very important—and demanding—part of many monitoring programs. Here are some helpful answers to common questions that may arise (excerpted from Miceli, 1998).

What does it mean when I get a high bacteria count?

The first action to take is to return to the same location and get more samples. If some or all of these sample results are high, too, then you should follow your organization's procedures—for example, calling your state agency to notify them.

A little detective work plays a big role in determining where contamination is coming from and whether it is of human origin. Always make observations—the presence of animals and birds, abundant leaf matter, any strange debris, any unusual smells, etc. Also note weather conditions since results can vary tremendously if it is raining.

Remember, too, that variability and unusual test results will occur and that a high level of fecal coliforms is not abnormal, especially since wildlife frequent estuaries. A long-term monitoring effort will provide baseline information about a sampling site and will enable you to quickly recognize any unusual results.

What exactly am I looking at and counting anyway?

A single bacterium in the water sample that is caught on the filter, if able to grow on the medium, can reproduce at a fast rate. Some bacteria multiply every 20 minutes, so after 24 hours, when you retrieve your plates, you are looking at a clump of about a million bacteria—visible to the naked eye!

I am using the membrane filtration method. Why do I see . . .

(a) a big blob of growth on only one spot on the filter?
This may occur when the sample aliquot being analyzed is small (1-10 ml) and is not distributed evenly on the filter. To ensure even distribution, be sure to add enough buffer or rinse water (5-10 ml) to the funnel prior to adding the sample—and prior to applying the vacuum. The sample will disperse in the buffer (picture the way a small dollop of cream spreads out in a cup of coffee), and the colonies should be evenly distributed on the filter.

(b) all the growth on only one side of the filter?
The funnel base may be clogged so that the vacuum is only pulling through one part of the base. Remove the base and thoroughly clean it of any buildup. It is recommended that funnels and bases be cleaned periodically.

(c) colonies that look runny and oblong?
First, you may be incubating the plates in the wrong position. Plates should be incubated in an inverted position—that is, medium side up—so that condensation will fall down on the cover, not on the growing colonies. Second, excessive moisture may remain on the filter if it is

(continued)

(Bacteria Testing Q & A, continued)

removed before all the sample is filtered. This may cause the bacterial growth to spread out. These "spreaders" should be counted as one colony.

There's a lot of background growth. Can I still count all my target colored colonies?

There is a maximum number of total colonies allowable on a plate. For the small-size membrane filtration plates, 80 (or even 60, depending on the method) is the maximum. The larger plates used with Coliscan Easygel can accommodate up to 300 colonies.

All those organisms compete for the limited nutrients in the medium. The ones that grow are those that were able to outcompete the others. This competition may mask what the actual numbers are. If the total number of colonies exceeds the allowable number, the count is invalid and the result should be reported as an estimate based on the quantity of sample analyzed and the plate size.

I have a hard time assessing if a colony is the "right" color.

Including positive and negative control organisms when you analyze your samples will give you a reference to compare to. It takes practice to learn which questionable colonies are positive for your method. When starting out, it's a good idea to pick a representative colony you are unsure about and verify what it is, perhaps with assistance from a professional lab. This is especially helpful if an entire plateful of a strange-looking colony appears. Identifying what it is may uncover an unknown problem in the area or point to a problem with your quality control.

On mTEC medium (before you add the urease reagent) some yellow colonies are bigger, some are smaller, and some are pinpoint, but they should all be considered fecal coliform colonies. Some may even start to turn a brown-yellow.

Plates of mFC media are usually easy to count; the one potential problem is crowding, because the colonies are big and flat.

Pour plates (such as the Coliscan Easygel plate) can be difficult to read since colonies grow both on top of and within the medium. The colonies may be smaller and more difficult to assess when there is a lot of growth. Total coliforms appear pink-red, *E. coli* appears purple, and non-coliforms, which are also able to grow, are usually green or white. Lots of background growth may interfere with "reading" the plates.

How do I store a plate that I want to send to a laboratory?

If you want to send a plate to a lab for help with identification, place it in a ziplock bag labeled "biohazard" and store it in the refrigerator, media-side up. Transport the plate to a laboratory as soon as possible, but the plates can be stored for a week or longer in the refrigerator because the cold temperature slows bacterial growth.

(continued)

(Bacteria Testing Q & A, continued)

I gave another laboratory a duplicate sample bottle and their results are very different! Why?

First, be clear about what you are duplicating. If you collect two separate samples from the same site, you are replicating collection. Since organisms are not homogenous in the environment, it is very possible that two separate grabs from the same area may yield different results.

Most often, what volunteer groups really want to replicate is the analysis. Never use two separate grab samples to test for comparability of analysis with another laboratory; rather, collect a single sample in a large container (you may need to buy a few larger sample bottles for this purpose), mix it well, then immediately pour half into another sterile container which you will provide to the other laboratory for analysis.

Both laboratories should use the same test method, and preferably both should analyze the sample at approximately the same time. If the results are not within acceptable limits of variability, determine where the discrepancy lies. (NOTE: Defining acceptable limits of variability is a complex problem; consult with a professional lab for guidance.) Common problems include not mixing the sample well enough prior to analysis, not measuring accurately, and incorrect incubation temperature.

What minimum quality control should I be doing?

Briefly, you should maintain records of positive and negative controls, incubator temperatures, and split sample results. Maintaining proof that your results were generated in a consistent, reproducible manner that adheres to the requirements of the method will allow others to accept your results. Quality control testing should not take too much extra time, but it will instill confidence that you are producing valid data.

Can I combine my results with others in my program who are using a different method?

No. When reporting results, it is necessary to specify the method used, the media used, and the lower limit of detection (the smallest number of test bacteria that could be found considering the method and the quantity of sample). Different methods have different precision and recovery ability. It is important to separate results that were generated by different test methods and under different conditions. ■

References and Further Reading

Portions of this chapter were excerpted and adapted from:

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 Groups Use?" *The Volunteer Monitor* 10(2): 10-13.

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

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

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. Office of Water, Washington, DC. 211 pp.

Other references:

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.

Behar, S. 1997. *Testing the Waters: Chemical and Physical Vital Signs of a River*. River Watch Network. Montpelier, VT.

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

Gleeson, C., and N. Gray. 1997. *The Coliform Index and Waterborne Disease*. E and FN Spon, London.

Gerba, C. 2000. "Indicator Microorganisms." In: *Environmental Microbiology*. R. Maier, I. Pepper, C. Gerba (eds). Academic Press, New York.

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

Kerr, M., L. Green, M. Raposa, C. Deacutis, V. Lee, and A. Gold. 1992. *Rhode Island Volunteer Monitoring Water Quality Protocol Manual*. University of Rhode Island Coastal Resources Center, Rhode Island Sea Grant, and URI Cooperative Extension. 38 pp.

Mitchell, M., and W. Stapp. 1999. *Field Manual for Water Quality Monitoring*. 12th ed. Kendall/Hunt. Available from GREEN, c/o Earth Force, Inc., 1908 Mount Vernon Ave., Alexandria, VA 22301; phone: 703-299-9400; Web site: http://www.earthforce.org/green/.

River Watch Network. 1996. *Escherichia coli (E. coli) Membrane Filter Procedure*. River Watch Network. Montpelier, VT.

Stancioff, E. 1996. *Clean Water: A Guide to Water Quality Monitoring for Volunteer Monitors of Coastal Waters.* Maine/New Hampshire Sea Grant Marine Advisory Program and Univ. of Maine Cooperative Extension. Orono, ME.

U.S. Environmental Protection Agency (USEPA). 1986. *Bacteriological Ambient Water Quality Criteria for Marine and Fresh Recreational Waters*. EPA 440/5-84-002. EPA Office of Water. PB-86-158-045.

U.S. Environmental Protection Agency (USEPA). 1985. *Test Methods for Escherichia coli and Enterococci in Water by the Membrane Filtration Procedure.* EPA 600/4-85-076. EPA Office of Water. PB-86-158-052.

Web sites:

U.S. Food and Drug Administration, National Shellfish Sanitation Program (NSSP): http://vm.cfsan.fda.gov/~mow/sea-ill.html and http://vm.cfsan.fda.gov/seafood1.html.

Many manufacturers of bacteria-testing equipment have Web sites that are informative and up-to-date on the bacteria-growing media they offer. See Appendix C for Web addresses.

Other resources:

Educational Video on Processing Fecal Coliform Samples

To assist volunteer organizations, a short educational video is available that describes and demonstrates the analysis of fecal coliform sampling. It includes information for the layperson on everything from sterilization techniques to QA/QC (quality assessment/quality control) procedures. The video costs $14 and can be ordered through the New Hampshire Sea Grant Communications Office, Kingman Farm House, University of New Hampshire, Durham, NH 03824; phone: 603-749-1565; fax: 603-743-3997.

Chapter 18

Submerged Aquatic Vegetation

In the shallows of many healthy estuaries, where sunlight penetrates the water to the estuary bottom, dense stands of aquatic plants sway in unison with the incoming waves. The aquatic plants are known collectively as submerged aquatic vegetation. Unfortunately, over the past several decades these plants have fared poorly in many of our nation's estuaries. Areas once covered by thick beds of these plants may have little or no vegetation remaining. In areas that can support them, the plants often serve as a barometer of estuarine ecosystem health. By monitoring the status of these plant populations over time, we can better determine the estuary's vitality.

Photos (l to r): K. Register, R. Ohrel, The Ocean Conservancy, E. Ely.

Overview

In the shallows of many healthy estuaries, where sunlight penetrates the water to the estuary bottom, dense stands of aquatic plants sway in unison with the incoming waves. The aquatic plants are known collectively as **submerged (or submersed) aquatic vegetation. SAV**—or sometimes called **seagrasses** in marine environments—generally include rooted vascular plants that grow up to the water surface but not above it (although a few species have flowers or tufts that may stick a few centimeters above the surface). The definition of SAV usually excludes algae, floating plants, and plants that grow above the water surface.

The plants are important components of estuarine systems, providing shelter, habitat, and a food source for many organisms. They also benefit estuarine species indirectly by helping to maintain the viability of the ecosystem. Their photosynthesis adds dissolved oxygen to the water, and their leaves and roots help stabilize the shoreline against erosion. The plants also absorb nutrients, which can be major estuarine pollutants.

Unfortunately, over the past several decades these plants have fared poorly in many of our nation's estuaries. Areas once covered by thick beds of these plants may have little or no vegetation remaining.

Not all healthy estuarine and near coastal areas have the physical and chemical properties necessary to support SAV. For example, areas with very high tidal ranges (e.g., more than two meters) or soft sediments may not provide a suitable habitat for the plants. In areas that can support them, the plants often serve as a barometer of estuarine ecosystem health. By monitoring the status of these plant populations over time, we can better determine the estuary's vitality.

This chapter describes the role of SAV in the estuarine ecosystem, describes some common SAV species, and provides basic steps for monitoring SAV.

Why Monitor SAV?

SAV forms a critical link between the physical habitat and the biological community. The plants require specific physical and chemical conditions to remain vigorous. In turn, they stabilize sediments and provide habitat, nourishment, and oxygen to other species in the estuary.

A viable and self-sustaining SAV population is the hallmark of a healthy estuary (in estuaries that naturally support SAV). By monitoring the occurrence of SAV beds and the changes in their distribution, density, and species composition, trained volunteers can help determine the health and status of SAV in an estuary. Scientists can then compare this information to historical data of SAV beds.

Volunteers and SAV Monitoring

SAV is extremely sensitive to disturbance. Therefore, it is essential that volunteers receive proper training and supervision from qualified scientists or resource managers. Volunteer leaders should check with the appropriate government agency to determine which monitoring or sampling activities may be suitable for volunteers.

The Role of SAV in the Estuarine Ecosystem

As critical to the shallow waters of an estuary as trees are to a forest, SAV beds play several roles in maintaining an estuary's health. Although only a few truly aquatic species consume the living plants (e.g., manatees, sea turtles, and some species of fish), several types of waterfowl and small mammals rely on them as a major portion of their diet. Even in death, the plants are a major estuary component. SAV forms huge quantities of decomposed matter as leaves die; several aquatic species use this detritus as a primary food source.

During the growing seasons of spring and summer, SAV supplies oxygen to the water through the process of photosynthesis, thereby helping to support aquatic organisms' survival. The plants also take up large quantities of nutrients, which remain locked in the plant biomass throughout the warm weather seasons. As the plants die and decay in autumn, they slowly release the nutrients back to the ecosystem at a time when phytoplankton blooms pose less of a problem (see Chapters 10 and 19).

Additionally, the plant communities provide shelter for various species of organisms. Juvenile and larval fish and crustaceans use SAV beds as protective nurseries and to hide from predators. Shedding crabs conceal themselves in the vegetation until their new shells have hardened. A variety of organisms [e.g., barnacles, bryozoans (a group of colonial invertebrates)] and eggs of many species attach directly to the leaves.

The sheer bulk of the plants often buffers the shoreline and minimizes erosion by dampening the energy of incoming waves. Plant roots bind the sediments on the estuary bottom and retard water currents. By minimizing water movement, SAV allows suspended sediments to settle and water clarity is improved.

SAV Habitat Requirements

Once established and under optimal conditions, these plants can spread quickly into large, thick stands. SAV habitat requirements are as follows (adapted from Bergstrom, 1999):

Adequate Light Penetration

SAV can grow only in those portions of the estuary shallow enough and clear enough to receive sufficient sunlight for photosynthesis. The plants tend to grow in shallow water, but may grow in deeper areas where the water is particularly clear.

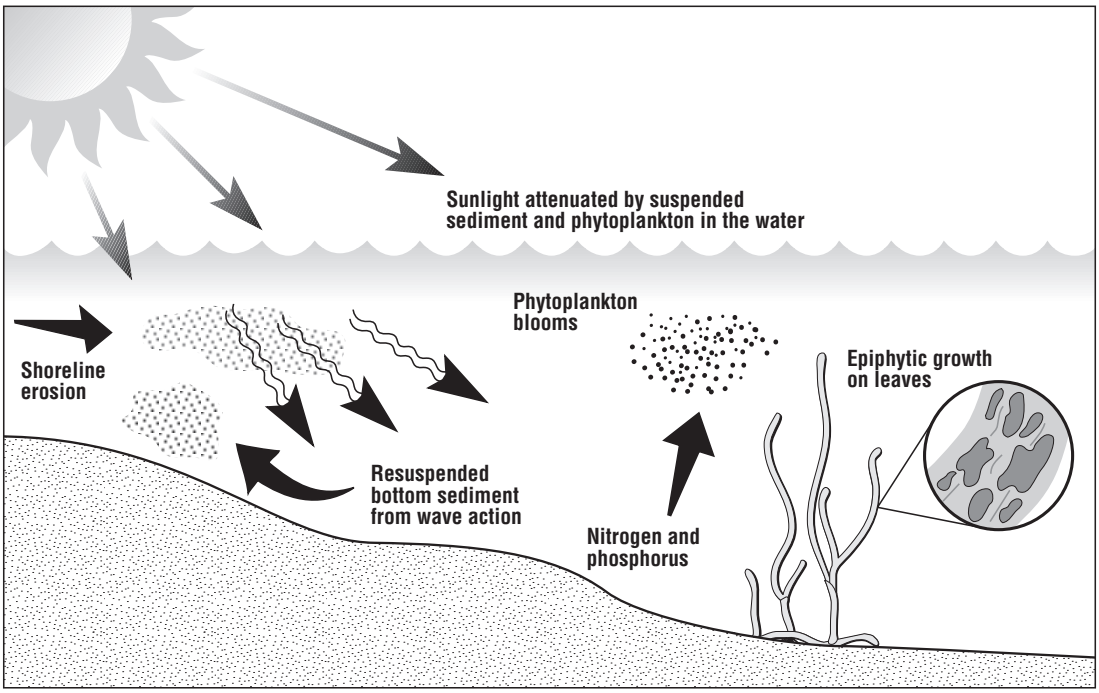


Figure 18-1. Impacts on SAV. Sediments, nutrients (and accompanying algal blooms), and epiphytic growth can ultimately affect the amount of sunlight reaching the plants *(adapted from Barth et al., 1989).*

Water Inundation

SAV species primarily live in areas where the plants will remain submerged; however, some species can withstand exposure during low-water periods (e.g., low tide). A large tidal range may limit SAV growth (i.e., prolonged exposure during low tide and inundation by deep water during high tide, especially when the water is cloudy, can make for undesirable habitat conditions).

Suitable Salinity, Temperature, and Sediments

The salinity, temperature, and sediments of a particular estuarine location determine, to a large extent, which species can survive. While some species tolerate a fairly wide range of salinity, others are restricted to very specific levels.

Low to Moderate Wave Action

Heavy waves impede SAV roots from getting established. Some water circulation is desirable, however, to prevent SAV from becoming choked with algae.

The Demise of SAV

In a balanced and healthy estuarine ecosystem, SAV species blanket the shallows with the composition of each bed attuned to controlling variables such as light availability, sediment, salinity, temperature, and depth. When an estuary is tipped out of balance, however, SAV beds usually suffer. The degradation or loss of these beds can set up a chain reaction of ill effects that ripples through the entire estuarine ecosystem.

As SAV beds decline, the need to protect them becomes ever more critical (photo by R. Ohrel).

This chain of events often starts with an overload of nutrients (Figure 18-1). Excessive quantities of nitrogen and phosphorus cause an overgrowth of phytoplankton (see Chapter 19). These **algal blooms** cloud the water and severely diminish sunlight penetration. The nutrients may also trigger a thick growth of **epiphytes**—plants that grow on the surface of SAV leaves. The epiphytes block sunlight from reaching the leaf surfaces of their hosts.

As the water clarity problem worsens, the area of the estuary that is able to support SAV becomes even smaller. For example, estuary water once capable of supporting plants to a depth of ten feet may now only transmit enough light for plant survival to a depth of six feet.

When plant beds thin or die back, water that may already be low in dissolved oxygen due to algal blooms (see Chapters 9 and 19) becomes even more depleted as the amount of oxygen generated by SAV photosynthesis declines. Nutrients once tied up in the plant leaves, roots, and bottom sediments may be released to the water where phytoplankton snap them up, thereby increasing the possibility of more blooms.

A bare substrate, where SAV once flourished, poses a whole set of new problems. Without plant roots to stabilize the sediment, waves easily kick up silt which remains suspended in the water until calmer conditions return. Like algal blooms, suspended silt cuts down on light transmission through the water. The silt may also settle onto the leaves of any remaining plants, further blocking the light needed for photosynthesis.

As some species lose a foothold in the estuary, non-indigenous (or invasive) and opportunistic species may move in and displace them. Non-indigenous SAV species (e.g., Eurasian watermilfoil, parrotfeather milfoil, and hydrilla) may overwhelm native SAV species and assume their habitat. While the growth of these new species often alleviates the problems associated with a bare substrate, other problems may arise (see Chapter 19).

While nutrients are one of the major causes of SAV disappearance or decline in many bays and estuaries (particularly on the Atlantic coast), other factors may also play a role. Runoff from different land uses and dredging activities can cloud waters over acres of SAV beds with sediment. Agricultural and lawn herbicides may cause a loss of some species, while industrial pollutants and foraging animals may selectively kill off local beds. Areas frequently subject to improper shellfish harvesting, boat-generated waves, and boat propeller scarring may also lose their SAV beds. ■

Sampling Considerations

What to Sample

There are numerous SAV species with different ranges throughout the United States. The type of SAV monitored by volunteers, then, will depend on geographic location. A few common and widely distributed SAV species are described below:

Eelgrass *(Zostera marina)*

Eelgrass (Figure 18-2) is the dominant seagrass in the cooler temperate zones of the Atlantic and Pacific coasts. Beds of this luxuriant plant survive in a wide range of salinities throughout these regions, but occur mainly in high salinity waters (18-30 parts per thousand-ppt) (Chesapeake Bay Program Web site). Flowing and elongate like an eel, the slender leaf blades grow up to several feet in length.

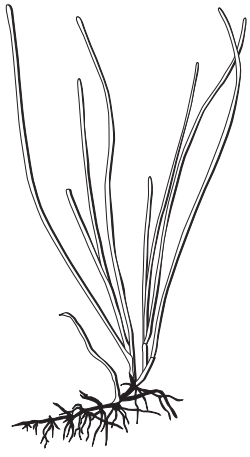


Figure 18-2. Eelgrass *(Zostera marina).*

Eelgrass spreads by sending out runners that creep along the bottom and repeatedly send up shoots that grow into new plants. The species produces tiny, rather inconspicuous flowers and seeds that appear on large and easily distinguished branching stalks. New plants take several years to reach maturation. Once a bed becomes established, however, this species of seagrass is highly productive.

Because of its predominance and widespread coverage, eelgrass is an important ecological element of many estuaries and nearshore areas. It may cover acres of the bottom, providing food and/or cover for fish, invertebrates, and waterfowl.

Eelgrass is subject to infection by a blight presumably caused by a slime moldlike organism called *Labyrinthula zosterae.* The disease causes dark lesions on the eelgrass leaves and can ultimately result in mass mortality of the plant beds. A major epidemic occurred in the 1930s, but by the 1960s most beds had recovered. Along with the dieback of eelgrass, animals dependent on this plant, such as the brant (a small goose) and bay scallops (an important economic resource), also declined precipitously.

In the past 15 years, scientists and volunteers have noted the characteristic lesions of the disease on some eelgrass plants once again. The blight, also known as eelgrass wasting disease, is not fully responsible for eelgrass bed demise. While some areas never fully recovered from the 1930s epidemic, other factors have contributed to the plant's decline. Nutrient-rich waters, herbicides, and abundant algal growth have also harmed eelgrass and other SAV species.

Volunteers in New England have worked with a technique to assess the degree of infestation on individual eelgrass leaves (Figure 18-3). This information provides an estimate of disease progression.

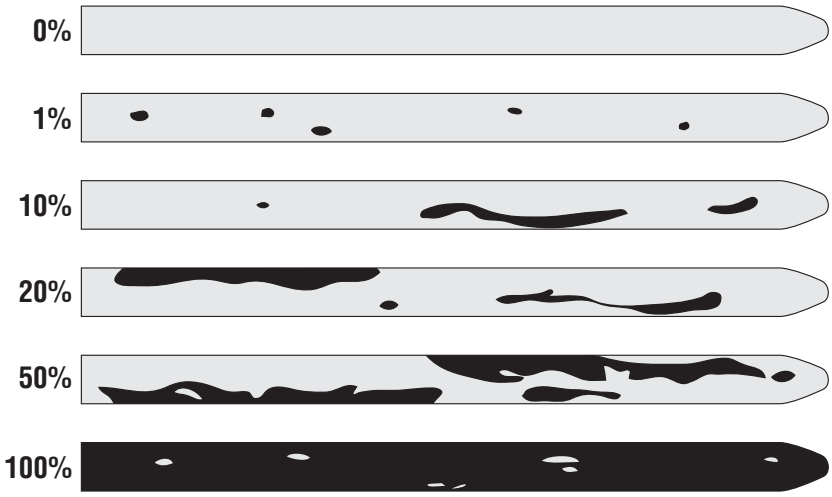


Figure 18-3. Eelgrass wasting disease index key. The disease causes black patches to appear on eelgrass leaves. Volunteer monitors can use the index to estimate the disease's presence on the leaves *(Burdick et al, 1993).*

Widgeon Grass *(Ruppia maritima)*

Widgeon or ditch grass (Figure 18-4) inhabits the entire Atlantic and Gulf Coasts, and part of the Pacific Coast of the United States. This plant is remarkably resilient and can withstand a wide range of salinities. Specimens have occasionally been found in fresh water, yet the species can also tolerate full ocean salinity. Its primary habitat, however, is in brackish bays and estuaries.

The leaves of widgeon grass are needlelike, short, and usually about two inches in length. They branch off of slender, elastic stems. Like eelgrass, this grass produces tiny, rather inconspicuous flowers and seeds found on stalks. The plants may also reproduce asexually by means of rhizomes which extend along the estuary bottom and send out shoots.

Widgeon grass is an extremely important SAV species for waterfowl. The American widgeon, a brown duck for which the plant is named, relies heavily upon widgeon grass as a major component of its diet. The plant is nutritious, making it a favored food item for many other waterfowl species as well.

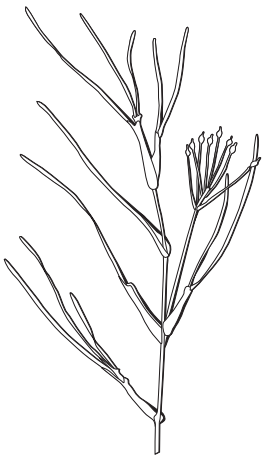


Figure 18-4. Widgeon grass *(Ruppia maritima).*

Wild Celery *(Vallisneria americana)*

Wild celery, also known as tapegrass or freshwater eelgrass (Figure 18-5), is found along the Atlantic Coast. It is widely distributed in fresh water, tidal freshwater rivers, and tidal tributaries to estuaries.

Wild celery has long, flattened, ribbonlike leaves that emerge from clusters at the base of the plant. The leaves, which can grow up to several feet in length, have a bluntly rounded tip and a light green stripe that runs down their centers.

Wild celery can reproduce by seed, rhizome, and tuber. It is an important food source for waterfowl, particularly the canvasback duck.

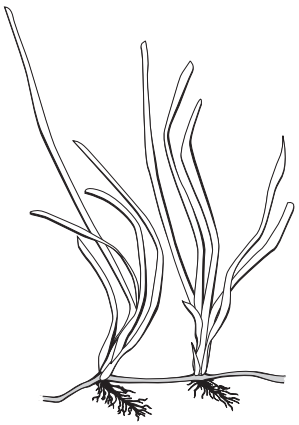


Figure 18-5. Wild celery *(Vallisneria americana).*

Turtle Grass *(Thalassia testudinum)*

Along the Florida and Gulf Coasts, turtle grass (Figure 18-6) replaces eelgrass as the dominant seagrass species. Turtle grass

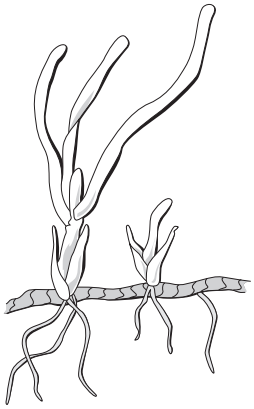


Figure 18-6. Turtle grass *(Thalassia testudinum).*

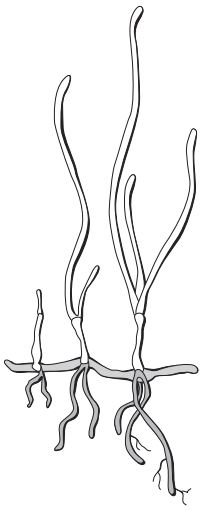


Figure 18-7. Manatee grass *(Syringodium filiforme).*

Figure 18-8. Shoal grass *(Halodule wrightii).*

meadows are highly productive and, therefore, play an important role in estuarine and near coastal ecosystems.

Turtle grass plants have broad, straplike blades, which are wider and shorter than those of eelgrass. This grass reproduces asexually by creeping rhizomes or sexually by water-borne flower pollen and forms dense meadows which often cover vast swaths of the shallow marine or estuarine substrate.

Manatee Grass *(Syringodium filiforme)* **and Shoal Grass** *(Halodule wrightii)*

Both of these seagrass species are common along southern Florida and the Caribbean islands.

Long and thin, the blades of manatee grass (Figure 18-7) are light green and up to three feet in length. Like other seagrasses, this grass has inconspicuous flowers. Manatee grass also propagates by rhizome extension. Manatee grass often mixes with turtle grass in seagrass meadows.

Shoal grass (Figure 18-8) has elongate stalks that often branch into flat, wide leaves with a maximum width of 1/8 inch. These stalks may grow to 15-16 inches in length. They have a naturally ragged, somewhat three-pointed tip on the leaf. This plant is aptly named since it inhabits very shallow areas, generally in water less than 20 inches deep. While shoal grass beds can grow on both the landward and ocean sides of turtle grass beds, they are usually found on turtle grass beds' landward sides.

When to Sample

As with all water quality variables, repetitive measures over a period of years give a more representative picture of SAV status than a single sampling approach. Unlike many of the other variables, however, volunteers usually need to measure SAV density and distribution and identify species only one to three times during the peak growing season.

The best time of year to sample is when the SAV species of interest is at its peak biomass (maximum growth). This varies by species and location.

Optimal sampling times are close to low tide on a sunny day when the water is fairly clear (Bergstrom, 1998). A notable exception may apply to SAV beds growing in very shallow water, which may be accessible only during high tide. In either case, monitors should try to avoid times when boat traffic is heavy (e.g., weekends) and the water tends to be cloudier.

Choosing a Sampling Method

There are several means of monitoring SAV. Choosing the most appropriate method will depend on the number and location of sites already being monitored by volunteers or others for water quality, the extent of SAV coverage, the location of problem areas, the availability of qualified scientists and resource managers to supervise the activity, and the planned uses for the collected data.

Helpful Hint

Collecting plant samples is not generally recommended. Only properly trained and authorized personnel should take minimal samples, if necessary, for positive identification.

Before collecting, transporting, or planting any SAV species, check with the appropriate government agency about obtaining necessary permits.

Observations at Established Water Quality Monitoring Sites

Volunteer monitoring programs may choose to analyze SAV concurrently with several other water quality variables. In this case, the simplest option is to estimate the shoot density of each SAV species in a pre-determined radius around the established monitoring sites (Figure 18-9). No plants should be removed from the site.

An SAV index (Table 18-1) or other density scale is a simple means of ranking the density

Table 18-1. Sample SAV index values. The index may be modified or expanded to include more categories (e.g., SAV coverage of 0-10%, 10-40%, 40-70%, and 70-100%).

SAV Index Value	Category	Description
0	None	No vegetation present
1	Patchy	Small colonies or clumps; sparse bottom coverage
2	Dense	Extensive grass beds; lush meadows

of plants at specific sites. Volunteers estimate SAV density and classify the bed as falling within one of three or more density classes.

The data collected from this approach is not scientifically rigorous and therefore may be considered only for general education purposes. The method is, however, a quick and easy means of obtaining relative information on the status of an estuary's SAV beds.

Transect Sampling

In transect sampling, a straight line is established across an area containing SAV. Records are made of each plant that touches the line at predetermined increments (Figure 18-10). If the vegetation is extremely dense, the data collector can place a rod into the vegetation at the designated point and record the different species that touch the rod. The method provides a rough estimate of the percent of vegetative cover and the frequency of each species.

In a modified version, discrete monitoring sites can be established along the transect (see case study, page 18-8).

Groundtruthing

Groundtruthing is done to verify maps of SAV beds that some government agencies or universities create from aerial surveys. The exercise involves on-the-ground observations to verify the presence of beds, identify species, and locate smaller beds that might not be captured by aerial photography. By groundtruthing, volunteer groups help scientists and resource managers get a more complete picture of year-to-year SAV distribution. Knowing SAV bed locations and species composition helps ensure their protection from activities that might have a negative impact on them (see case study, page 18-9).

Groundtruthing requires a great deal of on-the-ground effort, and resource agency personnel and other professional staff usually cannot cover the entire aerial survey area. Volunteers, then, can provide valuable assistance in verifying the SAV maps. ■

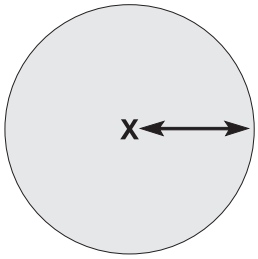


Figure 18-9. SAV shoot density can be estimated in a circle around a water quality monitoring site (marked with an X).

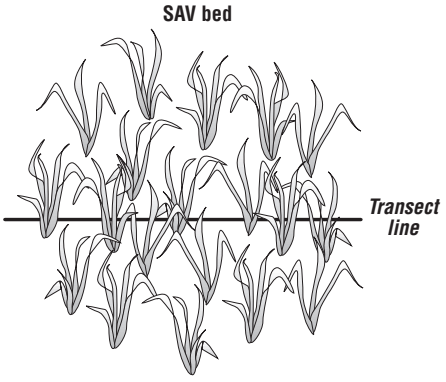


Figure 18-10. Transect sampling through a bed of SAV.

Case Study: Intertidal SAV Monitoring in Oregon

In 1998, the Tillamook Bay National Estuary Project initiated a four-year study to investigate the interactions of eelgrass with other estuarine species and its response to human disturbance.

Volunteers measuring percent cover and eelgrass shoot density in Oregon (photo by Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab).

Under the leadership of estuarine researchers, volunteers collect percent cover and density data on three different weeklong occasions between May and September. Intertidal eelgrass is examined, making volunteers' time in the field limited to the duration of the low tide. This limitation requires several volunteers to help collect data.

At three different intertidal sites, monitors establish five 30-meter transects and record data at five-meter intervals along each transect (e.g., at one meter, six meters, and so on). Using a one-meter square quadrat made from 1/2-inch PVC pipe, volunteers measure percent cover and eelgrass shoot density.

To measure percent cover, there are several ways to proceed: visual estimation, photo digitizing, grid overlay, and others. A "point intercept" method, which utilizes a clear piece of Plexiglas that has 50 randomly placed dots on it (marked with a permanent ink marker), is used in this program. The Plexiglas is placed over the experimental plot, and volunteers observe the item [e.g., sand, eelgrass (including shoots and blades), ulva (a green algae), etc.] covered by the majority of each dot. Then, a percent cover value is calculated by dividing the number of each component found by the total number of dots on the Plexiglas. For example:

Component	# Dots	Formula	Percent Cover
Eelgrass	31	31÷50 =	62%
Sand	6	6÷50 =	12%
Ulva	13	13÷50 =	26%

Determining eelgrass shoot density is somewhat less complex. Volunteers simply count the number of shoots (not blades) of eelgrass in each quadrat. A researcher familiar with eelgrass can teach volunteers how to distinguish between eelgrass shoots, blades, and rhizomes.

For More Information:

Tillamook Bay National Estuary Project
P.O. Box 493
Garibaldi, OR 97118
Phone: 503-322-2222
Fax: 503-322-2261
http://www.co.tillamook.or.us/gov/estuary/tbnep/nephome.html

Case Study: Chesapeake Bay SAV Hunt

Volunteers throughout the Chesapeake Bay region participate in the SAV Hunt, an annual effort coordinated by the U.S. Fish and Wildlife Service to locate, identify, and map SAV.

The SAV Hunt is used to groundtruth the results of an annual aerial survey. While the survey provides invaluable information about the location and extent of SAV beds, aerial photographs have some limitations:

- they miss small beds;
- they don't identify which species are growing;
- sometimes what looks like a bed of SAV in the photo turns out to be something else entirely, such as algae growing on underwater rocks or large rocks placed in the water usually as an erosion control measure; and
- photos are usually taken once a year (or even less frequently), and the SAV species in the beds change over the growing season.

The SAV Hunters' on-the-ground observations fill in the missing information; their data are vital supplements to the aerial survey (see Appendix A for a sample data sheet).

Volunteers select the area they want to survey. They receive a map of that location, showing where SAV has been found in aerial surveys and previous SAV Hunts. Volunteers also receive a field guide with line drawings, color photographs, and descriptive text to help them identify the species.

A new Maryland law bans clam dredging in SAV beds, and the information provided by citizens helps identify those areas that are now off-limits to clam dredging. Natural resource agencies use the information to help target SAV protection and restoration, and local planning agencies use it when considering approval for construction projects that may affect aquatic resources.

For More Information:

SAV Monitoring Coordinator
U.S. Fish and Wildlife Service
Chesapeake Bay Field Office
177 Admiral Cochrane Drive
Annapolis, MD 21401
Phone: 410-573-4500
http://www.fws.gov/r5cbfo/

(Excerpted and adapted from Reshetiloff, 1998.)

How to Groundtruth

Monitoring SAV beds may pose more logistical problems than the measurement of other water quality variables. Whereas volunteers measure other variables at set stations, SAV groundtruthing requires volunteers to go to areas where the SAV is growing—the plant beds may not be in exactly the same location from year to year.

Although land access to the beds may lie on private property, landowners are often willing to provide right-of-way to volunteer monitors. Water access may be limited by depths too shallow to accommodate some vessels—necessitating use of a shallower draft boat (e.g., canoe, kayak, johnboat, or skiff with outboard motor). The program manager should assist each volunteer in solving possible logistical problems before the volunteer heads for the field.

General procedures for monitoring SAV using the groundtruthing method are presented in this section for guidance only (they are adapted from the Chesapeake Bay SAV Hunt—see case study, page 18-9). **Monitors should consult with qualified scientists or resource managers overseeing the effort on proper equipment and techniques. Monitors should also make sure that necessary permits are obtained before collecting any samples.**

Before proceeding to the monitoring site, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7. Groundtruthers should be especially careful to note the tidal stage, weather conditions, water clarity, and the time of day, as these variables can substantially affect the visibility of SAV beds.

SAV Site Logistics

Reaching SAV beds marked on maps may require walking, motoring, rowing, paddling, wading, or swimming.

Volunteers can reach some SAV beds by walking along the shoreline. Attempt to reach the beds during low tide when they are in shallower water, but first ensure that the sediments support safe walking.

When using a boat, keep it in sufficiently deep water so that the propeller does not tear up the plants. If the beds are consistently located in shallow areas, consider using a rowboat, canoe, or even an inflated inner tube as an alternate vessel. In areas such as the Everglades in southern Florida, volunteers should consider using an airboat.

Keeping track of map position is extremely important. In areas of vast seagrass beds and few distinct landscape features, it is particularly easy to get lost. A Global Positioning System (GPS) or compass, used in conjunction with the map, may be a helpful orientation tool. The volunteer should:

- Travel to the SAV beds marked on the provided map. To find the beds, look for dark patches on the bottom or calmer surface water surrounded by ripples. The calm water may overlie SAV beds (Bergstrom, 1998).
- Compare the bed to its noted map position by examining its general location, notable landscape features (natural or manmade), position relative to the shoreline, and the overall extent of the bed. These distinctions may change from year to year, but collectively should provide sufficient information to confirm the identity of the bed.

If you are not sure that you are in the exact spot, if the bed seems to be in a different position than indicated on the map, or if other aspects of the bed are dramatically different, make sure to note this or record the changes on the survey sheet and map. Have a companion corroborate your observations if possible.

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site:

- map showing SAV beds covering the study site, as determined from aerial survey;
- global positioning system (GPS) receiver, if available;
- weighted and calibrated line to measure depth, or Secchi disk;
- SAV field identification guide;
- shoes for wading;
- plastic sealable bags (sandwich size);
- labels to go inside plastic bags, or waterproof marker;
- mask and snorkel or SCUBA, if necessary;
- instructions for monitoring SAV;
- rake to gather specimen for identification (see box below for details);
- view tube or hand lens, if available;
- polarized sunglasses; and
- waterproof copy of any required collection permits.

Raking It In

Unless you get into the water to identify SAV, some kind of tool may be needed to take a minimum number of samples. From a boat or pier, a properly trained person using the right rake is critical to groundtruthing success. At all times, care should be taken to avoid digging the rake into the sediment, since this can damage underground roots and rhizomes.

There are several rakes available (see Appendix C for suppliers); however, no one rake will find all SAV species at all times, and some species simply cannot be collected by raking.

Some recommended rakes are described below, with accompanying photographs on this page.

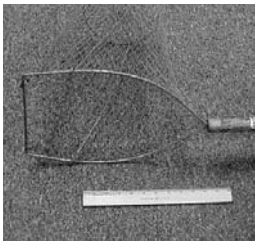
- A bamboo shrub rake is good for shallow water and SAV with short stems. It works much better from a canoe or kayak than the more common shrub rake with plastic tines. For deeper water, an extension pole can be attached. Most shrub rakes have 5-10 tines (although the bamboo ones have more) and are about 8" across, with a 4' handle.
- The crab landing net—consisting of a wire basket and long (6') handle—can be hard to find, but works well on very short, sparse SAV stems. As the net sweeps through the SAV, samples are collected in the net junctions. This quality may, however, make it difficult at times to remove one sample from the net in order to collect another. This net is not recommended for very dense SAV.
- A metal garden bow rake with stiff tines is used by some hunters, but it is probably the least effective of the four kinds. However, it is the one that most people already have on-hand.
- Though it may be difficult to find, a modified lawn thatch rake can work in water deeper than the length of a typical rake handle. Adapted with a short handle and rope and called a "throw rake," it can be tossed from a boat or pier. As a volunteer pulls it back by its rope, the rake picks up fairly tall, branched plants, leaving short, unbranched plants behind.

  The throw rake can be a useful tool, but extreme caution should be exercised.

As new and more effective designs are found, information will be made available at the U.S. Fish and Wildlife Service Chesapeake Bay Field Office Web site: http://www.fws.gov/r5cbfo/ under "Submerged Aquatic Vegetation (SAV)."

(Source: Bergstrom, 2000.)

a



b

c

d

Several rakes for collecting SAV samples: (a) bamboo shrub rake; (b) crab landing net; (c) bow rake; and (d) lawn thatch rake, or "throw rake," adapted with a short handle and rope (photos by P. Bergstrom, U.S. Fish and Wildlife Service).

Trained volunteer collecting SAV samples with a lawn thatch rake (photo by P. Bergstrom, U.S. Fish and Wildlife Service).

STEP 2: *Collect initial data and map bed area.*

If the map already shows the outline of the bed, use the map's name or code for the bed as its identifier on the data sheet. If the map contains no record of the bed, name it according to the format established by the program manager. Volunteers will need to roughly map unidentified beds to add them to the permanent record. Those areas marked as SAV beds on the map but having no plants should be designated on the survey form by writing "no plants."

Indicate the means by which the volunteer reached the beds (motor boat, canoe, by foot, pier, etc.).

Use the weighted, calibrated line to measure depth. A Secchi disk attached to a marked line can also be used to measure depth. Record the depth on the survey form.

STEP 3: *Monitor SAV.*

A bed may contain only one type of SAV or a variety of species. Move around within the bed and closely examine several areas to get a representative assessment of the species composition. Snorkeling or a view tube may be needed.

Assessing SAV bed condition

- To identify the plants, carefully use a rake or another implement to obtain a small sample of the stems and leaves. Try not to dig the tool into the sediment as it may damage underground roots and rhizomes. It may be necessary to snorkel or SCUBA for some species that rakes may not be able to pick up easily (e.g., eelgrass in summer when it is short).
- Using the identification guide or a key, match the specimen to the appropriate plant. **Do not record floating samples, as they may have come from a different location**. Record the common name of the plant on the survey form. If the match is tenuous or the plant does not seem to resemble any diagram, place the specimen in a plastic bag and bring it back to shore for a program leader to identify. Make sure to label the plastic bag with the site name, date, and collector using an indelible marker. Place one label inside the specimen bag and another on the outside of the bag as a precaution against lost labels or illegible writing. Record the identity of the collected plant as "unknown" on the survey form. Any collected sample should be refrigerated if not examined right away.
- Examine several different areas of the bed, estimating density and inspecting several plants. The program manager should train volunteers to recognize symptoms of common diseases or infestations.
- If this site has been visited previously, any noticeable differences, such as changes in the species composition, density, bed size, and general plant health, should be recorded.

"Mapping" SAV beds

When the SAV bed is unmarked on the map or has shifted in location, the volunteer should hand-draw the new location on the map. Shoreline features, manmade objects, buoys, shoals, and other landmarks may all be helpful in marking location. If possible, the volunteer should use a Global Positioning System (GPS) unit to roughly establish the position of the bed (see Chapter 7).

After completing all steps at the first SAV bed, navigate to the next designated bed on the map. Complete the same steps for each bed and record all information on a new survey form for each bed. Treat unmapped beds the same way; after establishing the bed position on the map, evaluate them like any other bed.

STEP 4: *Clean up and send off data.*

Volunteers should clean all equipment and deliver any unknown specimens to the program manager for plant identification assistance. The samples should be refrigerated if they will not be examined immediately.

Ensure that the data survey forms are complete and legible. Send the forms to the appropriate person or agency, preferably after identifying any unknown specimens. Identified specimens do not need to be sent with the forms; the program manager should provide guidance on dealing with the remaining unidentified plants. As with all data sheets, the volunteer should make a copy in case the original becomes lost. ■

SAV Bed Restoration and Monitoring

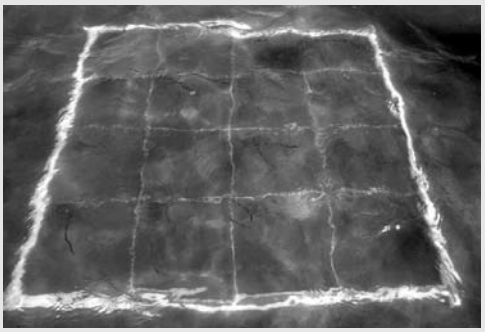
In an effort to restore SAV populations, many volunteer and professional groups are experimenting with planting SAV (Bergstrom, 1999).

Even with the right permits and supervision, however, simply planting grasses does not guarantee success. As photosynthetic plants, they depend on sunlight to survive. A comprehensive monitoring program can provide detailed information about water clarity and other water quality parameters important to SAV survival. Some programs use water quality data that volunteers are already collecting to help identify top candidates for SAV restoration projects.

While plants may show growth initially, they may disappear a few years later. Many volunteer restoration projects do not include follow-up monitoring to determine their long-term effectiveness. Without water quality and plant survival monitoring, volunteers are unable to understand what works and what fails.

Post-restoration monitoring can be a strain on organizational resources. It requires staff and volunteer time, which may be difficult to spare. SAV planting projects are usually one-time events, making it easier to oversee volunteers. Doing the necessary follow-up monitoring, however, often requires volunteers to work on their own with less oversight by the program leader (after all, the leader can't be everywhere at once!). Because follow-up monitoring may require the use of snorkel or SCUBA equipment, program leaders might be reluctant to support unsupervised volunteer SAV restoration monitoring; liability becomes an issue.

The Alliance for the Chesapeake Bay is working with other Bay-area organizations to standardize SAV monitoring and reporting methods throughout the region. This effort should improve the groups' knowledge of restoration sites and monitoring activities. It is hoped that this coordination will allow the groups to improve their tracking of SAV restoration projects.



Alliance for the Chesapeake Bay volunteers use a 1.0 x 1.0 m frame, constructed with nylon rope and 2.5 cm diameter PVC piping, to guide SAV replanting efforts. The frame is divided into 1/4-meter intervals. At each grid intersection, two mature plants (called "planting units"), held together with a biodegradable staple so that their rhizomes are aligned parallel, are anchored on the bottom with a bamboo skewer. Twenty-five planting units equaling 50 plants per square meter are placed in each 1m^2 grid. The use of the planting grid allows for the number of plants, and therefore planting density, to be easily quantified (photo by B. Murphy).

For More Information:

Alliance for the Chesapeake Bay
6600 York Road, #100
Baltimore, MD 21212
Phone: 410-377-6270
Fax: 410-377-7144
http://www.acb-online.org/index.htm

References and Further Reading

Portions of this chapter were excerpted and adapted from:

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. 52 pp. (NOTE: Out of print).

Other references:

Bergstrom, P. 1999. "Using Monitoring Data to Choose Planting Sites for Underwater Grasses." *The Volunteer Monitor* 11(1): 16-17.

Bergstrom, P. 2000. U.S. Fish and Wildlife Service, Chesapeake Bay Coastal Program, pers. com.

Blakesley, B.A., M.O. Hall, and J.H. Landsberg. 1999. "Seagrass Disease and Mortality: Understanding the Role of *Labyrinthula*." In: *The 15th Biennial International Conference of the Estuarine Research Federation Abstracts.* New Orleans, LA. Sept. 25-30, 1999.

Burdick, D. M., F. T. Short, and J. Wolf. 1993. "An Index to Assess and Monitor the Progression of the Wasting Disease in Eelgrass, *Zostera marina*." Marine Ecology Progress Series, 94: 83-90.

Fassett, N. C. 1969. *A Manual of Aquatic Plants.* University of Wisconsin Press, Madison, WI. 405 pp.

Gabrielson, P. W., R. F. Scagel, and T. B. Widdowson. 1990. *Keys to the Benthic Marine Algae and Seagrasses of British Columbia, Southeast Alaska, Washington and Oregon*. Phycological Contribution [Dept. of Botany, University of British Columbia, Vancouver]. No. 4. 187 pp.

Hotchkiss, N. 1972. *Common Marsh, Underwater, and Floating-Leaved Plants of the United States and Canada*. Dover Pubns, ISBN: 048622810X.

Kerr, M., L. Green, M. Raposa, C. Deacutis, V. Lee, and A. Gold. 1992. *Rhode Island Volunteer Monitoring Water Quality Protocol Manual.* URI Coastal Resources Center, RI Sea Grant, and URI Cooperative Extension. 38 pp.

Littler, D. S., M. M. Littler, K. E. Bucher, and J. N. Norris. 1989. *Marine Plants of the Caribbean: A Field Guide from Florida to Brazil*. Smithsonian Institution Press, Washington, DC. 263 pp.

Martin, E., and V. Lee. 1991. "Monitoring Diseased Eelgrass." *The Volunteer Monitor* 3(1): 13.

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.

Sheath, R. G., and M. M. Harlin. 1988. *Freshwater and Marine Plants of Rhode Island*. Kendall Hunt Publ. Company, Dubuque, IA. 149 pp.

Tampa Bay Estuary Program (TBEP). 1999. *Submerged Aquatic Vegetation Monitoring Protocols*. unpbl. Doc. Mail Station I-1/NEP, 100 8th Avenue, SE, St. Petersburg, FL 33701; Phone: 727-893-2765.

Tiner, R. W., Jr. 1987. *A Field Guide to the Coastal Wetland Plants of the Northeastern United States*. University of Massachusetts Press, Amherst, MA. 285 pp.

U.S. Environmental Protection Agency (USEPA). 1992. *Monitoring Guidance for the National Estuary Program: Final*. EPA 842-B-92-004. Washington, DC.

Web sites:

Chesapeake Bay Foundation: http://www.savethebay.cbf.org

Chesapeake Bay Program: http://www.chesapeakebay.net/baygras.htm

Maryland Department of Natural Resources: http://www.dnr.state.md.us/bay/sav/index.html

University of Hawaii Seagrass: http://www.botany.hawaii.edu/seagrass/

U.S. Fish and Wildlife Service Chesapeake Bay Field Office: http://www.fws.gov/r5cbfo/

Virginia Institute of Marine Science: http://www.vims.edu/bio/sav/index.html

Chapter 19

Other Living Organisms

While bacteria and submerged aquatic vegetation are popular biological parameters measured by volunteers, there are other living organisms that deserve—and receive—attention. Some of these organisms are monitored or collected to screen for potential problems in the estuary. Others serve to complement chemical, biological, and physical monitoring activities. For the most part, the monitoring of particular living organisms represents localized rather than nationwide efforts; that is, for many reasons, volunteer groups have the desire, equipment, support, and environmental need to work with these organisms in their particular estuary.

Photos (l to r): E. Ely, E. Ely, T. Monk, R. Ohrel

Overview

While bacteria and submerged aquatic vegetation are popular biological parameters measured by volunteers, there are other living organisms that deserve—and receive—attention. Some of these organisms are monitored or collected to screen for potential problems in the estuary. Others serve to complement chemical, biological, and physical monitoring activities.

For the most part, the monitoring of particular living organisms represents localized rather than nationwide efforts; that is, for many reasons, volunteer groups have the desire, equipment, support, and environmental need to work with these organisms in their particular estuary.

Clearly, there is a multitude of living organisms that a volunteer group may wish to monitor to help assess an estuary's health. This chapter discusses several of those biological parameters—macroinvertebrates, phytoplankton, and non-indigenous species—and describes their use as environmental health indicators, identifies sampling considerations, and provides steps for collecting and analyzing the organisms in the field.

Why Monitor Other Living Organisms?

The presence, absence, and abundance of many living organisms can serve as useful indicators of estuarine health. Some organisms require relatively clean water to survive, grow, and reproduce. Their presence suggests that water quality is good in that portion of the estuary. Other species are unfazed or even thrive under poor water quality conditions. If the number of pollution-tolerant organisms suddenly increases while pollution-sensitive species disappear or become difficult to find, the estuary may be under stress.

Volunteer monitoring of estuarine organisms, then, can serve as an early warning device. When biological monitoring suggests that a water quality problem may exist, the information can be used to alert government authorities, who in turn can intensify their own monitoring efforts to identify the problem's cause and solution. The identification and tracking of non-indigenous species can be used to further alert us to human disturbance of estuarine ecosystems. Early detection networks can help eradicate a non-indigenous species invasion before it becomes established.

Monitoring can also be used to complement chemical, biological, and physical measurements. Nutrient data, for example, provide useful information about the types and quantities of nutrients in the estuary, but may not tell us enough about potential impacts. The presence of phytoplankton blooms provides evidence that nutrient concentrations may have reached high levels.

As another example, turbidity and sediment deposition can affect the survival of many bottom-dwelling organisms. By monitoring these animals along with other parameters, we can gain a better sense of the estuary's overall health.

Finally, the collection and analysis of shellfish for pathogens and toxic materials complement monitoring for those pollutants in the water column. ■

MACROINVERTEBRATES

Macroinvertebrates are organisms that are large *(macro*) enough to be seen with the naked eye and lack a backbone *(invertebrate*) (USEPA, 1997). Aquatic macroinvertebrates are commonly used in freshwater stream monitoring as indicators of water quality. According to the USEPA (1997), macroinvertebrates make good indicators of stream quality because:

- They are affected by the physical, chemical, and biological conditions in the stream.
- They may show the effects of short- and long-term pollution.
- They may show the cumulative impacts of pollution.
- They may show the impacts from habitat loss not detected by traditional water quality assessments.
- They are a critical part of the food web.
- Some are very intolerant of and cannot escape pollution.

The Role of Macroinvertebrates in the Estuarine Ecosystem

Macroinvertebrates serve many of the same functions in estuarine systems as they do in streams. They are critical to the food web. Some impact water clarity through their feeding process, filtering with their gills or other body parts tiny plants, animals, and

other materials found in the water. Others, such as oysters and corals, grow together in groups, providing valuable habitat for a number of organisms. Burrowing macroinvertebrates help aerate bottom sediments.

Unfortunately, using macroinvertebrates as indicators of estuarine health is more problematic than for streams (Green, 1998; Ely, 1991).

- Estuaries support different macroinvertebrates than freshwater systems, with few key freshwater indicator species living in estuarine environments.
- Tidal fluctuations and muddy bottoms make collecting estuarine macroinvertebrates more difficult than in streams.
- In contrast with stream systems, there are as yet no identification keys and water quality indices, suitable for volunteers, that link estuarine macroinvertebrates with estuarine health.

As a result of these limitations, volunteer organizations currently find it difficult to use macroinvertebrates as indicators of estuarine water quality. However, that is not to say that volunteer programs should avoid monitoring macroinvertebrates altogether. Volunteer monitors are frequently recruited to monitor specific macroinvertebrate species, such as corals (see case study, below). Shellfish are other good examples of estuarine macroinvertebrates that volunteer groups monitor and sample.

Shellfish and Estuarine Health

Shellfish often reflect some of the most important measures of water quality. One way that volunteers can utilize shellfish is to take an inventory of their distribution throughout the estuary (see case study, page 19-4). Another way is to work with laboratories that analyze the hazardous compounds in the animals' tissues.

Case Study: Coral Monitoring

With support from the U.S. Environmental Protection Agency (EPA), The Ocean Conservancy manages the Reef Condition (RECON) Monitoring Program. RECON is an entry-level rapid-assessment protocol for volunteer recreational divers with an interest in reef conservation issues. The goals of RECON are to broaden the scope of available information about the benthic (bottom-dwelling) organisms on coral reefs, to alert local researchers and managers of changing reef conditions (e.g., mass bleaching events, outbreaks of disease, nuisance algal blooms), and to increase public understanding of the threats to coral reef ecosystems.

RECON divers take a short course from a certified RECON instructor, followed by two practice dives and a qualifying examination. Divers are trained to collect information about the reef environment, the health of stony corals, and the presence of key reef organisms and obvious human-induced impacts. Results of the cumulative data collection are posted on The Ocean Conservancy Web site for public access and archived for use by the scientific and research community.

For More Information:

The Ocean Conservancy
Office of Pollution Prevention and Monitoring
1432 N. Great Neck Road, Suite 103
Virginia Beach, VA 23454
Phone: 757-496-0920, Fax: 757-496-3207
Email: RECON@oceanconservancyva.org
http://www.oceanconservancy.org

A volunteer diver collects data at a coral reef in the Caribbean (photo by T. Monk).

Case Study: Shellfish Inventories in Florida

While some shellfish monitoring programs collect specimens for tissue analysis at a laboratory, others require only that volunteers count each organism they find in the field.

Tampa BayWatch and the Tampa Bay Estuary Program developed a volunteer activity known as the Great Bay Scallop Search. During this annual one-day event, volunteer snorkelers patrol seagrass beds and count scallops along transect lines (see Appendix A for the Scallop Search data sheet).

The purpose of the project is to document scallop population recovery. Poor water quality caused scallops to disappear from Tampa Bay during the 1960s. Thanks in part to regulatory action, the scallops are slowly returning. Stocking efforts are underway to help boost scallop recovery and establish viable breeding colonies in the bay.

For More Information:

Tampa BayWatch
Phone: 727-896-5320
http://www.tampabaywatch.org

Tampa Bay Estuary Program
Phone: 727-893-2765
http://www.tbep.org/

Chemical Uptake

Even water that appears clear and untainted may still contain harmful levels of chemical pollutants. Shellfish living in the water may assimilate and accumulate these chemicals through the intake of polluted water and sediment or by eating other contaminated organisms.

Several types of chemical contaminants can accumulate in shellfish. These include:

- heavy metals such as mercury and cadmium;
- petroleum hydrocarbons such as polyaromatic hydrocarbons (PAHs);
- pesticides such as endrin, dieldrin, endosulfan, mirex, and malathion; and
- industrial pollutants such as polychlorinated biphenyls (PCBs).

Bivalve shellfish, such as clams, mussels, and oysters, are filter-feeders and strain large quantities of estuarine water through their systems to extract small particles of food. Because they filter such large quantities of water, however, even relatively low concentrations of a waterborne contaminant may eventually translate to high tissue concentrations.

Non-bivalve shellfish, such as crabs, lobsters, and shrimp, are mobile scavengers which consume plants, small animals, and detritus from the estuary's waters and bottom. Contaminated prey or sediments can produce high contaminant levels in the tissues of these shellfish.

Biological Uptake

Studies or surveys often use shellfish as indicators of biological contamination as well. The non-mobile bivalves are particularly helpful as they pinpoint specific areas of contamination.

Shellfish collect fecal bacteria in their gut, making them good indicators of recent exposure to sewage waste. Since fecal coliforms can indicate the presence of human or animal pathogens, tainted shellfish serve as a warning and signal that an area may not be suitable for recreation or fishing. Unlike water sampling for bacterial contamination (see Chapter 17), shellfish tissue analysis acts as a market test; that is, it determines whether the shellfish are fit for human consumption.

Officials can set predetermined levels of fecal coliform in shellfish as a management standard. Areas where levels exceed this standard should be closed to commercial and recreational shellfish collection until the problem is resolved.

In addition to accumulating bacteria, shellfish can also consume phytoplankton, some of which produce toxins. When shellfish ingest the phytoplankton, the toxins accumulate in their tissues. The toxins can be transferred to humans who consume the shellfish. ■

Shellfish contaminated with pathogens or other pollution indicate that surrounding waters may be unsafe for fishing or swimming. It may be unsafe for humans to eat the shellfish (photo by R. Ohrel).

Shellfish Sampling Considerations

Shellfish are easier to collect than finfish because most tend to move more slowly or not at all. Moreover, they often congregate—an oyster bed or a boulder studded with mussels are two examples—and are fairly easy to reach.

Some shellfish are more susceptible to certain contaminants than others. While a species may easily tolerate high concentrations of one chemical, low concentrations of another can be lethal.

The life stage of an individual—larva, juvenile, or adult—will also greatly affect its response to a toxic substance. In general, larvae and juveniles are more vulnerable to injury or death from exposure to these substances. Studies of the effects of toxic compounds must consider both the age and species of the specimens to fully assess the chemical's toxicity. ■

Helpful Hint

Before collecting any organism, check with the appropriate government agency to determine whether you will need a permit.

How to Collect Shellfish

The tests for shellfish contaminants require sophisticated analyses, expensive equipment, and rigorous quality assurance procedures. Trained scientists must perform these tests to ensure accurate, scientifically valid results. Volunteers can assist the scientists, however, by collecting shellfish for analysis in designated study areas.

Scientists may need data to:

- identify areas of concern for a particular toxic substance;
- aid policy makers in setting regulatory limits on the recreational or commercial collection of shellfish species;
- identify the contaminant sources;
- examine the effects of particular contaminants on a species; and
- determine whether shellfish are safe for consumption.

The training of volunteers should include a session on the identification of the species required for testing. Most of the popular field guides for the coastal regions include sections on shellfish identification.

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- field guide for species identification;
- waterproof copy of any required collection permits;
- collection bucket;
- tools necessary to dig shellfish, dislodge clustered shellfish, or otherwise collect targeted shellfish species;
- sample containers; and
- sample preservative, if necessary.

STEP 2: *Collect the shellfish sample.*

Once at the sample site, volunteers should capture animals using the method designated by the program manager.

The volunteers should carefully label the sample container in which the animal will be transported with the date, site name, shellfish type, and the name of the collector. An indelible marker is best for ensuring that the labeling is permanent. Make sure that the sample container is not wet before using the marker. If required by the program manager, volunteers should add a preservative to the sample bottle.

STEP 3: *Clean up and send off sample and data.*

Volunteers should transport the live specimens at chilled temperatures appropriate for the species. The program manager should designate pickup locations for volunteers to deliver the specimens and supporting data sheets to program personnel. As with all data sheets, the volunteer should make a duplicate in case the original becomes lost.

Make sure to thoroughly clean all equipment. ■

Case Study: Shellfish Collection in Washington and Alaska

Very few programs currently use volunteers to collect shellfish for laboratory analysis. The Department of Health in Washington State, however, has successfully worked with different volunteer groups to gather shellfish at commercial and recreational beaches.

Youth Area Watch, managed by the Chugach School District, in Alaska, is also involved with shellfish collection. Students in the organization collect mussels for scientists who monitor planktonic activity and production capacity in Prince William Sound.

For More Information:

Washington State Department of Health
Food Safety and Shellfish Programs
Phone: 360-236-3330

Adopt A Beach
4649 Sunnyside Ave. N. #305
Seattle, WA 98103-6900
Phone: 888-57-BEACH or 206-632-1390
Email: aab@halcyon.com

Youth Area Watch
Web site: http://www.micronet.net/users/~yaw/

PHYTOPLANKTON

Organisms lacking the means to counteract transport by water currents are referred to as **plankton**, a name derived from the Greek word planktos for "wandering." Included in this group are bacterioplankton (bacteria), phytoplankton (plants), and zooplankton (animals). In general all plankton are very small and, in many cases, microscopic. However, relatively large animals, such as the jellyfish, are also included in the definition of plankton (Table 19-1; Figure 19-1).

Phytoplankton are microscopic plants that are common components of our natural waters. These plants are algae and contain an assortment of pigments in their photosynthetic cells. They are represented by single cell or colonial forms that are the primary food and oxygen producers within freshwater, estuarine, and marine

(a)

(b)

Volunteer phytoplankton monitors at work in Maine. (a) Samples are collected using a 1-meter plankton net. (b) Subsamples are examined immediately at 100X magnification (photos by E. Ely).

Table 19-1. Common types of phyto- and zooplankton *(see Levinton, 1982).*

	Taxonomic Grouping		Taxonomic Grouping	
Phytoplankton		diatoms	*Biddulphia* *Nitzschia* *Thalassiosira*	*Chaetoceros* *Skeletomena* *Melosira*
		dinoflagellates	*Dinophysis* *Gyrodinium*	*Ceratium* *Prorocentrum*
		cryptomonads	*Cryptomonas*	
		coccolithophorids	*Coccolithus*	*Phaeocystis*
		green algae	*Chlorella* *Cladophora*	*Codium*
		blue-green algae	*Oscillatoria/Trichodesmium*	*Lyngbya*
		red algae	*Porphyridium*	*Porphyra*
		brown algae	*Ectocarpus*	
Zooplankton	Crustaceans	copepods	*Calanus* *Temora*	*Acartia*
		euphausiids	*Euphausia*	
		cladocerans	*Podon*	
		amphipods	*Euthemisto*	*Hyperia*
	Protistans	radiolarians	*Globigerina*	
		foraminiferans		
	Ctenophores	comb jellies	*Pleurobrachia*	*Mnemiopsis*
	Chaetognaths	arrow worms		
	Coelentertates	true jellyfish	*Aurelia*	*Physalia*
	Pteropods			
	Tunicates	larvacea salps	*Pyrosoma*	

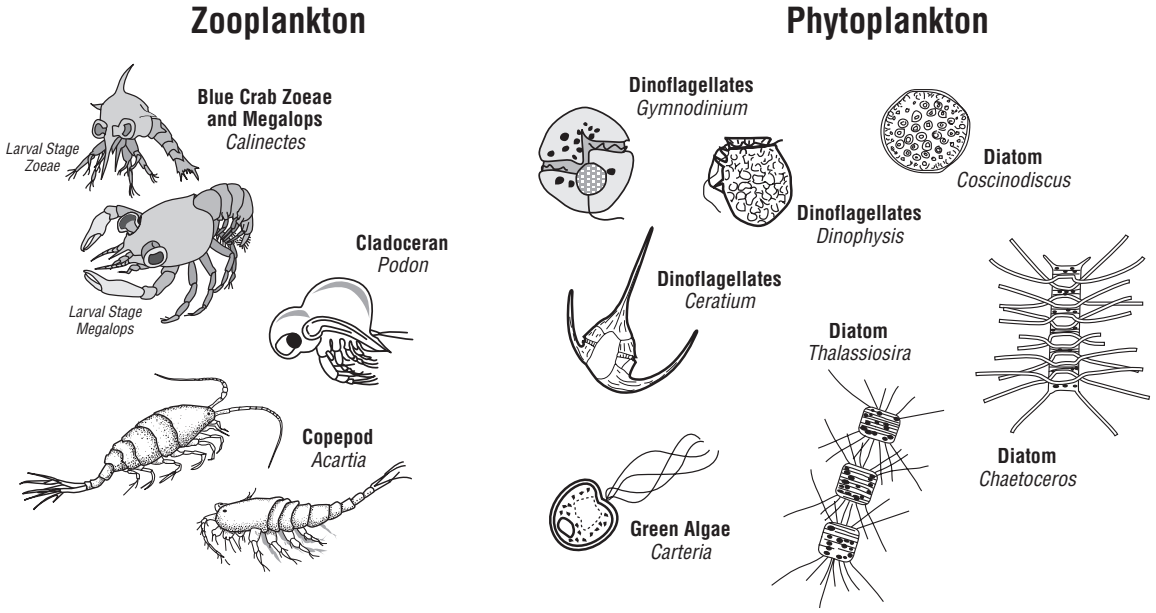


Figure 19-1. Examples of various planktonic forms found in coastal and estuarine waters.

habitats. **Zooplankton** are animal plankton that range in size and complexity. They include the larval forms of large adult organisms (e.g., crabs, fish) and small animals that never get larger than several millimeters (e.g. copepods).

The abundance of planktonic organisms in the water column follows predictable, geographically based seasonal patterns related to nutrients, light intensity, temperature, and grazing (predation) pressures. Monitoring the types and relative abundances of plankton populations in conjunction with nutrient and other environmental parameters can provide significant insight into the health of an aquatic ecosystem.

The Role of Phytoplankton in the Estuarine Ecosystem

Without phytoplankton, the intricate web of estuarine plants and animals would collapse. Phytoplankton are primary producers and form the base of the estuary's food pyramid. As photosynthesizers, phytoplankton transfer the sun's energy into plant matter and provide nourishment for the next level of organisms.

Phytoplankton are consumed primarily by zooplankton, which in turn are fed upon by other larger organisms. If the phytoplankton community is altered in composition or abundance, these changes may have serious ramifications throughout the food web and upset what may be considered a more favorable balance of life in these waters.

Water quality conditions will influence the composition and abundance of phytoplankton. Since phytoplankton respond rather rapidly to changes in nutrient concentrations, they are good indicators of nutrient-rich conditions. Waters having relatively low nutrient levels are dominated by diatoms, which are a highly desirable source of food. In water with higher nutrient concentrations, cyanobacteria and dinoflagellates become more abundant. These phytoplankton species are less desirable as a food source to animals.

As nutrients—and consequently phytoplankton—increase, various water quality variables are affected. Waters with low nutrient levels are generally clearer than water containing high concentrations of nutrients. As nutrient levels increase and the phytoplankton concentrations become more dense, the water often takes on the color of the algal pigments (e.g., reddish brown, green, brown) and odors become noticeable. In estuaries, the cells frequently collect along tidal fronts, where their presence is more evident.

Phytoplankton also influence oxygen concen-

trations in the estuary. As photosynthesizers, they produce oxygen, which is critical to all but a few estuarine organisms. When sunlight is unavailable (e.g., at night), phytoplankton respire, removing oxygen from the water. Oxygen is also consumed when bacteria work to decompose phytoplankton. A common aftermath of excessive phytoplankton growth in confined waterways is that oxygen is depleted, thus producing hypoxic conditions that may result in the deaths of many organisms.

Levels of Phytoplankton

At certain times, conditions are very good for phytoplankton growth. When there are adequate nutrients, increased light intensity, warmer water, and minimal predation pressures from zooplankton, phytoplankton population explosions, or **algal blooms**, may occur. The phytoplankton will continue to bloom until one or more of the key factors promoting phytoplankton growth is no longer available.

For example, during the spring months in temperate regions, diatom blooms usually coincide with increases in nutrient levels, water temperature, and light intensity. This increase in phytoplankton biomass is typically followed by an increase in zooplankton (often copepods) into the summer months. During the summer, the dominant phytoplankton assemblage shifts to include dinoflagellates and the grazing pressures of the zooplankton subsides. Another, but smaller, bloom of diatoms occurs in the fall, leading to a successive repeat in the nutrient/bloom cycle. Figure 19-2 illustrates seasonal bloom fluctuations in different geographic locales.

In recent years, there has been an increasing presence of bloom-forming algae in estuaries worldwide. This has been attributed to increased levels of nutrients entering these waters.

Harmful Algal Blooms

Some phytoplankton—mostly dinoflagellates and some diatoms—produce toxins, which have been known to cause illness or death in many aquatic organisms, including fish, shellfish, and marine mammals, by causing lesions, clogging gills, and depleting oxygen in the water. The toxins can also have serious impacts on humans (Table 19-2). The toxins can be transferred to humans through the consumption of shellfish (e.g., clams, oysters, mussels, and scallops). These organisms feed by filtering water through their gills to extract various forms of plankton. The plankton may not be toxic to the shellfish, but they could be toxic to humans who consume them. Therefore, state or local authorities routinely close areas to shellfish harvesting if excessive amounts of toxins are detected in the water.

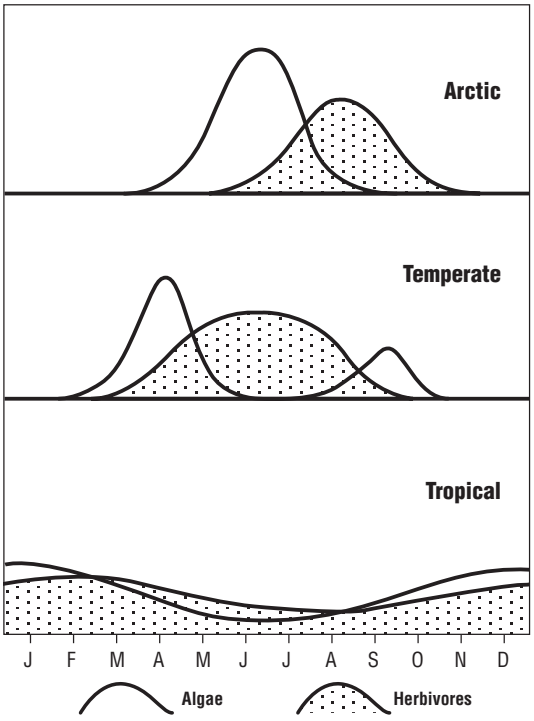


Figure 19-2. Typical seasonal cycles for plankton in arctic, temperate, and tropical regions.

One example of a harmful algal bloom is a "red tide." It is so named because the bloom is intense enough to change the color of the water. Some phytoplankton will produce a reddish, brown, or green color. In some cases, however, no color is produced at all—thus dispelling the myth that there is a definite connection between abnormally colored water and toxicity. Although there are many species that can bloom enough to change the color of the water, only a few species are toxic.

An increase in the frequency of harmful algal blooms in the U.S. and worldwide has led to increased efforts to develop effective monitoring and detection methods. By detecting blooms early, we can better ensure the safety of seafood products. The states of Maine and California have instituted coast-wide volunteer monitoring programs aimed at early detection of harmful blooms (Ely, 1998). Other states have a combination of formal and informal mechanisms to detect the blooms. The cost of toxic plankton monitoring is relatively high, so volunteer monitoring is an important way to protect public health in a cost-effective manner (Griffin, 1998). ■

Table 19-2. Some toxic phytoplankton important in the United States and their human impacts *(excerpted and adapted from Ely, 1998).*

Phytoplankton	Illness Caused	U.S. Outbreaks	Symptoms
Alexandrium spp.	PSP (paralytic shellfish poisoning)	New England, West Coast (including Alaska)	Numbness of lips and fingers; lack of coordination. Respiratory failure in severe cases. Can be fatal.
Pseudonitzschia spp.	ASP (amnesic shellfish poisoning)	No human illness reported in U.S. Human illness reported in Canada (east coast) and marine mammal illness on U.S. West Coast.	Abdominal cramps, disorientation. Permanent memory loss in severe cases. Can be fatal.
Gymnodinium breve	NSP (neurotoxic shellfish poisoning)	Mid-Atlantic and Southeast Coast, Gulf of Mexico	Gastroenteritis, painful amplification of sensation. No deaths.
Dinophysis spp.	DSP (diarrhetic shellfish poisoning)	No human illness reported in U.S.	Gastroenteritis. Nonfatal.

Sampling Considerations

When and Where to Sample

As stated in the discussion on algal blooms, dominant plankton populations change throughout the year. This should be considered when planning a sampling program. For long-term monitoring, a consistent time period for sampling is needed for comparability.

What to Sample

In temperate regions, the cyclic pattern of increased nutrient availability, sunlight, and algal blooms provides a baseline for comparison to other spikes in the phyto-plankton populations. If an increase in the numbers of a given species or genus is conspicuously absent when one normally

Helpful Hint

Adversely affected by strong light, zooplankton groups descend to great depths during the day and ascend during the night to feed on phytoplankton. Staying in deeper, colder waters during the day requires less energy for respiration and aids in avoiding predation by fish and seabirds.

If sampling zooplankton populations, considerations must be made to collect samples from depths what will yield representative samples of the plankton assemblages being monitored. This determination should be made as part of the overall planning process and establishment of a monitoring protocol.

expects an increase, or vice versa, this may serve as a warning that some environmental parameter has changed. In this case, the data set from phytoplankton monitoring serves as a general indicator of estuarine conditions.

Choosing a Sampling Method

Several different methods of obtaining phytoplankton data are available. The monitoring coordinator should choose a method based on the precision of the data required, the reason for collecting phytoplankton data, and the money available for this portion of the monitoring effort.

Visual Assessment

This method is the easiest and least expensive way to monitor phytoplankton. In this approach, volunteers estimate phytoplankton abundance based on field observations. This gross assessment of the waterbody is very limited and should be used as an indicator to follow-up with a more rigorous assessment procedure.

Plankton Net Tow

This method uses a cone-shaped mesh net, towed by boat or by hand along a dock or bridge through the water, to collect a variety of plankton species. This approach provides a decent estimate of phytoplankton density, but smaller species are likely to be excluded from the sample because they are able to pass through the net. If a more comprehensive quantitative assessment is required for the taxonomic identification of phytoplankton species, an alternative method of sampling, such as water samplers, should be used.

Water Samplers

If plankton population density measures are needed (number of cells/liter), then a monitoring technique to collect a specific amount of water must be used. A device that can be lowered into the water to capture a precise amount of water at a set depth is needed.

Traditional water samplers, such as Kemmerer or Van Dorn (see Chapter 7), are useful for collecting samples at different depths, thus ensuring better representation of the entire plankton community. In addition, small plankton are unable to escape the samplers, which is not the case for nets. ■

Reminder!

To ensure consistently high quality data, appropriate quality assurance and quality control measures are necessary. See Chapter 5 for details.

How to Monitor Phytoplankton

General procedures for collecting and analyzing phytoplankton samples are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to government agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

Besides the general considerations in Chapter 7, each phytoplankton sampling method involves a specific set of steps. Regardless of the method used, the program manager should designate how the data will be provided to program personnel. If the data is used as an early warning indicator of harmful algal blooms, volunteers may need to submit data sheets immediately (e.g., via fax) to program staff. As with all data sheets, volunteers should make a duplicate in case the original becomes lost.

When finished sampling, volunteers should also make sure to thoroughly clean all equipment with fresh water and store dry. Nets should be kept out of sunlight whenever possible.

Specific instructions for measuring phytoplankton using the different methods are presented here.

VISUAL ASSESSMENT

STEP 1: Check equipment.

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring a Secchi disk to measure transparency (see Chapter 15).

STEP 2: Record phytoplankton assessment.

Estimate the presence of phytoplankton blooms based on water color, transparency (using a Secchi disk), and odor. In general, a waterbody with a significant phytoplankton bloom will display a green, brown, or red color, although—as discussed earlier—this is not always the case. The transparency level will be considerably reduced when compared with prior measurements. There may also be an odor (usually a sulfur or "rotten egg" smell) due to the decomposition of phytoplankton cells at the end of the bloom period.

PLANKTON NET TOW

STEP 1: Check equipment.

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- properly-sized tow net, sampling container, and towing apparatus;
- dropper;
- field microscope with slides (e.g., depression slides) and slide covers;
- guide for plankton identification; and
- sample preservative (iodine- or formalin-based solution for phytoplankton and zooplankton, respectively) if species identification will not be made soon after collection.

STEP 2: *Collect the sample.*

The deployment method of the plankton net is important, as many phytoplankton assemblages tend to form clumps within the water column. Numerous horizontal tows, done in a diagonal sweep through the water column, are useful to account for zooplankton migration patterns and phytoplankton clumps. A diagonal sweep conducted during a horizontal tow requires that the plankton net be deployed to a depth that is 0.5 m off the bottom. During the tow, the net is pulled diagonally toward the surface, thus transecting the water column.

In the horizontal tow method, volunteers should allow the net to be pulled through the water for a predetermined distance at a set speed. Slow speeds are recommended—less than 3 feet per second if towing manually; 1-3 miles per hour if towing by boat. A record should be maintained as to the duration of the tow and distance so that the quantity of water filtered can be computed and plankton density derived.

STEP 3: *Calculate density.*

Figure 19-3 shows how to calculate plankton density. The plankton captured by the net represent the number of organisms in the pre-measured volume of water. A slide sample of 0.05 ml (a drop from an eyedropper) should be prepared and plankton cells counted using a microscope. Multiplying the number of cells by 1,000 reveals the number of plankton per liter. This density figure can then be converted to the number of individuals per cubic meter, again multiplying by 1,000. A sample equation for extrapolating plankton density is given

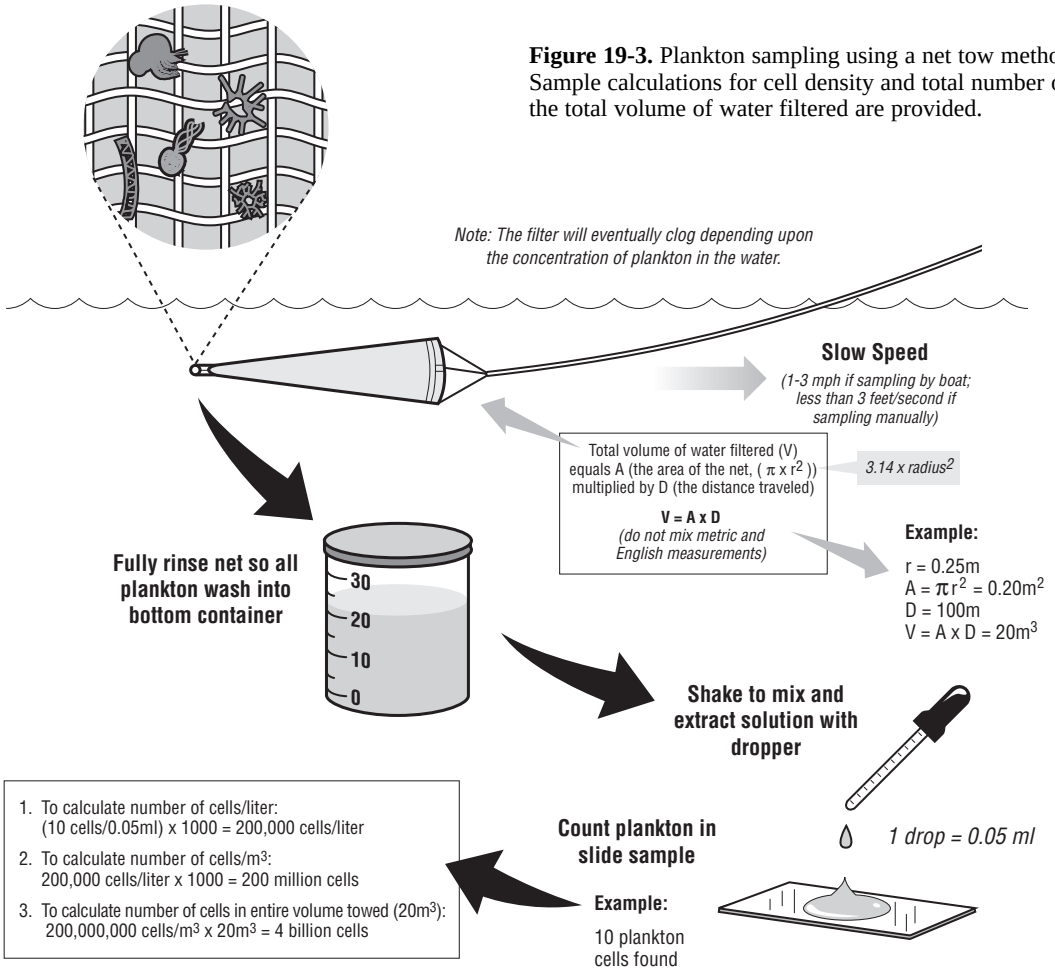


Figure 19-3. Plankton sampling using a net tow methodology. Sample calculations for cell density and total number of cells in the total volume of water filtered are provided.

below using a slide sample of 0.05 ml containing 10 plankton cells:

(a) (10 cells/0.05 ml) x 1,000 = 200,000 cells/liter

(b) 200,000 cells/liter x 1,000 = 200,000,000 cells/m^3

Calculating further to determine the total number of cells in the tow (total volume = $20m^3$ in our example; see Figure 19-3):

(c) 200,000,000 cells/m^3 x $20m^3$ = 4,000,000,000 cells

The density calculation is only approximate due to the "net factor"—the effect of the net as it is towed—forcing some water off the side rather than through its opening.

STEP 4: *Identify the species.*

Plankton collected in the cod-end jar at the base of the net can also be analyzed microscopically for species identification. Trained volunteers can conduct a gross field analysis of species found in the water column. A more rigorous laboratory analysis may be needed to fully quantify species composition and density. This method could provide a means to establish a joint research project with a local university.

Species identification must be conducted soon after collection (4-8 hours), unless a recommended preservative is used. Many phytoplankton samples can be preserved in an iodine-based preservative (e.g., Lugol's solution),

Case Study: Searching for Toxic Phytoplankton in Maine

In 1996, the United States Food and Drug Administration, the Maine Department of Marine Resources, and the University of Maine Cooperative Extension developed a marine phytoplankton monitoring program for the state. This volunteer-based monitoring effort has proven to be integral to harvesting safe shellfish.

In this program, community members and students use plankton nets and field microscopes to monitor for toxic algal species. Guidelines are established for volunteers to quantify their observations on the various species of algae. The volunteers collect data at least once a week, providing valuable information that otherwise would not be available to scientists. The data:

- help agencies identify toxic condition trends and where more thorough sampling is needed;
- serve as an early warning system for harmful algal blooms, which can lead to shellfish bed closures; and
- help officials understand the correlations between toxins in the water column and toxins in shellfish.

Volunteers receive training on phytoplankton identification and receive preserved samples of toxic species to take home as references. Agency staff periodically visit volunteers in the field to help with species identification and to answer questions. Many volunteers simultaneously test their sites for other water quality parameters to give a more complete summary of estuary health.

For More Information:

Maine Shore Stewards
University of Maine Cooperative Extension
235 Jefferson Street
P.O. Box 309
Waldoboro, ME 04572
Phone: 207-832-0343
Fax: 207-832-0377
http://www.ume.maine.edu

which "fixes" the sample and stains the cellulose walls of the phytoplankton cells to aid in identification. A zooplankton sample should be preserved using a formalin-based solution.

WATER SAMPLE

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

Gross Density Sample Technique

- sampler (e.g., Kemmerer, Van Dorn, or plankton net);
- dropper;
- field microscope with slides (e.g., depression slides) and slide covers;
- guide for plankton identification; and
- sample preservative (iodine- or formalin-based solution for phytoplankton and zooplankton, respectively) if species identification will not be made soon after collection.

Composite Cell Count Technique

- sampler (e.g., Kemmerer or Van Dorn sampler);
- 500 ml labeled bottles;
- guide for plankton identification; and
- sample preservative (iodine- or formalin-based solution for phytoplankton and zooplankton, respectively).

STEP 2: *Collect the sample.*

Using a Kemmerer or Van Dorn sampler, collect plankton samples from various depths. In many cases, phytoplankton clumps within the water column can cause problems for analysis. These problems can be compensated for in multiple and/or composite samples.

STEP 3: *Analyze the sample.*

Samples can be analyzed using the gross density sample technique or the composite cell count technique.

Gross Density Sample Technique

The collected water can be poured through the mesh of a plankton net where the plankton are strained out of the water sample. Calculate density as explained in the plankton net tow method and Figure 19-3.

It should be noted that a density figure calculated from a mesh-strained plankton sample will likely not contain the smaller phytoplankton forms as they will pass through the mesh of most plankton nets. To obtain a more accurate density measure, an alternative method of analysis (e.g., composite cell count) should be used to better assess the types and numbers of phytoplankton cells obtained in each sample.

Composite Cell Count Technique

Using water sampling devices such as a Kemmerer or Van Dorn, collect a series of 1-liter volumes of water from predetermined areas representing vertical and horizontal distributions. Combine these samples into a larger, composite sample. This method of creating composite samples provides the mechanism to reduce the effects of distribution patterns of phytoplankton assemblages and also ensures that a better sampling is obtained of smaller phytoplankton forms for analysis as the sample is not filtered through a mesh.

While in the field, mix the composite sample thoroughly and pour subsamples into 500 ml labeled bottles containing a preservative solution. At a laboratory, these samples will be processed into concentrates for more rigorous microscopic analysis. Volunteer monitors can be trained to scan slide samples of these composite samples to determine species types and density levels. This method could provide a means to establish a joint research project with a local university. ■

Special Topic: Chlorophyll Collection for Lab Analysis

Another procedure for determining the abundance of phytoplankton is to measure the amount of chlorophyll that is present. Chlorophyll is a pigment common to all photosynthetic algae, and its amount in the water is in relation to the algal concentration. This analysis is conducted in a laboratory where the density of chlorophyll may be determined with appropriate instrumentation.

Three replicate water samples, often ranging from 250-500 ml, are usually taken for this analysis. The samples should be collected in opaque bottles, which are placed on ice, kept in the dark, and transported to a laboratory.

In the lab, the water sample is processed through a glass fiber filter, which is then placed in acetone and ground up. Technicians measure the amount of chlorophyll in the processed sample using a fluorometer, an instrument that measures the fluorescence of a substance. If the laboratory cannot process the sample immediately, it may be frozen and filtered at a later date. ■

NON-INDIGENOUS SPECIES

Recently, attention has been given to the great numbers of organisms that have been introduced to ecosystems outside their normal range of occurrence. These "alien invaders" are known by many names, including non-native species, non-indigenous species, nuisance species, invasive species, and exotic species. Regardless of the name, some of these organisms can wreak havoc on any ecosystem—including estuaries—once they become established.

Non-indigenous species (NIS) enter estuarine systems by a variety of pathways. These include:

- Boats and Ships

  Vessels often take on ballast water and sediment to keep them stable at sea. Often, the ballast and associated sediment contain small aquatic plants, animals, and pathogens which can be introduced to the estuary when the ballast is discharged near ports. Fouling organisms (e.g., barnacles) on the vessel's hull can also be transported to different regions. Plant fragments get caught on boat propellers and fishing gear, creating another introduction pathway.

- Seafood Imports and Processing

  Packing materials for live seafood (e.g., seaweed and seawater) can contain living organisms. When materials are improperly discarded, species introductions are possible. Organisms living in or on seafood can also find a way into the estuary.

- Aquaculture and Fishery Enhancement

  This includes introductions of non-indigenous fish and shellfish that are intentionally released to the estuary or escape from captivity. Intentional introduction of one species can inadvertently bring other associated species, such as parasites.

- Biological Control

  Some organisms are introduced to control the growth and spread of other species.

- Artificial Waterways

  Channels, canals, and locks are artificial connections between waterways. They facilitate movement of various organisms to new locales via vessels or natural spread.

- Live Bait

  Bait species and their packing material can be intentionally and accidentally released to the estuary.

- Research and Education

  Laboratories, schools, and aquariums use NIS for testing, teaching, and research. Poor management can allow organisms to escape or be intentionally released.

- Aquarium and Nursery Trades

  These industries transport and sell NIS. Intentional releases and escapes of organisms can lead to NIS invasions.

- Natural Spread

  Some organisms are transported to new locations by natural means, including migration and transport (e.g., by birds, insects, natural floating debris, etc.).

NIS have been introduced into environments for hundreds of years, but the rate of these introductions is increasing, thanks in part to greater and faster international shipping traffic and international trade. The problem of NIS is worldwide and involves nearly all taxonomic groups (Heimowitz, 1999).

The Role of NIS in the Estuarine Ecosystem

Some NIS have impacts on estuarine ecosystems that are being felt in many ways. The following sections describe these various impacts:

Ecological Impacts

Many NIS are relatively innocuous to their new environments; others, however, are notorious for causing major problems to estuarine ecology. In fact, NIS are the second most significant threat to threatened and endangered species, behind only habitat loss (Wilcove et al., 1998).

Through predation and competition, NIS have disrupted many native populations—some to the point of total disappearance from the estuarine system. Because many NIS have few, if any, predators or competitors in their new homes, they are able to reproduce essentially unchecked. As a result, they dominate their habitats and cause a reduction in biodiversity.

NIS can also affect habitats. Atlantic smooth cordgrass, for example, is native to the eastern United States but has been introduced to the Pacific Northwest. It is now causing havoc along Pacific Northwest estuaries, where it traps sediment and converts extensive mudflats to nearshore meadows. The increased elevation and root mass displaces animal communities adapted to surviving in the mud, destroys foraging habitat for fish and birds, and out-competes other plants that are included in animals' diets (*Coastlines*, 1999).

Other impacts are also being seen. Some non-indigenous herbivores (plant-eating animals), such as the nutria, have decimated wetland, marsh, and submerged aquatic vegetation. This leads to increased erosion and loss of food and habitat for native species. Some NIS crossbreed with native species, a situation which can ultimately lead to local extinction of the natives. NIS may also carry diseases or parasites with them, against which local species have no defense. Finally, some NIS can transform estuarine chemical dynamics, exposing the food web to new or increased amounts of toxins.

Human Health Impacts

Some NIS threaten human health. Ballast water discharges are suspected as causes of bacterial and viral outbreaks. Ballast water can also contain the dinoflagellates which cause red tides (see previous sections in this chapter). These occurrences can have severe health consequences for people who swim, boat, or eat fish or shellfish from contaminated waters.

Non-Indigenous Species: A Different Kind of Pollution

Non-indigenous species (NIS) are viewed as a biological pollutant requiring management under the federal Clean Water Act. NIS is markedly different from most traditional pollutants, however.

Unlike many other forms of pollution, such as nutrients, oil spills, or sewage, NIS do not eventually dissipate over time. Instead, they grow and reproduce, spreading their impacts throughout the estuary. Because of this characteristic, an NIS is very difficult to eliminate once it becomes established. Consequently, prevention and early detection are the only cost-effective options for keeping NIS out of estuaries.

Socio-Economic Impacts

Not only can NIS have significant impacts on ecosystems and human health, but they also exact a great financial cost. NIS that grow in unchecked abundance can clog water intake pipes (the zebra mussel is probably the most notorious NIS in this regard) and cause instability to levees. These problems keep municipal utilities and land managers on the lookout, and cost millions—even billions—of dollars to address. One study has estimated that environmental damages caused by NIS add up to $138 billion annually (Pimentel et al, 1999). In the marine environment alone, it costs $5 billion each year to control NIS (Valigra, 1999).

Because of the damage they cause to native populations, NIS can have a direct impact on local fisheries. The Chinese mitten crab has been blamed for shutting down fish salvage operations in the Sacramento River delta. In the Chesapeake Bay, scientists and watermen fear that the recently discovered veined rapa whelk—an Asian native with a voracious appetite for shellfish—will decimate the region's already suffering oyster and clam fisheries.

Levels of NIS Invasion

All estuaries in the United States probably have some NIS, but no one knows exactly how many. San Francisco Bay is one of the most invaded estuaries in the world, supporting approximately 230 non-indigenous organisms (Cohen and Carlton, 1998). Approximately 160 NIS are known to infest the Chesapeake Bay (SERC Web site), and the numbers are growing. ■

Sampling Considerations

Once non-indigenous species become established, they are very difficult—or even impossible—to eradicate. Therefore, early detection of NIS invasions is critical. Volunteers can serve an important function by working with experts to find NIS. In fact, one of the most firmly established and destructive species in the San Francisco Bay area—the Asian clam—was first discovered by a college biology class doing basic monitoring exercises in 1986 (Sheehan, 2000).

NIS include the full range of plants, animals, and microbes, so sampling approaches will vary depending on the species. To help find and control NIS, it is important to understand the organisms' life histories and habitats (Graves, 1999). Awareness of native natural history is important for volunteer monitors, who may not know all NIS in the region but can at least recognize what doesn't look typical. ■

Helpful Hint

It may be illegal to possess or transport certain NIS specimens. Volunteer leaders should check with the appropriate government agency about obtaining the necessary collection and transport permits. Obtain the permits before starting any sampling activities.

How to Monitor Non-Indigenous Species

Because NIS include nearly all taxonomic groups, there is no standard procedure for monitoring them. **Monitors should therefore consult with their data users to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5) for their organisms of interest.**

Regardless of the method used, volunteers should review the topics addressed in Chapter 7 before proceeding to the monitoring site and collecting samples. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

The training of volunteers should include a session on the identification of the organisms of interest.

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- guide to aid species identification;
- equipment necessary to collect and transport the organism(s) of interest;
- waterproof copy of any required species collection/transport permits; and
- sample preservative, if necessary.

STEP 2: *Collect the sample.*

Volunteers should capture the organisms using the method designated by the program manager and approved by the data users.

The volunteers should carefully label the sample container in which the organism will be transported with the date, site name, organism name (if known), and the name of the collector. An indelible marker is best for ensuring that the labeling is permanent. Make sure that the sample container is not wet before using the marker.

STEP 3: *Clean up and send off sample and data.*

Volunteers should transport live specimens at chilled temperatures appropriate for the species collected in containers supplied by the program. The program manager should designate pickup locations for volunteers to deliver the specimens and supporting data sheets to program personnel. As with all data sheets, the volunteer should make a duplicate in case the original becomes lost.

Make sure to thoroughly clean all equipment. ■

Hunting for NIS—and Bounty

In 1999, the Virginia Institute of Marine Science began offering a bounty for the veined rapa whelk. Citizens collect and donate the animals in return for money or t-shirts.

The project is used to help scientists document the whelk's distribution in the Chesapeake Bay and investigate potential impacts on the Bay's ecosystem.

For More Information:

The Virginia Institute of Marine Science
P.O. Box 1346
Gloucester Point, VA 23062-1346
Phone: 804-684-7000
http://www.vims.edu/fish/oyreef/rapven.html

Case Study: Keeping Tabs on Green Crabs in the Pacific Northwest

Spreading northward from California, the non-indigenous European green crab (*Carcinus maenas*—see Figure 19-4) first appeared on the Oregon coast in 1997. By 1999, green crabs occupied most Oregon estuaries, Washington's Willapa Bay and Grays Harbor, and sites in British Columbia. A capable predator, this invader raises concerns about impacts to native and commercial shellfish in the Pacific Northwest.

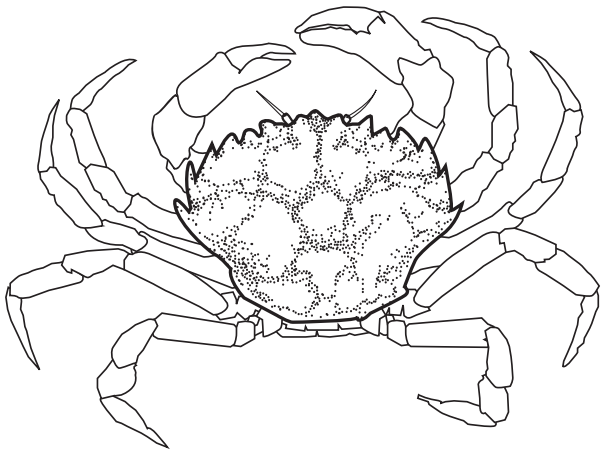


Figure 19-4. The European green crab, which can have severe environmental and economic impacts in the Pacific Northwest.

Given the invasion rate and extensive area at risk, agency monitoring alone is insufficient to detect the spread of the green crab. Volunteer programs provide many more sets of eyes to watch for this species as well as other NIS invasions.

To help the public distinguish green crabs from similar native crabs, Oregon and Washington Sea Grants have produced a color photo identification guide. In addition, Washington Sea Grant (with support from the U.S. Department of Fish and Wildlife) held a workshop for volunteer groups to provide information on green crab biology and monitoring techniques. Washington State's Department of Fish and Wildlife has contracted with Adopt-A-Beach, a nonprofit volunteer group to train and coordinate volunteers on green crab monitoring. Between July and September of 1999, 35 volunteers were trained and 32 monitoring sites, ranging from south Puget Sound to the San Juan Islands and the U.S.-Canadian border, were established. Volunteers search for the crab using baited traps in the intertidal zone.

Through the combined actions of agencies, tribes, schools, and volunteers, approximately 80 sites are monitored for green crabs in Washington. Numerous efforts to track the status of the green crab in Oregon estuaries also continue. For example, volunteers and high school students along the northern coast are monitoring for green crabs using live bait and modified minnow traps in six estuarine and marine sites.

For More Information:

Washington Department of Fish and Wildlife
1111 Washington St. SE
Olympia, WA 98501
Phone: 360-902-2200
Fax: 360-902-2230

Oregon Sea Grant,
Marine Invasive Species Team
500 Kerr Admin. Bldg., OSU
Corvallis, OR 97331-2131
Phone: 541-737-2714
Fax: 541-737-2392

Washington Sea Grant,
Marine Invasive Species Team
3716 Brooklyn Avenue NE
Seattle, WA 98105-6716
Phone: 206-543-6600
Fax: 206-685-0380

Biological Monitoring: Something for Everyone

Volunteers have many opportunities to become involved in biological monitoring activities. This chapter discusses just a few organisms monitored by volunteers. Below are references to other biological monitoring parameters. Volunteer leaders should contact their state monitoring agencies for information on other monitoring opportunities.

Birds

- "Bird Monitoring in North America"-U.S. Geological Survey Web site: http://www.mp1-pwrc.usgs.gov/birds.html.
- International Black Brant Monitoring Project: http://www.sd69.bc.ca/~brant/. (See also Alexander, G. 1998. "The International Black Brant Monitoring Project: Education That Spans a Flyway." *Coastlines* 8.2. Web site: http://www.epa.gov/owow/estuaries/coastlines/spring98/blackbrt.html.)

Salt Marshes/Wetlands

- Ferguson, W. 1999. "Fixing a Salt Marsh: Citizens, Shovels, and Sweat." *The Volunteer Monitor* 11(1). Web site: http://www.epa.gov/owow/volunteer/spring99/index.html.
- Bryan, R., M. Dionne, R. Cook, J. Jones, and A. Goodspeed. 1997. *Maine Citizens Guide to Evaluating, Restoring, and Managing Tidal Marshes*. Falmouth, ME. Web site: http://www.maineaudubon.org.
- Lipsky, A. 1996. *Narragansett Bay Method: A Manual for Salt Marsh Evaluation*. Save the Bay, Providence, RI. 22 pp. (Save the Bay, 434 Smith St., Providence, RI 02908-3770; phone: 401-272-3540).
- *The Volunteer Monitor* 10(1). 1998. Issue Topic: "Monitoring Wetlands." Web site: http://www.epa.gov/volunteer/spring98/index.html.

Replanting/Restoration Projects

- The Volunteer Monitor 11(1). 1999. Issue Topic: "Restoration." Web site: http://www.epa.gov/owow/volunteer/spring99/index.html.

References and Further Reading

——. 1999. "The Cordgrass Is Not Always Greener on the Other Side." *Coastlines* 9.5: 6-7.

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.

Cohen, A.N., and J.T. Carlton. 1998. "Accelerating Invasion Rate in a Highly Invaded Estuary." *Science* 279: 555-557.

Cushing, D.H. 1975. *Marine Ecology and Fisheries*. Cambridge Univ. Press. 278 pp.

Ellett, K. 1993. *Chesapeake Bay Citizen Monitoring Program Manual*. Alliance for the Chesapeake Bay. Richmond, VA. 57 pp.

Ely, E. 1991. "Benthic Macroinvertebrate Monitoring in Estuaries—A New Direction for Volunteer Programs?" *The Volunteer Monitor* 3(1): 5.

Ely, E. 1994. "The Wide World of Monitoring: Beyond Water Quality Testing." *The Volunteer Monitor* 6(1): 8-10.

Ely, E. 1998. "'Early Warning System' for Shellfish Poisoning." *The Volunteer Monitor* 10(2): 4-7.

Graves, J. 1999. "Exotic Species" In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

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

Griffin, K. 1998. *A Citizen's Guide to Plankton Monitoring in Tillamook Bay.* Tillamook Bay National Estuary Project, Garibaldi, OR. 45 pp.

Heimowitz, P. 1999. "Exotic Species" In: Meeting Notes—U.S. Environmental Protection Agency (USEPA)/Center for Marine Conservation (CMC) workshop: *Volunteer Estuary Monitoring: Wave of the Future*. Astoria, OR: May 19-21, 1999.

Levinton, J.S. 1982. *Marine Ecology*. Prentice-Hall, Englewood Cliffs, NJ. 526 pp.

Matthews, E. 1998. "Washington State Volunteers Fight *Spartina." The Volunteer Monitor* 10(2): 19.

Nordeen, W. 1999. *Phytoplankton Cell Count Protocol*. University of Maine Cooperative Extension and Maine Dept. of Marine Resources. April.

Parsons, T.R., M. Takahashi, and B. Hargrave. 1984. *Biological Oceanographic Processes*. New York: Pergamon Press. 330 pp.

Pfauth, M., and M. Sytsma. 1998. *Key to West Coast* Spartina *Species Based on Vegetative Characters.* Portland State University Lakes and Reservoirs Program Publication 98-1.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 1999. *Environmental and Economic Costs Associated with Non-Indigenous Species in the United States*. Cornell University. Manuscript available on Internet: http://www.news.cornell.edu/releases/Jan99/species_costs.html.

The Plankton Net—Maine's Phytoplankton Monitoring Newsletter. Available from University of Maine Cooperative Extension, 235 Jefferson Street, P.O. Box 309, Waldoboro, ME 04572; phone: 207-832-0343; fax: 207-832-0377.

Sheehan, L. 2000. Center for Marine Conservation, pers. communication.

Smith, D.L., and K. Johnson. 1996. *A Guide to Marine Coastal Plankton and Marine Invertebrate Larvae*. Kendall/Hunt, Dubuque, IA.

Tampa BayWatch and Tampa Bay National Estuary Program. 1998. "Great Bay Scallop Search Equipment List," "Field Procedures" (information sheets).

Tomas, C.R. (ed.). 1997. *Identifying Marine Phytoplankton*. Academic Press, Harcourt Brace & Co., New York. 858 pp.

U.S. Environmental Protection Agency (USEPA). 1997. *Volunteer Stream Monitoring: A Methods Manual.* EPA 841-B-97-003. November. Office of Water, Washington, DC. 211 pp.

Valigra, L. 1999. "Alien Marine Life Eats Locals for Lunch." *Christian Science Monitor* Web site: http://www.csmonitor.com/durable/1999/02/11/p13s1.htm. Feb. 11, 1999.

Washington Sea Grant Program. 1998. *Bioinvasions: Breaching Natural Barriers*. WSG 98-01. Web site: http://www.wsg.washington.edu/pubs/bioinvasions/biowarning.html.

Wilcove, David et al. 1998. "Quantifying Threats to Imperiled Species in the United States." *Bioscience* 48(8).

Web sites:

Shellfish

U.S. Food and Drug Administration

1. Center for Food Safety and Applied Nutrition

   Fish and Fishery Products Hazards and Controls Guide: http://vm.cfsan.fda.gov/~dms/haccp-2.html

   Foodborne Pathogenic Microorganisms and Natural Toxins Handbook: http://vm.cfsan.fda.gov/~mow/chap37.html

   Seafood Information and Resources: http://vm.cfsan.fda.gov/seafood1.html

2. Office of Seafood: http://vm.cfsan.fda. gov/~mow/sea-ill.html

Harmful Algal Blooms

Washington Sea Grant: http://www.wsg.washington.edu/outreach/mas/aquaculture/algalfacts.html

Non-Indigenous Species

Washington Sea Grant: http://www.wsg.washington.edu/outreach/mas/nis/nis.html

San Francisco Estuary Institute: http://www.sfei.org/invasions.html

Smithsonian Environmental Research Center (SERC): http://www.invasions.si.edu

U.S. Fish and Wildlife Service Invasive Species Program: http://invasives.fws.gov/

Sea Grant Non-Indigenous Species Site: http://www.sgnis.org/

Phytoplankton

Melbourne Parks and Waterways, Biological Surveys: http://140.211.62.101/streamwatch/swm13.html

Appendix A

Sample Data Forms

Photos (l to r): R. Ohrel, R. Ohrel, Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab, U.S. Environmental Protection Agency

Appendix A: Sample Data Forms

The following pages contain examples of data forms that may be useful to volunteer estuary monitoring programs. Many of the forms are currently being used by volunteer groups throughout the U.S.

The data forms that can be found on the following pages include:

PATUXENT RIVER DATA COLLECTION FORM

[Please return to: Joyce Brooks, ACB, P.O. Box 1981, Richmond, VA 23218]

Collection Date_____ Time of Day_____(military time)

MONITOR NAME _____ MONITOR NUMBER _____

SITE NAME _____ SITE NUMBER _____

DATA

Air Temperature_____._____°C

Secchi Depth_____._____M

Water Depth_____._____M

Water Temperature (in bucket)_____._____°C

Hydrometer Reading___.___ ___ ___ ___

Hydrometer Reading ___.___ ___ ___ ___

Correction Factor ___ ___

Adjusted Reading ___.___ ___ ___ ___

Salinity ___.___ppt

Water Temperature (in Hydrometer Jar)____._____°C pH_____._____SU

Dissolved Oxygen: Test I_____._____ Test II (must be within .6 of Test I)_____._____

GENERAL CONDITIONS

Water Surface (circle one): 1 Calm 2 Ripple 3 Waves 4 White Caps

Weather (circle one): 1 Sunny 2 Partly Cloudy 3 Overcast 4 Fog/Haze
5 Drizzle 6 Intermittent Rain 7 Rain 8 Snow

Rainfall_____._____mm (weekly accumulation)

Other: 1 Sea Nettles 2 Dead Fish 3 Dead Crabs 4 SAV 5 Oil Slick 6 Ice 7 Debris
8 Erosion 9 Foam 10 Bubbles 11 Odors

Water Color: (circle one) Normal Abnormal (describe) _____

_____

Nutrient Sample Taken (circle one): Yes No

Tidal Stage (circle one): High Outgoing Low Incoming

COMMENTS: _____

_____

_____

Signature_____ Date _____

(**Source:** Alliance for the Chesapeake Bay)

Citizen Monitoring Program
Water Quality Data Sheet

1 I.D.

Site name/Number: _____ Collection date (mo/dy/yr): __/__/__

Monitor name(s): _____ Time (military): _____ hours

_____

2 WEATHER CONDITION

Air temperature: ____.____ C

Weather (check one) ❑ clear ❑ snow ❑ overcast ❑ fog/haze
❑ drizzle ❑ downpour ❑ partly cloudy

Number of days with similar weather _____ days

Rainfall in previous 24 hours (check one): ❑ none ❑ light ❑ heavy _____ inches

3 SITE OBSERVATIONS

Tidal stage (check one): ❑ high ebb ❑ high
❑ low ebb ❑ low
❑ low flood ❑ flood
❑ high flood

Water surface (check one): ❑ calm ❑ ripple ❑ waves ❑ white caps

Indicators (check all that apply):

❑ fish kills ❑ dead crabs ❑ oil on surface ❑ debris
❑ erosion ❑ foam ❑ bubbles ❑ odors
❑ abnormal color ❑ birds ❑ animals ❑ other

Please elaborate on the above: _____
_____
_____
_____

4 FIELD/LAB MEASUREMENTS

Secchi depth: ____.____ m Water temperature: ____.____ C pH: ____.____

Dissolved oxygen Test 1 – mg/l ____.____ Test 2 – mg/l ____.____

Salinity: ____.____ 0/00 Fecal coliform colonies: _____ per 100 ml

Lab analysis by: _____

Return to: _____

(**Source:** Stancioff, E. 1992. *Clean Water: A Guide to Water Quality Monitoring for Volunteer Monitors of Coastal Waters*. Maine/New Hampshire Sea Grant Marine Advisory Program and Univ. of Maine Cooperative Extension. Orono, ME. 73 pp.)

CITIZEN MONITORING DATA SHEET

Date of Sampling: _____ Time of Day: _____ a.m. or p.m.

Volunteer Name: _____ Site Name: _____

SITE CONDITIONS

(Check one item under each category except under "Other," in which you should check all that apply.)

Wind: Calm ___ Slight Breeze ___ Moderate Breeze ___ Windy ___

Weather: Clear ___ Partly Cloudy ___ Overcast ___ Rainy ___ Drizzle ___ Fog ___ Snow ___

Wind Direction: N __ NE __ E __ SE __ S __ SW __ W __ NW __

Air Temperature: ___ °C

Rainfall: Weekly Accumulation (in inches) ____.___

Tidal Stage: Flooding ___ High Slack ___ Ebbing ___ Low Slack ___

Water Surface: Calm ___ Ripples ___ Chop ___ Swells ___

Water Color: Med. Brown ___ Dk. Brown ___ Red-Brown ___ Green-Brown ___
Green ___ Yellow-Brown ___ Other _____

Smell: Sewage ___ Oily ___ Fishy ___ Rotten Eggs ___ None ___ Other _____

Other: Sea Nettles ___ Dead Fish ___ Dead Crabs ___ Algal Bloom __ Oil Slick ___
Ice ___ Debris ___ Erosion ___ Foam___ Bubbles ____ Other_____

WATER QUALITY MEASUREMENTS

Secchi Disk: ____.____ meters **Water Depth:** ____.____ meters

Hydrometer (uncorrected): ___ °C **Water Temp. in Bucket:** ___ °C

Water Temp. in Hydrom. Jar: ___ °C **Hydrometer (corrected):** ___°C

Salinity: _____ ‰ **pH:** _____

Dissolved Oxygen: Test 1 ____ ppm Test 2 ____ ppm **Average:** ____ ppm

Time spent doing above sampling: _____

General Comments: _____
_____
_____

Signature: _____

(**Source**: unknown)

Coastal Watershed Survey Data Sheet

Surveyors: _____ Sector: _____ Site: _____
_____ Date: _____ Time: _____
_____ Rainfall: _____ # of Photos _____

Location (Describe landmarks and mark the site number on the sector map.)

Person(s) contacted at site:

Directions: Check off the appropriate items in categories 1-6.
Use the back side of this sheet for comments or site sketches.

1. POLLUTANT(s) (potential or known):
Toxic___ Bacteria ___ Nutrients___ Sediment___ Other_____

2. DIRECT DISCHARGE TO WATER BODY? Yes___ No___
Distance to water body or channel _____
Slope between location and water body or channel: flat___ moderate___ steep___

3. VEGETATED BUFFER? (between activity you are documenting and water body or channel)
Yes___ No___ Width____

4. SOURCE OF POLLUTANT(s)

Commercial & Residential:
- ___ Impervious areas
- ___ Septic system
- ___ Driveway
- ___ Lawn
- ___ Industrial runoff
- ___ Golf course runoff
- ___ Commercial runoff
- ___ Residential runoff
- ___ Construction site
- ___ Shoreline erosion
- ___ Other _____

Roads:
- ___ Ditch erosion
- ___ Shoulder erosion
- ___ Surface erosion
- ___ Culvert inlet/outlet
- ___ Stream crossing
- ___ Private road
- ___ Town road
- ___ State road
- ___ Logging road
- ___ Other _____

Agriculture:
- ___ Livestock grazing
- ___ Tilled fields
- ___ Manure/fertilizer spreading
- ___ Manure storage
- ___ Other _____

Marinas:
- ___ Boat maintenance
- ___ Waste discharge
- ___ Impervious areas
- ___ Fueling station
- ___ Refuse disposal
- ___ Other _____

Other Source: _____

5. SIZE OF AFFECTED AREA: Area or Length _____

6. COMMENTS, RECOMMENDATIONS, AND SKETCH (use back side)

(**Source:** Maine Department of Environmental Protection (DEP). 1996. *A Citizen's Guide to Coastal Watershed Surveys*. 78 pp.)

Please fill out the survey data sheet as follows:

SURVEY INFORMATION BOX:

Surveyors: Enter names of survey team members that identified the site.
Sector: Enter the number of the survey sector.
Site: Enter a site reference number 1, 2, etc. to give each site a unique identification.
Date and Time: Enter the date and time of day the problem was observed.
Rainfall: Enter the estimated rainfall amount during the past 24 hours.
Number of Photos: Record the number of photos taken at each site.*
Location: This information is critical for the follow-up analysis. Indicate the location of the site on your sector map. Describe access roads and distances from reference points to the site on the data sheet.
Person(s) Contacted at Site: Indicate if your survey team talked with a property owner or anyone else while at the site.

1. **POLLUTANT(S):** Check the pollutants generated at the site that are impacting or may potentially impact a waterbody.

2. **RUNOFF:** Determine if there is a direct pathway for runoff to carry the pollutants into the water body. Indicate the distance of the site to nearest water body or channel, and estimate the slope of the land between the site to the nearest waterbody or channel.

3. **VEGETATED BUFFER:** Indicate if runoff from the site flows through a vegetated buffer before reaching the nearest water body or channel, and the buffer width. Check the type of vegetation growing in the buffer. Determine if runoff in the buffer can spread evenly as it flows through the buffer, rather than flowing into the buffer.

4. **SOURCE OF POLLUTANTS:** Check the land uses/sources generating pollutants at each site.

5. **SIZE OF AFFECTED AREA:** Try to estimate the size of the area involved, such as the length or an eroding road ditch or the area of exposed soil.

6. **COMMENTS SKETCHES:** Use the back side of the survey data sheet for any additional comments or any drawings that would help to describe the site for future follow-up work and to prioritize. Include any recommendations your survey team has to eliminate or reduce the severity of the problem that you have identified.

***NOTE:** Photographs should be taken where they can help document the nature and severity of the problem. They will be used by those who do the follow-up analysis and may be used for documentation in any efforts to obtain funding for remedial efforts in the watershed. One close and one distance photo should be taken for perspective. When taking a close shot, try to include some object in the photo to provide a reference of size.

INTERNATIONAL COASTAL CLEANUP™ DATA CARD

Data collected during the International Coastal Cleanup™ is used to educate the public and develop solutions to solid waste management practices. Through cooperative efforts among government agencies, private industries, community associations, environmental organizations and local citizens, changes in behavior and practices result which help to conserve and protect the environment. The annual cleanup is how we measure our continued success. Thank you for being a very important part of this process.

Type of Cleanup: ❑ Shoreline/Beach ❑ Underwater

Country Where Cleanup Was Conducted:_____

Zone or County Cleaned:_____

Beach Site Name:_____

Today's Date: Month_____ Day_____ Year_____

Name of Coordinator:_____

Number of People Working on This Card:_____

Distance Cleaned:_____

Number of Trash Bags Filled:_____

Total Estimated Weight Collected:_____

NAMES OF PARTICIPANTS IN YOUR GROUP

If you are interested in learning more about **The Ocean Conservancy's** efforts to protect our oceans and waterways and if you would like to receive *Action Alerts* on critical marine conservation issues from The Ocean Conservancy's free Ocean Action Network (OAN), please check the box below with your name and address.

1. Name:_____ Age:_____
Address:_____
City:_____ State:_____
Country:_____ Zip Code:_____
Phone: (_____) _____
Email:_____
I would like information on: ❑ The Ocean Conservancy ❑ The OAN

2. Name:_____ Age:_____
Address:_____
City:_____ State:_____
Country:_____ Zip Code:_____
Phone: (_____) _____
Email:_____
I would like information on: ❑ The Ocean Conservancy ❑ The OAN

3. Name:_____ Age:_____
Address:_____
City:_____ State:_____
Country:_____ Zip Code:_____
Phone: (_____) _____
Email:_____
I would like information on: ❑ The Ocean Conservancy ❑ The OAN

4. Name:_____ Age:_____
Address:_____
City:_____ State:_____
Country:_____ Zip Code:_____
Phone: (_____) _____
Email:_____
I would like information on: ❑ The Ocean Conservancy ❑ The OAN

ENTANGLED ANIMALS: (❑ Dead or ❑ Alive). Type of Animal(s) and What Entangled the Animal:_____

WHAT WAS THE MOST PECULIAR ITEM YOU COLLECTED?_____

The following national and international organizations endorse and/or support the International Coastal Cleanup:

- U.S. Environmental Protection Agency
- IUCN – The World Conservation Union
- Intergovernmental Oceanographic Commission (IOC) of the United Nations' Educational, Scientific, and Cultural Organization (UNESCO)

Please return this card to your area coordinator or mail it to:

The Ocean Conservancy
Pollution Prevention and Monitoring Office
1432 N. Great Neck Road, Suite 103
Virginia Beach, VA 23454 USA
Phone (757) 496-0920
Fax (757) 496-3207

The Ocean Conservancy
Formerly the Center for Marine Conservation

ITEMS COLLECTED

The debris forms listed on this data card should be considered as indicator items based on their known uses (related activities) and impacts in the marine/aquatic environment (animal entanglement and ingestion, habitat destruction, human health and safety, vessel disablement, and economics and aesthetics).

Volunteers should clean up all debris found on the beach but only record information on the items listed below.

Keep a count of your items using tick marks and enter the item total in the box.

Example: [8] Bags/Food Wrappers 𝍸 |||

SHORELINE AND RECREATIONAL ACTIVITIES

(Debris from beach-goers, sports/games, festivals, litter from streets/storm drains, etc.)

- ☐ Bags/Food Wrappers
- ☐ Balloons
- ☐ Beverage Bottles (plastic) 2 liters or less
- ☐ Beverage Bottles (glass)
- ☐ Beverage Cans
- ☐ Caps, Lids
- ☐ Clothing, Cloth
- ☐ Cups, Plates, Forks, Knives, Spoons
- ☐ Diapers
- ☐ Fast-food Containers
- ☐ 6-Pack Holders
- ☐ Pull Tabs
- ☐ Shotgun Shells/Wadding
- ☐ Straws, Stirrers
- ☐ Toys

OCEAN/WATERWAY ACTIVITIES

(Debris from recreational/commercial fishing and boat/vessel operations)

- ☐ Bait Containers/Packaging
- ☐ Bleach/Cleaner Bottles
- ☐ Buoys/Floats
- ☐ Crab/Lobster/Fish Traps
- ☐ Crates
- ☐ Fishing Line
- ☐ Fishing Lures
- ☐ Fishing Nets
- ☐ Light Bulbs/Tubes
- ☐ Oil/Lube Bottles
- ☐ Pallets
- ☐ Plastic Sheeting/Tarps
- ☐ Rope
- ☐ Strapping Bands

SMOKING-RELATED ACTIVITIES

(Debris associated with smoking-related waste)

- ☐ Cigarettes/Cigarette Filters
- ☐ Cigarette Lighters
- ☐ Cigar Tips
- ☐ Tobacco Packaging/Wrappers

MEDICAL/PERSONAL HYGIENE

- ☐ Syringes
- ☐ Condoms
- ☐ Tampons/Tampon Applicators

DUMPING ACTIVITIES

- ☐ Appliances (refrigerators, washers, etc.)
- ☐ Batteries
- ☐ Cars/Car Parts
- ☐ Construction Materials
- ☐ 55-Gal. Drums
- ☐ Tires

DEBRIS ITEMS OF LOCAL CONCERN

(Items listed determined by local ICC Coordinator)

- ☐
- ☐
- ☐

National Marine Debris Monitoring Program
Data Card

Thank you for completing this data card. Please answer the questions and return to your survey director. This information will be used in The Ocean Conservancy's National Marine Debris Monitoring Program's data base to determine trends and sources of specific debris items.

Name_____ Affiliation _____

NMDMP Region _____ Survey Site _____

Survey Number _____ Today's date: _____ /_____ /_____

Air Temperature _____ Wind Direction _____

Wind Speed _____ (1=no wind, 2=slight, 3=moderate, 4=heavy, 5=gale)

Brief Description of Weather _____

Weather Conditions from previous week: _____

_____

Time (Beginning of Survey) _____ Time (End of Survey) _____

Other Remarks _____

_____

Safety Tips

1. Wear gloves and closed-toed shoes.
2. Be careful with sharp objects and syringes.
3. Stay out of dunes.
4. Watch out for wildlife.
5. Don't lift heavy objects.
6. Do not go near any large drums.

Dead, Live and/or Entangled Animals:

_____

_____

Foreign Labels: _____

_____

_____

Survey Director: _____

_____

Please return this card to your survey director or mail it to:

The Ocean Conservancy
1432 N. Great Neck Road, Suite 103
Virginia Beach, VA 23454

The Ocean Conservancy

Printed on recycled paper

Items Collected

You may find it helpful to work with a buddy as you clean the area, one of you picking up trash and the other taking notes. An easy way to keep track of the items you find is by making tick marks. The box is for total items; see sample below.

Example:

Balloons 𝍸 𝍸 𝍸 || 17

Ocean-Based

Gloves
Pl. sheets ≥ 1 meter
Light bulbs/tubes
Oil/gas containers (> 1 quart)
Pipe-thread protectors
Nets ≥ 5 meshes
Traps/pots
Fishing line
Light sticks
Rope ≥ 1 meter
Salt bags
Fish baskets
Cruiseline logo items
Floats/Buoys

Land-Based

Syringes
Condoms
Metal beverage cans
Motor oil containers (1 quart)
Balloons
Six-pack rings
Straws
Tampon applicators
Cotton swabs

General Sources

Plastic bags with seam < 1 meter
≥ 1 meter
Straps Open
Closed
Plastic bottles: beverage
food
bleach/cleaner
other pl. bottles

Comments:

SUBMERGED AQUATIC VEGETATION SURVEY FORM

Please use only one form for each area surveyed

SURVEYOR

Name: _____ Area Code and Telephone: _____

Address: _____

City: _____ State: _____ Zip: _____

AREA SURVEYED

Date of Sighting: _____ Time of Sighting: _____

Name of Map/ Quadrangle: _____

Method of Survey? (circle) Boat Pier Shore Other_____

Water Conditions: (circle) Clear Murky Other_____

Approximate Water Depth (in feet) _____

SAV SURVEY

Using the SAV map as a guide, locate SAV beds. Consult the field guide to identify the type of SAV in each bed. Use common plant names on this form. If you find a bed which is not shown on your map, mark the location of this new bed and identify the plants. Assign roman numerals to identify new SAV beds.

SAV BED	SAV SPECIES
EXAMPLE: (a). AB2 (b). I (new bed) (c). CB4	(a). Horned Pondweed , Redhead Grass (b). Widgeon Grass (c). No Plants Present
1. 2. 3. 4. 5. 6.	1. 2. 3. 4. 5. 6.

Did you survey this area last year? _____ If yes, were there any noticeable changes in the composition, size, or density of the beds? Please explain. _____

_____

_____

Any other comments or observations? (i.e. weather/ water conditions, wildlife sightings, problems etc.)

_____

_____

_____

Return to: **U.S. Fish and Wildlife Service**
177 Admiral Cochrane Drive
Annapolis, MD 21401
Attention: Kathryn Reshetiloff

(**Source:** U.S. Fish and Wildlife Service SAV Hunt)

SAV Survey Form

Name: _____ **Telephone:** (_____) _____-_____

Address: _____

City: _____ **State:** _____ **Zip:** _____

SURVEY SITE

Name of Site/Map/Quadrangle: _____

Date: _____ **Time:** _____ a.m. or p.m. **Water Depth:** _____ meters

Plants surveyed from: Boat Shore Pier Other _____

Water Conditions: Clear Murky Other _____

SURVEY

For each plant bed marked on the accompanying map, verify location and size, estimate SAV density, and identify plants present using a field guide. Write "no plants" for marked beds with no SAV. With a pencil, outline the position of new beds and identify them by number directly on the map.

Bed Name: _____ **Approximate Density:** _____

Species Present: _____
_____
_____

Comments (bed location and size changes, density or species changes since last sighting, weather and water conditions, problems, etc.):

_____
_____
_____

Bed Name: _____ **Approximate Density:** _____

Species Present: _____
_____
_____

Comments (bed location and size changes, density or species changes since last sighting, weather and water conditions, problems, etc.):

_____
_____
_____

(Send completed forms to the SAV Survey Coordinator)

(**Source:** unknown)

TAMPA BAYWATCH

TAMPA BAY NATIONAL ESTUARY PROGRAM

SCALLOP SEARCH DATA SHEET

Date:	Boat Captain:
Bay Segment:	Phone #:
Map Number:	Address:

	FIRST SITE	SECOND SITE	THIRD SITE	FOURTH SITE	FIFTH SITE
Site # or Letter					
Time					
Latitude					
Longitude					
LORAN/GPS Coordinates					
Water Depth					
Start					
End					
Transect Length					
Diver 1					
Diver 2					
Scallop Count					
Diver 1					
Diver 2					
Veg. Type					
Veg. Density					
Diver 1 Signature					
Diver 2 Signature					
Boat Captain Signature					

(**Source:** Tampa BayWatch and Tampa Bay Estuary Program)

Washington State Department of Health
Public Health Laboratories
1610 NE 150th Street, Seattle, WA 98155-9701

For LAB Use Only
SAMPLE #
DOMOIC #

SHELLFISH BIOTOXIN SAMPLE FORM

DATE COLLECTED ____/____/____ DATE SUBMITTED ____/____/____

COLLECTOR/COMPANY _____ TELEPHONE ( ) _____

CERT # _____ GRID# _____

SAMPLING SITE _____

STATE WA COUNTY _____ ☐ (M) MONITORING ☐ (S) SUPPLEMENTAL ☐ (O) OTHER ☐ (U) UNKNOWN

☐ (C) COMMERCIAL
☐ (S) SPORT/SUBSISTENCE
☐ (R) RESEARCH
☐ (P) PROGRAM
☐ (T) CONTRACT _____
☐ (O) OTHER _____

☐ (S) IN SHELL
☐ (K) SHUCKED

☐ (F) FRESH
☐ (Z) FROZEN
☐ (C) COOKED

SPECIES: *(Mark only one)*

☐ (CB) BUTTER CLAMS
☐ (CL) LITTLENECK CLAMS
☐ (MB) BLUE MUSSELS
☐ (MC) CALIFORNIA MUSSELS
☐ (CR) RAZOR CLAMS
☐ (OP) PACIFIC OYSTERS
☐ (CM) MANILA CLAMS
☐ (KD) CRAB
☐ (SP) PINK SCALLOPS
☐ (CG) GEODUCK
☐ (XX) OTHER _____

OF ORGANISMS _____

COMMENTS _____

LABORATORY RESULTS - LAB USE ONLY

DATE/TIME RECEIVED

Mark only one	PSP µg/100gm	PSP TIME AND DATE REPORTED	PSP INITIALS	Mark only one	DOMOIC ACID PPM	DOMOIC ACID TIME AND DATE REPORTED	DOMOIC ACID INITIALS
☐ MEAT				☐ MEAT			
☐ GUT				☐ GUT			
☐ WHOLE				☐ WHOLE			
☐ OTHER				☐ OTHER			
COMMENTS							

Revised 1/99

Visit the Biotoxin Bulletin on the Internet: http://www.doh.wa.gov/ehp/sf/biotoxin.htm

Crustacean Volunteer Survey Form

Date:
Name:
Phone Number:
Estuary:
Specific Location:

Time of Day:
Number of Searchers:
Tidal Stage:
Extent of Search:

GREEN CRAB#_____
SIZE(S)_____
SEX(ES)_____

Chinese Mitten Crab#_____
Size(s)_____
Sex(es)_____

GEAR:
_ Shore Trap
_ Minnow Trap
_ Pit Trap
_ Shore Walk
_ Other _____

HABITAT TYPE:
_ Cobbles
_ Riprap
_ Tidal Flat
_ Tidal Channel
_ Other _____

List of Other Species Observed **Size across the carapace in MM**

Crustaceans

_ **Purple shore crab** (*Hemigrapaus nudas)* TOTAL NUMBER _____

Sex										
Size										

_ **Oregon shore crab** (*H. oregonensis)* TOTAL NUMBER _____

Sex										
Size										

_ **Lined shore crab** (*Pachygrapsus crassipes*) TOTAL NUMBER _____

Sex										
Size										

_ **Red rock crab** (*C. productus*) TOTAL NUMBER _____

Sex										
Size										

_ **Pacific rock crab** (*C. antennarius*) TOTAL NUMBER _____

Sex										
Size										

_ **Dungeness crab** (*Cancer magister)* TOTAL NUMBER _____

Sex										
Size										

_ **Flat porcelain crab** (*Petrolisthes cinctipes*) TOTAL NUMBER _____

Sex										
Size										

_ **Other crab species**

Sex										

Mollusks

_ **Native oyster** (*Ostrea lurida)* TOTAL NUMBER _____

Size										
Size										

_ **Pacific oyster** (*Crassostrea gigas*) TOTAL NUMBER __

Size										
Size										

_ **California Mussel** (*Mytilus californianus*) TOTAL NUMBER _____

Size										
Size										

_ **Butter clam** (*Saxidomas giganteus*) TOTAL NUMBER _____

Size										
Size										

_ **Gaper clam** (*Tresus capax*) TOTAL NUMBER _____

Size										
Size										

_ **Cockle clam** (*Clinocardium nuttalli*) TOTAL NUMBER _____

Size										
Size										

_ **Little Neck clam** (*Protothaca staminea*) TOTAL NUMBER _____

Size										
Size										

_ **Soft-shell clam** (*Mya arenaria*) TOTAL NUMBER _____

Size										
Size										

_ **Manila clam** TOTAL NUMBER _____

Size										
Size										

_ **Other**

Size										
Size										

Algae
_ Focus
_ Eel grass (*Zostera* spp.)
_ Filamentous
_ Other

Numbers of Snails
____ Blue Top Snail (*Calliostoma ligatum*)
____ Checkered Periwinkle (*Littorina scutulata*)
____ Black Turban Snail (*Tegula funebralis)*
____ Wrinked Dove Snail (*Amphissa columbiana)*
____ Emarginate Whelk (*Nucella emarginata)*

COMMENTS

Contact: Jon Graves PSU/MERTS Phone (503) 338-6749 FAX (503) 338-6750
Email: jgraves@orednet.org **PLEASE RETURN:**
PSU/MERTS 6550 Liberty Lane, Astoria, OR 97103

(**Source:** Portland State University Nonindigenous Species Monitoring Program)

EUROPEAN GREEN CRAB SURVEY FORM

Surveyor Info

Name: _____ Date: _____

Daytime Phone: _____ Organization: _____

Trapping Location

Water Body: _____ County: _____

Nearest Landmarks: _____ Nearest City: _____

_____

Shoreline Type: ☐ Salt Marsh ☐ Tidal Channel ☐ Tidal Flat ☐ Other _____

Substrate Type: ☐ Cobble ☐ Gravel ☐ Mud ☐ Sand ☐ Other _____

Algae/Vegetation: ☐ *Ulva* (sea lettuce) ☐ *Fucus* (rockweed) ☐ Filamentous
☐ *Zostera* (eel grass) ☐ *Spartina* (cordgrass) ☐ Other _____

Trap Info

Trap Type: ☐ Crayfish/Minnow ☐ Pit Fall ☐ Other _____

Trap Number (1 of ?): _____ of _____ Bait Used: _____

Date & Time Traps Set: _____ Low Tide Time (Seattle): _____ (day 1)

Date & Time Traps Retrvd.: _____ Tide Height (Seattle): _____ (day 1)

Catch Info for Crab Species Trapped

☐ **No Crabs Caught**

☐ **European green crab (*Carcinus maenas*)**

✆**DO NOT RELEASE GREEN CRAB! Freeze sample and call WDFW at (360)796-4601.**

# M:	# F:	Total #:
# M Molts:	# F Molts:	Total # Molts:

☐ Oregon/Hairy/Yellow shore crab (*Hemigrapsus oregonensis*)

# M:	# F:	Total #:

☐ Purple shore crab (*Hemigrapsus nudus*)

# M:	# F:	Total #:

☐ Red rock crab (*Cancer productus*)

# M:	# F:	Total #:

☐ Dungeness crab (*Cancer magister*)

# M:	# F:	Total #:

☐ Other crab species

Species:	# M:	# F:	Total #:

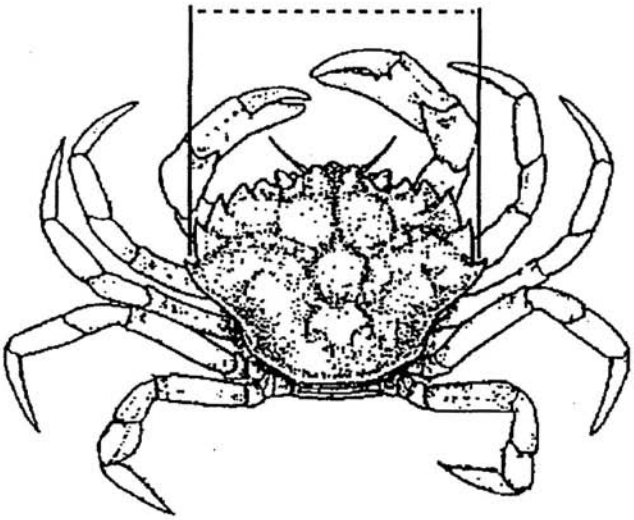
**** See back for carapace diagram and Comments section.***

(**Source:** Washington Department of Fish and Wildlife)

EUROPEAN GREEN CRAB

Carcinus maenas

Measure the widest distance across the back directly in front of the tips



Up to 3 ½ inches across the back of the shell
Color varied, dark, mottled, often green, orange or red

Comments: _____

Appendix B

Resources

Photos (l to r): R. Ohrel, R. Ohrel, Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab, U.S. Environmental Protection Agency

Appendix B: Resources

DOCUMENTS NOT REFERENCED IN PREVIOUS CHAPTERS

U.S. EPA. 1992. *National Estuary Program Monitoring Guidance*. Office of Water, Washington, DC. EPA 842-B-92-004. Web site: http://www.epa.gov/OWOW/estuaries/guidance/.

U.S. EPA. 1995. *Proceedings of the Fourth National Citizen's Volunteer Monitoring Conference.* EPA Office of Water, Washington, DC. EPA 841-R-94-003.

U.S. EPA. 1992. *Proceedings of the Third National Citizen's Volunteer Monitoring Conference.* EPA Office of Water, Washington, DC. EPA 841-R-92-004.

U.S. EPA. *Bibliography of Methods for Marine and Estuarine Monitoring (Files 61-80).* Web site: http://www.epa.gov/owowwtr1/info/PubList/monitoring/docs/list4.html.

U.S. EPA Technical Information Packages (TIPS) Publications List. Web site: http://www.epa.gov/clhtml/tips.html.

NEWSLETTERS

Coastlines

National Estuary Program Newsletter
Subscriptions are free. To subscribe, contact:
Coastlines
Urban Harbors Institute
100 Morrissey Blvd.
Boston, MA 02125-3393
Fax: 617-287-5575
E-mail: coastlines@umb.edu
Also available online at www.epa.gov/nep/coastlines/.

NPS News-Notes

EPA Office of Wetlands, Oceans and Watersheds Occasional bulletins dealing with the condition of the water-related environment, the control of nonpoint sources of water pollution, and the ecosystem-driven management and restoration of watersheds.

Subscriptions are free. To subscribe, send name and address to:
NPS News-Notes
c/o Terrene Institute
4 Herbert St.
Alexandria, VA 22305
Phone: 703-548-5473
Fax: 703-548-6299
Also available online at http://www.epa.gov/owowwtr1/info/NewsNotes/.

The Volunteer Monitor

The National Newsletter of Volunteer Water Quality Monitoring
Published twice yearly. Subscriptions are free. To subscribe, contact:

River Network
The Volunteer Monitor Newsletter
520 SW 6th Ave, Suite 1130
Portland, OR 97204-1535
Phone: 503-241-3506
E-mail: volmon@rivernetwork.org
Also available online at www.epa.gov/OWOW/monitoring/volunteer/vm_index.html.

INTERNET RESOURCES

EPA Volunteer Monitoring ListServe

To subscribe or unsubscribe, send an email to listserver@unixmail.rtpnc.epa.gov. Leave the subject line blank. In the message type:
subscribe volmonitor lastname firstname or unsubscribe volmonitor lastname firstname
To post a message, address your email to volmonitor@unixmail.rtpnc.epa.gov

The Ocean Conservancy's Ocean Action Network

You can help protect marine wildlife, and the ecosystems of which they are a part, by joining The Ocean Conservancy's Ocean Action Network (OAN). Subscribers will receive free OAN Alerts and Updates on issues by e-mail or regular mail:

Ocean Action Network
1725 DeSales St., NW
Suite 600
Washington, DC 20036

If you prefer to receive and respond to alerts via email, visit The Ocean Conservancy's Web site (www.oceanconservancy.org) and go to "Ocean Action Network"; or send a message, including your name, postal address and email address to ocean-alert@oceanconservancy.org.

Federal Agency Web Pages:

EPA

EPA homepage: http://www.epa.gov/
EPA Office of Water: http://www.epa.gov/ow/
EPA Office of Wetlands, Oceans & Watersheds: http://www.epa.gov/owow/
National Estuary Program: http://www.epa.gov/owow/estuaries/nep.html
Surf Your Watershed: http://www.epa.gov/surf
Volunteer Monitoring: http://www.epa.gov/ OWOW/monitoring/vol.html
Watershed Information Network: http://www.epa.gov/win

NOAA

National Sea Grant Program: http://www.nsgo.seagrant.org/index.html
NERRS Estuary-Net Project: http://inlet.geol.sc.edu/estnet.html
Volunteering for the Coast: http://volunteer.nos.noaa.gov/

Others

U.S. Department of Agriculture, Natural Resources Conservation Service:
http://www.nrcs.usda.gov/
U.S. Fish and Wildlife Service: http://www.fws.gov/
U.S. Forest Service: http://www.fs.fed.us/
U.S. Geological Survey: http://www.usgs.gov/

Links to Environmental Groups:

EnviroLink: http://www.envirolink.org/
Kentucky Water Watch: http://water.nr.state.ky.us/ww/vm.htm
U.S. EPA Office of Water: http://www.epa.gov/owow/estuaries/links.htm#local

FEDERAL AGENCIES AND PROGRAMS

Environmental Protection Agency (EPA)

Office of Wetlands, Oceans, and Watersheds
Volunteer Monitoring (4504T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Phone: 202-566-1200
Fax: 202-566-1336
E-mail: OW-General@epamail.epa.gov

National Estuary Program (NEP)
Web site: http://www.epa.gov/owow/estuaries/nep.html

National Oceanic and Atmospheric Administration (NOAA)

U.S. Department of Commerce
14th Street & Constitution Ave., NW
Room 6013
Washington, D.C. 20230
Phone: 202-482-6090
Fax: 202-482-3154
Email: answers@noaa.gov

NOAA Estuarine Reserve Division (NERRS)
1305 East West Highway N/ORM5
Silver Spring, MD 20910
Phone: 301-713-3132
Fax: 301-713-4363
Web site: http://www.ocrm.nos.noaa.gov/nerr/

National Estuary Porgram (NEP) Contacts

Alabama

Mobile Bay Estuary Program
4172 Commanders Drive
Mobile, AL 36615
Phone: 251-431-6409
Fax: 251-431-6450
Web site: http://mobilebaynep.com

California

Moro Bay Estuary Project
601 Embarcadero, Suite 11
Morro Bay, CA 93442
Phone: 805-772-3834
Fax: 805-772-4162
Web site: http://www.mbnep.org

San Francisco Estuary Project
1515 Clay St., Suite 1400
Oakland, CA 94612
Phone: 510-622-2465
Fax: 510-622-2501
Web site: http://www.abag.ca.gov/bayarea/sfep/sfep.html

Santa Monica Bay Restoration Project
320 W. Fourth St., 2nd floor
Los Angeles, CA 90013
Phone: 213-576-6615
Fax: 213-576-6646
Web site: http://www.smbay.org

Connecticut

Long Island Sound, CT/NY
Long Island Sound Study
64 Stamford Government Center
888 Washington Boulevard
Stamford, CT 06904-2152
Phone: 203-977-1541
Fax: 203-977-1546
Web site: http://www.epa.gov/region01/eco/lis

Delaware

Delaware Estuary Program, DE/NJ/PA
Delaware River Basin Commission
P.O. Box 7360
West Trenton, NJ 08628
Phone: 609-883-9500 ext. 217
Fax: 609-883-9522
Web site: http://www.delep.org/

Center for the Inland Bays
467 Highway One
Lewes, DE 19958
Phone: 302-645-7325
Fax: 302-645-5765
Web site: http://www.udel.edu/CIB

Florida

Charlotte Harbor Estuary Program
SW Florida Regional Planning Council
4980 Bayline Dr., 4th Fl.
North Fort Myers, FL 33917-3909
Phone: 941-995-1777
Fax: 941-656-7724
Web site:
http://www.charlotteharbornep.com/

Indian River Lagoon Program
1900 South Harbor City Blvd., #107
Melbourne, FL 32901
Phone: 407-984-4950
Fax: 407-984-4937
Web site: http://www.epa.gov/owow/oceans/lagoon/

Sarasota Bay Project
5333 N. Tamiami Trail, Suite 104
Sarasota, FL 34234
Phone: 941-359-5841
Fax: 941-359-5846
Web site: http://www.sarasotabay.org

Tampa Bay Estuary Program
100 8th Avenue, SE, MS I-1/NEP
St. Petersburg, FL 33701
Phone: 727-893-2765
Fax: 727-893-2767
Web site: http://www.tbep.org/

Louisiana

Barataria-Terrebonne Estuary Program
P.O. Box 2663
Nicholls State University Campus
Thibodaux, LA 70310
Phone: 504-447-0868 or 800-259-0869
Fax: 504-447-0870
Web site: http://www.mail.btnep.org

Maine

Casco Bay Estuary Project
University of Southern Maine
P.O. Box 9300
49 Exeter Street
Portland, ME 04104-9300
Phone: 207-780-4820
Fax: 207-780-4917
Web site:
http://www.cascobay.usm.maine.edu

Maryland

Maryland Coastal Bays Program
9609 Stephen Decatur Highway
Berlin, MD 21811
Phone: 410-213-2297
Fax: 410-213-2574
Web site: http://www.dnr.state.
md.us/coastalbays

Massachusetts

Buzzards Bay Estuary Program
2870 Cranberry Highway
E. Wareham, MA 02538
Marion, MA 02738
Phone: 508-291-3625
Fax: 508-291-3628
Web site: http://www.buzzardsbay.org/

Massachusetts Bays Program
251 Causeway Street
Suite 900
Boston, MA 02114-2151
Phone: 617-626-1230
Fax: 617-626-1240
Web site:
http://www.state.ma.us/massbays

New Hampshire

New Hampshire Estuaries
152 Court Street
Portsmouth, NH 03801
Phone: 603-433-7187
Fax: 603-431-1438
Web site: http://state.nh.us/nhep

New Jersey

Barnegat Bay Estuary Program
P.O. Box 2191
Toms River, NJ 08753
Phone: 732-506-5313
Fax: 732-244-8396
Web site: http://www.bbep.org

Delaware Estuary Program, DE/NJ/PA
Delaware River Basin Commission
P.O. Box 7360
West Trenton, NJ 08628
Phone: 609-883-9500 ext. 217
Fax: 609-883-9522
Web site: http://www.delep.org/

New York-New Jersey Harbor Estuary
Program
290 Broadway
24th Floor.
New York, NY 10007
Phone: 212-637-3816
Fax: 212-637-3889
Web site: http://www.harborestuary.org

New York

Long Island Sound Study
64 Stamford Government Center
888 Washington Boulevard
Stamford, CT 06904-2152
Phone: 203-977-1541
Fax: 203-977-1546
Web site: http://www.epa.gov/region01/eco/lis

New York-New Jersey Harbor Estuary Program
290 Broadway
24th Floor.
New York, NY 10007
Phone: 212-637-3816
Fax: 212-637-3889
Web site: http://www.harborestuary.org

Peconic Estuary Program
Department of Health Services
County of Suffolk
Riverhead County Center, 2nd floor
Riverhead, NY 11901
Phone: 631-852-2077
Fax: 631-852-2743
Web site: http://www.co.suffolk.ny.us/health/eq/pep.html

North Carolina

Albemarle-Pamlico Sounds NEP
N.C. DENR
P.O. Box 27687
Raleigh, NC 27611-7687
Phone: 919-733-5083 ext. 585
Fax: 919-715-5637
Web site: http://h2o.enr.state.nc.us/nep/

Oregon

Lower Columbia River Estuary Program
811 SW Naito Parkway
Portland, OR 97204
Phone: 503-226-1565
Fax: 503-226-1580
Web site: http://www.lcrep.org

Tillamook Bay Estuary Program
613 Commercial Avenue
P.O. Box 493
Garibaldi, OR 97118
Phone: 503-322-2222
Fax: 503-322-2261
Web site:
http://www.co.tillamook.or.us/gov/estuary/tbnep/nephome.html

Pennsylvania

Delaware Estuary Program
Delaware River Basin Commission
P.O. Box 7360
West Trenton, NJ 08628
Phone: 609-883-9500 ext. 217
Fax: 609-883-9522
Web site: http://www.delep.org/

Puerto Rico

San Juan Bay NEP
400 Fernandez Juncos Ave., No. 400
San Juan, PR 00901-3299
Phone: 787-725-8162
Fax: 787-725-8164
Web site: http://www.estuariosanjuan.org

Rhode Island

Narragansett Bay Estuary Program
235 Promenade Street
Providence, RI 02908-5767
Phone: 401-222-4700 ext. 7271
Fax: 401-521-4230
Web site: http://www.nbep.org

Texas

Coastal Bend Bays and Estuaries Program
Natural Resources Building, Suite 3300
6300 Ocean Drive
Corpus Christi, TX 78412
Phone: 361-980-3425
Fax: 361-980-3437
Web site: http://tarpon.tamucc.edu

Galveston Bay Estuary Program
711 West Bay Area Boulevard, # 210
Webster, TX 77598
Phone: 281-332-9937
Fax: 281-332-8590
Web site:
http://gbep.tamug.tamu.edu/gbepix.html

Washington

Lower Columbia River Estuary Program
811 SW Naito Parkway
Portland, OR 97204
Phone: 503-226-1565
Fax: 503-226-1580
Web site: http://www.lcrep.org

Puget Sound Water Quality Action Team
Puget Sound Estuary Program
P.O. Box 40900
Olympia, WA 98504-0900
Phone: 360-407-7300;
800-54-SOUND (WA only)
Fax: 360-407-7333
Web site:
http://www.wa.gov/puget_sound

National Estuarine Research Reserve System (NERRS) Contacts

Alabama

Weeks Bay NERR
11300 U.S. Highway 98
Fairhope, AL 36532-5476
Phone: 334-928-9792
Fax: 334-928-1792

Alaska

Kachemak Bay NERR
Homer Office - Reserve Headquarters
202 West Pioneer Avenue
Homer, AK 99603
Phone: 907-235-4799
Fax: 907-235-4794

Anchorage Office - ADF&G
Alaska Department of Fish and Game
Habitat and Restoration Division
333 Raspberry Rd.
Anchorage, AK 99518
Phone: 907-267-2331
Fax: 907-267-2464

California

Elkhorn Slough NERR
1700 Elkhorn Road
Watsonville, CA 95076
Phone: 831-728-2822
Fax: 831-728-1056

Tijuana Estuary Visitor Center
301 Caspian Way
Imperial Beach, CA 91932
Phone: 619-575-3613
Fax: 619-575-6913

San Francisco Bay (Proposed) NERR
Romberg-Tiburon Center
P.O. Box 855
Tiburon, CA 94920
Phone: 415-338-3703
Fax: 415-435-7120

Delaware

Delaware NERR
818 Kitts Hummock Rd.
Dover, DE 19901
Phone: 302-739-3436
Fax: 302-739-3446

Florida

Apalachicola NERR
Visitor and Education Center
261 7th Street
Apalachicola, FL 32320
Phone: 850-653-8063/2296

Administrative and Technical Offices
350 Carroll Street
Eastpoint, FL 32328
Phone: 850-670-4783
Fax: 850-670-4324

Rookery Bay NERR
Department of Environmental Protection
300 Tower Road
Naples, FL 34113
Phone: 941-417-6310
Fax: 941-417-6315

Guana Tolomato Matanzas NERR
PO Box 840069
St. Augustine, FL 32084
Phone: 904-461-4053
Fax: 904-461-4053

Georgia

Sapelo Island NERR
P.O. Box 15
Sapelo Island, GA 31327
Phone: 912-485-2251
Fax: 912-485-2141

Maine

Wells NERR
342 Laudholm Farm Road
Wells, ME 04090
Phone: 207-646-1555
Fax: 207-646-2930

Maryland

Chesapeake Bay NERR - Maryland
Maryland Department of Natural Resources
Tawes State Office Building, E-2
580 Taylor Avenue
Annapolis, MD 21401
Phone: 410-260-8713
Fax: 410-260-8739

Massachusetts

Waquoit Bay NERR
P.O. Box 3092
149 Waquoit Highway
Waquoit Bay, MA 02536
Phone: 508-457-0495
Fax: 617-727-5537

Mississippi

Grand Bay NERR
Department of Marine Resources
6005 Bayou Heron Resources
Moss Point, MS 39562
Phone: 228-475-7047
Fax: 228-475-8849

New Hampshire

Great Bay NERR
N.H. Fish and Game Department
Marine Fisheries Department
225 Maine Street
Durham, NH 03824
Phone: 603-868-1095
Fax: 603-868-3305

Sandy Point Discovery Center; GBNERR
89 Depot Road
Stratham, NH 03885
Phone: 603-778-0015

New Jersey

Jacques Cousteau NERR
Institute of Marine and Coastal Sciences
Rutgers University
71 Dudley Road
New Brunswick, NJ 08903-0231
Phone: 732-932-6555
Fax: 732-932-8578

New York

Hudson River NERR
NYS DEC, c/o Bard College Field
Station
Annandale-on-Hudson, NY 12504-5000
Phone: 914-758-7010
Fax: 914-758-7033

St. Lawrence River (Proposed) NERR
317 Washington Street
Watertown, NY 13601
Phone: 315-785-2443
Fax: 315-785-2574

North Carolina

North Carolina NERR
5001 Masonboro Loop Road
1 Marvin Moss Lane
Wilmington, NC 28409
Phone: 910-962-2470
Fax: 910-962-2410

North Carolina NERR
c/o Duke University Marine Laboratory
135 Pivers Island Road
Beaufort, NC 28516
Phone: 252-728-2170
Fax: 252-728-6273

Ohio

Old Woman Creek NERR
Department of Natural Resources
2514 Cleveland Road East
Huron, OH 44839
Phone: 419-433-4601
Fax: 419-433-2851

Oregon

South Slough NERR
P.O. Box 5417
Charleston, OR 97420
Phone: 541-888-5558
Fax: 541-888-5559

Puerto Rico

Jobos Bay NERR
Department of Natural and
Environmental Resources
Call Box B
Aguirre, PR 00704
Phone: 787-853-4617
Fax: 787-953-4618

Rhode Island

Narragansett Bay NERR
55 South Reserve Drive
Prudence Island, RI 02872
Phone: 401-683-6780 (on-site)
Fax: 401-682-1936

South Carolina

Ace Basin NERR
P.O. Box 12559
Charleston, SC 29412
Phone: 843-762-5062
Fax: 843-762-5001

North Inlet-Winyah Bay NERR
Baruch Marine Field Laboratory
University of South Carolina
P.O. Box 1630
Georgetown, SC 29442
Phone: 843-546-3623
Fax: 843-546-1632

Virginia

Chesapeake Bay NERR - Virginia
Virginia Institute of Marine Science
P.O. Box 1346
Gloucester Point, Virginia 23062
Phone: 804-684-7135
Fax: 804-684-7120

Washington

Padilla Bay NERR
Department of Ecology
10441 Bayview-Edison Road
Mount Vernon, WA 98273-9668
Phone: 360-428-1558
Fax: 360-428-1491
TDD: 360-757-1549

Appendix C

Equipment Suppliers

Photos (l to r): R. Ohrel, R. Ohrel, Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab, U.S. Environmental Protection Agency

Appendix C: Equipment Suppliers

This is a partial list of suppliers from which a volunteer estuary monitoring program might obtain scientific equipment. This list does not imply endorsement by the U.S. Environmental Protection Agency.

Aquatic Research Instruments
P.O. Box 93
Lemhi, ID 83465
Phone: 800-320-9482; 208-756-8433
Web site: www.aquaticresearch.com
Water samplers, sediment samplers, plankton samplers, drift nets, calibrated lines, armored thermometers, BOD bottles.

Ben Meadows Company
190 Etowah Industrial Court
Canton, GA 30114
Phone: 800-241-6401
Web site: www.benmeadows.com
Waders, rubber boots, field water test equipment, kick nets, dip nets, wash buckets, forceps.

Carolina Biological Supply Company
2700 York Road
Burlington, NC 27215-3398
Phone: 800-334-5551
Web site: www.carolina.com
Flexible arm magnifiers, hand lenses, forceps, kick nets, microscopes, reagents, educational materials, live and mounted specimens for instruction.

Cole Parmer Instruments, Inc.
625 East Bunker Court
Vernon Hills, IL 60061
Phone: 800-323-4340
Web site: www.coleparmer.com
Lab equipment, field water test equipment, microscopes.

Chemetrics
Route 28
Calverton, VA 20138
Phone: 800-356-3072
Web site: www.chemetrics.com
Water testing kits for field analysis of dissolved oxygen, nitrate, nitrite, ammonia, phosphates, chlorine, sulfur, manganese, others.

Consolidated Plastics
8181 Darrow Road
Twinsburg, OH 44087
Phone: 800-362-1000
Web site: www.consolidatedplastics.com
Sampling trays, buckets, Nalgene bottles, Whirl-paks.

Earth Force
1908 Mt. Vernon Avenue, 2nd Floor
Alexandria, VA 22301
Phone: 703-299-9485
Web site: www.earthforce.org
Earth Force's GREEN program has low-cost, self-contained, nontoxic, premeasured water monitoring kits designed for young people.

Fisher Scientific Company
711 Forbes Ave.
Pittsburgh, PA 15219
Phone: 800-766-7000
Web site: www.fishersci.com
Lab equipment, sample bottles, sieves, reagents and chemicals, incubators, water test equipment, Whirl-paks.

Forestry Suppliers, Inc.
P.O. Box 8397
Jackson, MS 39284-8397
Phone: 601-354-3565
Web site: www.forestry-suppliers.com
Secchi disks, transparency tubes, water sampling equipment, bottom dredges, sediment samplers, plankton and other nets, fish measuring boards. Ask for "Environmental Source" catalogue.

GREEN
See Earth Force

Hach Equipment Company
P.O. Box 389
Loveland, CO 80539-0389
Phone: 800-227-4224
Web site: www.hach.com
Field and lab water testing equipment, spectrophotometers, incubators, water sampling kits, fecal coliform sampling supplies (including presence-absence tests), reagents, educational materials.

Hydrolab Corporation
8700 Cameron Road
Austin, TX 78754
Phone: 800-949-3766
Web site: www.hydrolab.com
Multi-parameter electronic meters for physical and chemical parameters.

Idexx Laboratories
One Idexx Drive
Westbrook, ME 04092
Phone: 800-321-0207
Web site: www.idexx.com
Colilert products for bacterial testing.

J. L. Darling Corporation
2614 Pacific Highway East
Tacoma, WA 98424-1017
Phone: 253-922-5000
Web site: www.riteintherain.com
All-weather writing paper.

LaMotte
P.O. Box 329
Chestertown, MD 21620
Phone: 800-344-3100; 410-778-3100 (in Maryland)
Web site: www.lamotte.com
Water sampling kits, field and lab water testing equipment, Secchi disks, water samplers, armored thermometers, calibrated lines, plankton nets, kick nets, educational materials.

Lawrence Enterprises
See Water Monitoring Equipment & Supply

Micrology Laboratories
206 West Lincoln Avenue
Goshen, IN 46526
Phone: 888-327-9435
Web site: www.micrologylabs.com
Lab equipment and media for bacterial testing, including Coliscan products (Coliscan EasyGel and Coliscan MF) and ECA Check.

Millipore Corporation
80 Ashby Road
Bedford, MA 01730
Phone: 800-645-5476
Web site: www.millipore.com
Fecal coliform testing supplies (complete sterile water filtration system), membrane filters, sterile pipettes, petri dishes, sterile media, other water sampling and testing equipment and lab supplies, incubators, Whirl-paks.

Nalge Nunc International
P.O. Box 20365
Rochester, NY 14602
Phone: 800-625-4327
Web site: www.nalgenunc.com
Fecal coliform testing supplies, membrane filters, sterile pipettes, petri dishes, incubators, Whirl-paks.

National Archives and Records Administration
Cartographic and Architectural Branch
8601 Adelphi Road
College Park, MD 20740-6001
Phone: 301-713-7040
E-mail: carto@arch2.nara.gov (Note: when submitting a request via e-mail, be sure to include a regular mail address.)
Web site:
www.nara.gov/research/ordering/mapordr.html
Photographs, generally from before 1955.

Nichols Net and Twine, Inc.
2200 Highway 111
Granite City, IL 62040
Phone: 618-797-0211; 800-878-6387
Nets of all kinds (dip, kick, insect, larvae, macroinvertebrates), seines, custom nets.

Ocean Pro Shop
4060 DuPont Parkway
Townsend, DE 19734
Phone: 302-378-8666
Web site: www.wserv.com/oceanpro/
Nets.

Onset Computer Corporation
P.O. Box 3450
Pocasset, MA 02559-3450
Phone: 800-564-4377; 508-759-9500
Web site: www.onsetcomp.com
Data loggers.

Strategic Diagnostics Inc. (SDI)
111 Pencader Drive
Newark, DE 19702
Phone: 800-544-8881
Web site: http://www.sdix.com
Immunoassay kits for pesticides, other contaminants.

Thomas Scientific Company
99 High Hill Road
P.O. Box 99
Swedesboro, NJ 08085
Phone: 856-467-2000; 800-345-2100
Web site: www.thomassci.com
Lab equipment, sample bottles, sieves, reagents, incubators, water test equipment, Whirl-paks.

U.S. Department of Agriculture
USDA Consolidated Farm Service Agency
Aerial Photography Field Office
2222 West 2300 South
Salt Lake City, UT 84119-2020
Phone: 801-975-3500
Web site: www.fsa.usda.gov
Recent aerial photos.

U.S. Environmental Protection Agency
Maps on Demand Web site:
www.epa.gov/enviro/html/mod/index.html
Internet site that allows users to generate maps displaying environmental information for most locations in the U.S. Types of information that can be mapped include EPA-regulated facilities, demographic information, roads, and waterbodies. Maps of varying scales can be generated on the site (latitude and longitude), zip code, county, and basin levels. Submit your request and email address, and after a brief wait, you will be able to view your map on-line or download it.

U.S. Geological Survey
USGS Information Services
Box 25286
Denver Federal Center
Denver, CO 80225
Phone: 888-ASK-USGS
Web site: mapping.usgs.gov/
Topographic maps and aerial photos.

VWR Scientific
P.O. Box 626
Bridgeport, NJ 08014
Phone: 800-932-5000; 908-757-4045
Web site: www.vwrsp.com
Glassware, labeling tape, sample vials, lab equipment, incubators, reagents, Whirl-paks.

Wards Natural Science Establishment, Inc.
P.O. Box 92912
Rochester, NY 14692-9012
Phone: 800-962-2660; 716-359-2502
Web site: www.wardsci.com
Alcohol lamps, balances, microscopes, sample trays, goggles, rubber stoppers, autoclaves, spectrophotometers, incubators, petri dishes, sterile pipettes, glassware, educational materials, live and mounted specimens for instruction.

Water Monitoring Equipment & Supply
P.O. Box 344
Seal Harbor, ME 04675
Phone: 207-276-5746
Web site: watermonitoringequip.com
Monitoring equipment: transparency tubes, view scopes, Secchi disks, water samplers, kick nets, sieve buckets.

Wildlife Supply Company
95 Botsford Place
Buffalo, NY 14216
Phone: 800-799-8301
Web site: www.wildco.com
Kick nets, plankton nets, wash buckets, field biological sampling equipment, water bottles.

YSI Incorporated
1725 Brannum Lane
Yellow Springs, Ohio 45387
Phone: 937-767-7241
Web site: www.ysi.com
Electronic water quality monitoring meters, other water quality supplies.

Glossary

Glossary and Acronyms

Photos (l to r): R. Ohrel, R. Ohrel, Tillamook Bay National Estuary Project and Battelle Marine Sciences Lab, U.S. Environmental Protection Agency

Glossary and Acronyms

Note: The terms contained within this glossary are general definitions and are accurate as they relate to water analysis. They are for reference only.

Abiotic – Pertaining to factors or things that are separate and independent from living things: nonliving.

Accuracy – A measure of confidence in a measurement. As the difference between the measurement of a parameter and its "true" or expected value becomes smaller, the measurement becomes more accurate.

Acid – Any substance capable of giving up a proton; a substance that ionizes in solution to give the positive ion of the solvent; a solution with a pH measurement less than 7. See also alkaline.

Acid rain – Precipitation composed of water particles, sulfuric acid, and/or nitric acid. These acids are formed from sulfur dioxides from the smokestacks of coal and oil burning power plants and from nitrogen oxides emitted by motor vehicles. This precipitation form can change the chemistry of healthy soils and waters, potentially making them unfit to support life.

Acidity – A measure of the number of free hydrogen ions (H^+) in a solution that can chemically react with other substances. Also see pH.

Acute toxicity – When exposure levels result in death within 96 hours. Lethal doses differ for each toxin and species, and are influenced by the potency and concentration of the toxin.

Aerobic – Living or occurring only in the presence of oxygen.

Algae – Organisms containing chloropyll and other pigments that permit photosynthesis. Algae lack true roots, stems, or leaves.

Algaecide – Chemical agent added to water to destroy algae.

Algal bloom (algae bloom) – Excessive growth of aquatic algae resulting from nutrients such as nitrogen and phosphorus being added to the environment. Other physical and chemical conditions can also enable algae to reproduce rapidly.

Alkaline or basic – A solution with a pH measurement above 7.0. Alkaline solutions contain an alkali, which is any base or hydroxide (OH^-) that is soluble in water and can neutralize acids. Also see base, acid.

Alkalinity – The capacity of water to neutralize acids, a property imparted by the water's content of carbonate, bicarbonate, hydroxide, and on occasion borate, silicate, and phosphate. It is expressed in milligrams per liter of equivalent calcium carbonate (mg/l $CaCO_3$).

Anaerobic – Living or occurring only in the absence of free oxygen.

Analyte – Parameter being tested.

Anion – Ion having a negative charge; an atom with extra electrons. Atoms of non-metals, in solution, become anions. See conductivity.

Anoxia – A condition when the water becomes totally depleted of oxygen (below 0.5 mg/l) and results in the death of any organism that requires oxygen for survival. The adjective is anoxic.

Anthropogenic – Coming from human activities, e.g., human sources of pollutants and other impacts on natural environments.

Atmospheric deposition – The process whereby air pollutants are deposited on land and water, sometimes at great distances from their original sources. Pollution deposited in snow, fog, or rain is called wet deposition, while the deposition of pollutants as dry particles or gases is called dry deposition. Air pollution can be deposited into waterbodies either directly from the air or through indirect deposition, where the pollutants settle on the land and are then carried into a waterbody by runoff.

Atomic absorption – Quantitative chemical method used for the analysis of elemental constituents.

Autoclave – An oven-like vessel used for sterilization of equipment, carrying out chemical reactions, etc., at high temperature and pressure.

BMP – See best management practices.

BOD – See biochemical oxygen demand.

Bacteria – Any of numerous unicellular microorganisms of the class Schizomycetes, occurring in a wide variety of forms, existing either as free-living organisms or parasites, and having a wide range of biochemical, often pathogenic properties. Some bacteria are capable of causing human, animal or plant diseases; others are essential in pollution control because they breakdown organic matter in air and water.

Bacterial examination – The examination of water and wastewater to determine the presence, number, and identification of bacteria. Also called bacterial analysis.

Ballast water – Water taken on vessels to keep them stable at sea. Ballast water can contain aquatic plants, animals, and pathogens that can be introduced to an estuary when it is discharged near ports.

Base – Any substance that contains hydroxyl (OH^-) groups and furnishes hydroxide ions in solution. A molecular or ionic substance capable of combining with a proton to form a new substance; a substance that provides a pair of electrons for a covalent bond with an acid; a solution with a pH of greater than 7.0. Also see pH.

Baseline data – Initial data generated by consistent monitoring of the same sites over time.

Benthic – Pertaining to the bottom (bed) of a waterbody.

Best Management Practices (BMPs) – Pollution control techniques that aim to reduce pollution from agriculture, timber harvesting, construction, marinas, stormwater and other sources.

Bioassay (biological assay) – A controlled experiment using a change in biological activity as a qualitative or quantitative means of analyzing a biological response to a pollutant by using viable organisms. Depending on the test, microorganisms, planktonic animals, or live fish can be used as test organisms to determine the effects a toxic substance has on living organisms.

Biochemical oxygen demand (BOD) – The amount of oxygen taken up by microorganisms that decompose organic waste matter in water.

Biocides – Chemical agents with the capacity to kill biological life forms. Bactericides, insecticides, herbicides, pesticides, etc. are examples.

Biodegradability – The susceptibility of a substance to decomposition by the actions of microorganisms.

Biological accumulation (bioaccumulation) – The uptake and storage of chemicals (e.g., DDT, PCBs) from the environment by animals and plants. Uptake can occur through feeding or direct absorption from water or sediments. The concentration of a substance in the tissue of an individual organism.

Biological magnification (also called bioamplification or bioconcentration) – The progressive increase in the concentration of chemical contaminants (e.g., DDT, PCBs, methyl mercury) from the bottom of the food chain (e.g., bacteria, phytoplankton, zooplankton) to the top of the food chain (e.g., fishing-eating birds such as a cormorant).

Biomass – The amount of living matter in a given habitat or the total mass of a particular species or groups of species in a specified area.

Biomonitoring – The use of living organisms to evaluate the anthropogenic, or human-induced, impacts on biota.

Bioturbation – Disturbance of sediment by animals.

Bloom – A dramatic increase in the number and volume of planktonic species as a result of favorable environmental conditions (e.g., temperature, nutrient availability, etc.). See algal bloom.

Brackish – Having a salinity between that of fresh and marine water.

Buffer – A substance dissolved in water that resists changes in pH (minimizes changes in hydrogen ion concentration).

Buret – A graduated glass tube used for measuring and releasing small and precise amounts of liquid.

Calibration – The checking, adjusting, or systematic standardizing of the graduations of a quantitative measuring instrument.

Carcinogen – A substance that causes cancer.

Cation – A positively charged atom or group of atoms, or a radical which moves to the negative pole (cathode) during electrolysis. See conductivity.

Chlorinated hydrocarbons – Compounds such as DDT and PCBs made of carbon, hydrogen, and chlorine atoms. Once released into the environment, these chemicals become biologically amplified as they move up the food chain; that is, as minnows eat zooplankton, larger fish eat minnows, and seabirds eat the larger fish, the concentration of these chemicals in tissues is greatly increased.

Chlorophyll – A group of green pigments found in most plants, including phytoplankton, which are used for photosynthesis. The chlorophyll a pigment is generally measured.

Chronic toxicity – Also referred to as sub-lethal. Does not result in death (at exposures of at least 96 hours) but can cause impairment to aquatic animals, organ damage and failure, gastro-intestinal damage, and can affect growth and reproduction.

Coliform bacteria – Any of several bacilli, especially of the genera *Escherichia*, found in the intestines of animals. Their presence in water suggests contamination with sewage of feces, which in turn could mean that disease-causing bacteria or viruses are present. Fecal coliform bacteria are used to indicate possible sewage contamination. Fecal coliform bacteria are not harmful themselves, but indicate the possible presence of disease-causing bacteria, viruses, and protozoans that live in human and animal digestive systems. In addition to the possible health risks associated with them, the bacteria

can also cause cloudy water, unpleasant odors, and increased biochemical oxygen demand.

Combined sewer – Sewer system that carries both sanitary wastes and storm runoff to a wastewater treatment plant to be treated and released to a body of water.

Combined sewer overflow (CSO) – If a wastewater treatment plant does not have the capacity to treat the increased volume caused by stormwater runoff, the combined sewer may discharge untreated sewage and stormwater directly into a body of water.

Comparability – The extent to which data from one study can be compared directly to either past data from the current project or data from another study. Using standardized sampling and analytical methods, units of reporting, and site selection procedures help ensure comparability.

Completeness – A measure of the number of samples you must take to be able to use the information, as compared to the number of samples you originally planned to take.

Compound – Two or more elements combined; a substance having properties different from those of its separate elements.

Concentrated – Being of full strength or undiluted.

Conductivity – A measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). As the concentration of salts in the water increases, electrical conductivity rises; the greater the salinity, the higher the conductivity. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is extrapolated to a standard temperature (25°C).

Contamination – A general term signifying the impairment of water, sediments, plants or animals by chemicals or bacteria to such a degree that it creates a hazard to public and/or environmental health through poisoning, biomagnification, or the spread of disease.

DDT – Dichlorodiphenyltrichloroethane. A chlorinated hydrocarbon widely used as a pesticide in the United States until its use was banned in the United States in 1972. Toxic to humans and wildlife when swallowed or absorbed through the skin.

DO – See dissolved oxygen.

DQOs – See data quality objectives.

Data Quality Objectives (DQOs) – Statements that define quantitative and qualitative information required by the data users to meet program needs.

Deionized water – Water with all ions removed.

Denitrification – The process whereby bacteria convert nitrate to nitrite and then to nitrogen gas.

Detection limit – The lowest concentration of a given pollutant that an analytical method or equipment can detect and still report as greater than zero. Generally, as readings approach the detection limit (i.e., as they go from higher, easier-to-detect concentrations to lower, harder-to-detect concentrations), they become less and less reliable.

Detritus – Small particles of dead and decomposing organic matter, including twigs, leaves and other plant and animal wastes.

Digital titrator – A titrator unit having a counter that displays numbers. As the reagent is dispensed, the counter changes in proportion to the amount of reagent used.

Dilute – To thin out, or having been thinned out; less than full strength.

Dinoflagellate – A dominant planktonic form occurring as a microscopic single cell. Often has two flagella to assist with movement.

Dioxin – A family of some 210 synthetic, organic chemicals of the chlorinated hydrocarbon class. Some dioxins are known to be highly toxic and are thought to increase the incidence of cancer and birth defects in humans.

Dissolved oxygen (DO) – Oxygen molecules that are dissolved in water and available for living organisms to use for respiration. Usually expressed in milligrams per liter or percent of saturation. The concentration of DO is an important environmental parameter contributing to water quality.

Dissolved solids – The total amount of dissolved material, organic and inorganic, contained in water or wastewater. Measurements are expressed as ppm or mg/l.

Distilled water – Water that has been purified by distillation (boiling the water off as steam and condensing it back to a liquid, leaving the impurities behind). Having been boiled, the water is also sterile.

Dry deposition – See atmospheric deposition.

Ecosystem – A community of species interacting with each other and with the physical (nonliving) environment.

Effluent – A discharge to a body of water from a defined or point source, generally consisting of a mixture of waste and water from industrial or municipal facilities.

Emergent Plants – Plants rooted under water, but with their tops extending above the water.

Endpoint – That stage in titration at which an effect, such as a color change, occurs, indicating that a desired point in the titration has been reached.

Endocrine disrupters – chemicals that can mimic, block, or otherwise disrupt human hormones.

Enrichment – The addition of nitrogen, phosphorous, carbonaceous compounds, or other nutrients into a waterway that greatly increase the growth potential for algae and other aquatic plants.

Entanglement – To become tangled in or ensnared. A common cause of death for marine animals is entanglement by marine debris. Animals can become caught in discarded fishing nets, monofilament line, and other gear, rope, six-pack rings, balloon ribbons, plastic grocery bags, and other floating debris.

Enterococci – A group of bacteria found primarily in the intestinal tract of warm-blooded animals. Enterococci are unrelated to the coliforms; rather, they are a subgroup of the fecal streptococci group.

Environment – All the factors that act upon an organism or community of organisms, including climate, soil, water, chemicals, radiation, and other living things.

Environmental Protection Agency (EPA) – A federal agency, established in 1970, concerned with air and water quality, radiation, pesticides, and solid-waste disposal. It is responsible for enforcing most federal environmental laws and for administering the National Estuary Program (NEP).

Epiphyte – A plant that grows upon another plant, but is not parasitic. On aquatic plants, excessive epiphytes can decrease the amount of sunlight reaching the host plant.

Erosion – The process where wind, water, ice, and other mechanical and chemical forces wear away rocks and soil, breaking up particles and moving them from one place to another.

***Escherichia coli* –** A single species within the fecal coliforms group. Commonly used as indicator bacteria. Occurs only in the feces of warm-blooded mammals

Estuary – A semi-enclosed coastal body of water which has free connection with the open sea and within which seawater is measurably diluted with fresh water derived from land drainage. Estuaries are transition zones between fresh water and the salt water of an ocean.

Eutrophic – Highly productive condition, generally the result of nutrient enrichment in the water column that may cause algae (e.g., phytoplankton) to bloom.

Eutrophication – A condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae (e.g., phytoplankton). Algal decomposition may lower dissolved oxygen concentrations. Although eutrophication is a natural process in the aging of lakes and some estuaries, it can be accelerated by both point and nonpoint sources of nutrients.

Fecal coliforms – See coliform bacteria.

Filter feeders – Animals (e.g., clams and oysters) that feed by filtering out of the water column small food items such as detritus, phytoplankton, and zooplankton.

Filtration – The process of separating solids from a liquid by means of a porous substance (filter) through which only the liquid can pass.

Fish Consumption Advisory – An advisory issued by government agencies and used to reduce human health risks associated with exposure to chemical contaminants (e.g., PCBs, DDT, mercury) found in fish and shellfish. Advisories may recommend bans and restricted consumption of specific species in specific geographical areas of an estuary.

Fixed sample –A sample that has been rendered chemically stable or unalterable, meaning that atmospheric oxygen will no longer affect the test result.

Flushing rate – The time it takes for all the water in an estuary to be moved out to sea. Flushing rates vary from days to weeks.

Food chain – A sequence of organisms in an ecological community, each of which is food for the next higher organism, from the primary producer to the top consumer.

Food web – A complex system of energy and food transfer between organisms in an ecosystem. Refers to the way that organic matter is transferred from the primary producers (plants) to primary consumers (herbivores), and on up to higher feeding (trophic) levels.

Formalin – A 40% solution of Formaldehyde (CH_2O), which is a preservative, an irritant, and a probable carcinogen. Formalin is used to preserve organisms for later observation.

Fresh water – Water that is not salty. Fresh water enters estuaries from rivers, streams and through precipitation (rain, snow).

Habitat – The place where a population or community (e.g., microorganisms, plants, animals) lives and its surroundings, both living and nonliving.

Habitat disruption – Destruction or alteration of a habitat by cutting across or establishing barriers to migration routes or destroying breeding areas or food sources. Loss of habitat is the primary cause of loss of biodiversity.

Heavy metals – A general term given to the ions of metallic elements such as mercury, copper, zinc, chromium, and aluminum.

Herbicide – A pesticide designed to kill specific plants.

Hydrocarbon – A chemical compound containing only hydrogen and carbon.

Hypoxia – A condition where very low concentrations of dissolved oxygen are in the water column. When the level of dissolved oxygen falls below 3 mg/l, water is considered hypoxic. At this level, many species will move elsewhere and immobile species may die.

Indicator – 1) A compound that changes color under a particular condition or over a particular range of conditions. 2) An organism whose presence suggests the presence of other organisms. See coliform bacteria. 3) A measurement of environmental conditions or trends in environmental quality which can be used to evaluate resource protection programs and assess the general sate of the environment.

Ingestion – To eat. Some animals die from marine debris when they mistakenly ingest humanmade materials. By consuming these materials, damage can be caused to the animals' digestive systems, or animals may stop eating because their stomachs are full. Because the debris in their stomachs offers no nutritional value, creatures eventually starve to death.

Inorganic – Being or composed of matter that is not organic.

Invertebrates – Animals that lack a spinal column or backbone. Includes molluscs (e.g., clams and oysters), crustaceans (e.g., crabs and shrimp), insects, starfish, jellyfish, sponges, and many types of worms that live in the benthos.

Land use – The way land is developed and used in terms of the kinds of anthropogenic (human) activities that occur (e.g., agriculture, residential areas, industrial areas).

Larva, larvae – An immature form of an organism that will undergo metamorphosis to become a juvenile and then an adult.

mg/l – See milligrams per liter.

MPN – See most probable number.

Macro – A prefix meaning large. Usually refers to organisms large enough to be seen with the un-aided eye.

Macroinvertebrates – Organisms that are large (macro) enough to be seen with the naked eye and lack a backbone (invertebrate).

Marsh or **salt marsh –** A protected intertidal wetland where fresh water and salt water meet. Characterized by plants such as salt hay, black rush, and smooth cordgrass.

Mean (Average) – Using a set of *n* numbers, the sum of the numbers divided by *n*.

Measurement range – The range of reliable measurements of an instrument or measuring device.

Membrane filtration – An analytical method commonly used to identify coliforms in water. A measured amount of water is passed through a membrane filter, trapping bacteria on its surface. The filter is then placed on a pad that has been saturated with a specific medium designed to permit the growth of the organism or organisms being sought. The filter is incubated, and the bacterial colonies which have grown on the filter surface are counted to determine the number of bacteria in the water sample.

Meniscus – The curved upper surface of a non-turbulent liquid in a container; it is concave (curves upward) if it wets the container walls, and convex (curves downward) if it does not. For accurate measurements, readings should be taken at the flat center of the meniscus. The curve of the meniscus is due to surface tension.

Metadata – "Data about data." Information that helps characterize the data that volunteers collect. Metadata answer who, what, when, where, why, and how about every facet of the data being documented. This information helps others understand exactly how the data was obtained.

Metals, toxic – Some fifty of the eighty elemental metals used in industry, many of which (e.g., cadmium, lead, mercury and zinc) are toxic to humans and are primarily absorbed into the body by inhalation or ingestion.

Micro – A prefix meaning one-millionth of a unit.

Microorganisms – Organisms (microbes) observable only through a microscope; larger, visible types are called macroorganisms.

Milligrams per liter (mg/l) – A weight per volume designation used in water and wastewater analysis. Equivalent to parts per million (1 ppm = 1 mg/l).

Molecule – The simplest structural unit of a substance that retains the properties of the substance and is composed of one or more atoms.

Most probable number (MPN) – An analytical method used to detect the presence of coliforms in a water sample and estimate their numbers.

NEP – See National Estuary Program.

NERRS – See National Estuarine Research Reserve System.

National Estuarine Research Reserve System (NERRS) – A federal program administered by the National Oceanic and Atmospheric Administration (NOAA). NERR sites monitor the effects of natural and human activities on estuaries to help identify methods to manage and protect coastal areas.

National Estuary Program – A federal program administered by the EPA that targets a broad range of issues and engages local communities in the process. Each NEP is made up of representatives from federal, state, and local government agencies and members of the community working together to identify problems in the estuary, develop specific actions to address those problems, and create and implement a formal management plan to restore and protect the estuary.

Nephelometer – An instrument that measures scattered light in a liquid.

Nephelometric turbidity unit (NTU) – A standard unit of turbidity measurement.

Neutral – On the pH scale, neither acid nor alkaline. Pure water is neutral, and has a pH of 7.0.

Nitrates – One form of nitrogen that plants can use for growth.

Nitrification – The process whereby some bacteria transform ammonium into nitrite and then to nitrate.

Nitrogen – An essential nutrient for plant and animal development. Too much of this nutrient can cause accelerated plant growth, algae blooms, and increase the amount of material available for decomposition (which lowers dissolved oxygen).

Non-Indigenous Species (NIS) – Species that migrate or are carried by animals and humans into ecosystems outside their normal range of occurrence. These " alien invaders" are known by many names, including alien, non-native,

introduced, nuisance, invasive, and exotic species. Some of these organisms can wreak havoc on any ecosystem—including estuaries—once they become established.

Nonpoint source pollution – Pollution that enters water from sources that cannot be traced to a single point. Generally initiated by stormwater runoff from agricultural, urban, forestry, marina, construction, and other land uses.

Nonsettleable matter – Suspended matter that neither settles nor floats to the surface of water in a period of one hour.

Nutrient – Any of a necessary complement of organic or inorganic elements or compounds that are considered essential to the biological growth of an organism.

Nutrient loading – Delivery of nutrients to a waterbody. An excess of nutrient loads beyond normal levels may lead to a phytoplankton population increase. See algal blooms.

Organic matter – Composed of chemical compounds based on carbon chains or rings, and also containing hydrogen with or without oxygen, nitrogen, or other compounds.

Orthophosphate – An acid or salt containing phosphorus as PO_4, such as K_3PO_4 (potassium phosphate).

Outliers – Findings that differ radically from past data or other data from similar sites.

Overturn – A process characterized by a breakdown in the stratification of a waterbody (e.g., by changing seasons or storms) and the subsequent mixing of deep water with surface water.

PAHs – See polycyclic aromatic hydrocarbons.

ppm – See parts per million.

ppt – See parts per thousand.

PCBs – See polychlorinated biphenyls.

Parts per million (ppm) – The unit commonly used to represent the degree of pollutant concentration where the concentrations are small. Larger concentrations are given in percentages. Equivalent to milligrams per liter (mg/l) where 1 ppm = 1 mg/l; in water, ppm represents a weight/volume ratio.

Patchiness – Refers to the uneven spatial distribution of organisms. Plankton tend to exhibit patchiness in the water column, grouping together in " patches."

Pathogen – An organism (such as a bacterium or virus) that can cause a disease.

Percent saturation – Amount of oxygen in the water compared to the maximum it could hold at that temperature.

pH – A measure of the alkalinity or acidity of a substance. Also defined as " the negative logarithm of the hydrogen ion concentration ($-\log10[H^+]$)" where H^+ is the hydrogen ion concentration in moles per liter. The pH of a substance is neutral at 7.0, acidic below 7.0, and alkaline above 7.0.

Phosphorus – An essential nutrient for plant and animal development. However, too much of this nutrient can cause accelerated plant growth, algae blooms, and increase the amount of material available for decomposition (which lowers dissolved oxygen).

Photosynthesis – Process by which chlorophyll-containing cells in green plants convert incident light to chemical energy and synthesize organic compounds from inorganic compounds (including carbon dioxide and water).

Phytoplankton – Microscopic plants that are common components of our natural waters. These plants are microalgae, and contain an

assortment of pigments in their cells. They are represented by single cell or colonial forms that are the primary food and oxygen producers within freshwater, estuarine, and marine habitats. Through the process of photosynthesis they utilize the sun's energy to reproduce and provide the food resources necessary to support other organisms.

Plankton – A broad group of aquatic microorganisms that form the basis of the food chain. They are incapable of moving against water currents. Included in this group are bacterioplankton (bacteria), phytoplankton (plants), and zooplankton (animals).

Point source pollution – Pollution discharged into a waterbody from any discrete pipe or other conveyance. Easier to identify, and often less expensive to cleanup than nonpoint sources of water pollution.

Polychlorinated biphenyls (PCBs) – Group of more than two hundred chlorinated toxic hydrocarbon compounds that can be amplified, that is, spread and increased, in food chains and webs.

Polycyclic aromatic hydrocarbons (PAHs) – A class of chemical compounds composed of fused six-carbon rings. PAHs are commonly found in petroleum oils (e.g., gasoline and fuel oils) and are emitted from various combustion processes (e.g., automobile exhausts, coal-burning operations).

Precipitant – A chemical or chemicals that cause a precipitate to form when added to a solution.

Precipitate – The discrete particles of material separate from a liquid solution.

Precision – The degree of agreement among repeated measurements of the same parameter on the same sample or on separate samples collected as close as possible in time and place. It tells you how consistent and reproducible your methods are by showing you how close your measurements are to each other. Typically, precision is monitored through the use of replicate samples or measurements.

Presence-absence test (P-A test) – A method commonly used to determine whether the target organism or organisms (for example, total coliforms or *E. coli*) are present in a water sample or not.

Protozoans – Any of a number of one-celled, usually microscopic animals, belonging to the lowest division of the animal kingdom.

QA/QC – See quality assurance/quality control.

Quality assurance project plan (QAPP) – A written plan which details monitoring objectives, scope of the program, methods, procedures (field and lab), and the activities necessary to meet stated data quality objectives.

Quality assurance/quality control (QA/QC) – The total integrated program for assuring reliability of monitoring and measurement data.

Reagent – A chemical substance used to cause a reaction for the purpose of chemical analysis.

Replicate samples – Two or more samples taken from the same place at the same time.

Representativeness – The extent to which measurements actually depict the true environmental condition or population you are evaluating.

Risk management – To control issues that can cause physical or financial injury or damage. Risk management programs include plans to reduce risk and liability by stressing safety with volunteers, purchasing insurance, and using waivers.

Runoff – Water from rain, melted snow or agricultural or landscape irrigation that flows over the land surface.

SAV – See submerged aquatic vegetation.

Salinity – A measure of the amount of salts dissolved in water. Generally reported as " parts per thousand" (i.e., grams of salt per 1,000 grams of water) and abbreviated as "ppt" or ‰. Estuaries vary in salinity from 0 ppt to 34 ppt depending on the relative input of fresh and marine water.

Salt – Any compound formed by combination of any negative ion (except hydroxide) with any positive ion (except hydrogen or hydronium); the precipitate produced as the result of neutralization of an acid with a base.

Seagrass – In marine environments, rooted vascular plants that generally grow up to the water surface but not above it. See submerged aquatic vegetation.

Secchi depth – The depth beneath the water's surface at which a Secchi disk can no longer be seen.

Secchi disk – A round, eight-inch (20 cm), weighted, usually black and white disk that is lowered by rope into the water. Secchi disks are used to measure transparency, which is an integrated measure of light scattering and absorption.

Sediment – Mud, sand, silt, clay, shell debris, and other particles that settle on the bottom of waterways.

Sedimentation – The deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material. Also called settling.

Sensitivity – The capability of a method or instrument to discriminate between measurement responses. The more sensitive a method is, the better able it is to detect lower concentrations of a variable. Sensitivity is related to detection limit, which is the lowest concentration of a given pollutant your methods or equipment can detect and report as greater than zero.

Settleable solids – Particles of debris and fine matter heavy enough to settle out of water.

Sewage – The total of organic waste and wastewater generated by residential and commercial establishments.

Sewage, combined – Wastewater containing both sanitary sewage and surface or stormwater with or without industrial wastes.

Sewage, industrial – Sewage in which industrial wastes predominate.

Sewage, raw – Sewage prior to receiving any treatment.

Shellfish – Any aquatic animal with a shell, as the clam, oyster, mussel, and scallop. The organism feeds by filtering water through its gills and removing food materials.

Solution – A liquid (solvent) that contains a dissolved substance (solute).

Species, alien, invasive or introduced – See non-indigenous species.

Species – 1) A single, distinct kind of organism, having certain distinguishing characteristics. Organisms forming a natural population that transmit specific characteristics from parent to offspring. 2) Chemical forms. For example, nitrogen comes in many different chemical forms, including nitrite (NO_2^-) and nitrate (NO_3^-).

Specific gravity – Also called relative density. The ratio of the density of a substance to the density of some reference substance. Hydrometers use this principle to determine salinity of a water sample, compared to fresh water.

Standard (or **standardized solution) –** A solution containing a known, precise concentration of an element or chemical compound, often used to calibrate water quality monitoring equipment.

Standard deviation – A statistical measure of the dispersion of data.

STORET – (Store-Retrieve) A data storage system operated by EPA that stores raw data on water quality, bacteriological, biological, and other parameters. Using the data, one can create reports for a given site and compare one watershed with another.

Stratification – The formation, accumulation, or deposition of material in layers, such as layers of fresh water overlying salt water in estuaries.

Submerged Aquatic Vegetation (SAV) – Aquatic plants that generally include rooted vascular plants that grow up to the water surface but not above it (although a few species have flowers or tufts that may stick a few centimeters above the surface). The definition of SAV usually excludes algae, floating plants, and plants that grow above the water surface. Sometimes called seagrass in marine environments.

Suspended Sediments – Particles of soil, sediment, living material, or detritus suspended in the water column.

Temperature – A measure of the hotness or coldness of anything, as usually determined by a thermometer. Temperature is a determining factor for biological and chemical processes.

Tide – The alternating rise and fall of the ocean and estuary surface, caused by the gravitational pull of the sun and the moon upon the earth.

Titration – A method of analyzing the composition of a solution by adding known amounts of a standardized solution until a given reaction (color change, precipitation, or conductivity change) is produced.

Titrator – Instrument that forcefully expels a reagent by using a manual or mechanical plunger. The amount of reagent used is calculated by subtracting the original volume in the titrator from the volume left after the endpoint has been reached.

Total coliforms – A group of closely related bacterial genera that all share a useful diagnostic feature: the ability to metabolize (ferment) the sugar lactose, producing both acid and gas as byproducts.

Toxic waste – Discarded material that is capable of causing serious injury, illness, or death. Toxins can be poisonous, carcinogenic, or otherwise harmful to living things.

Transparency – An integrated measure of light scattering and absorption. Secchi disks are commonly used to measure transparency of water.

Turbidimeter – An instrument for measuring turbidity in which a standard suspension is used for reference.

Turbidity – A measure of how clear the water is; how much the suspended material in water results in the scattering and absorption of light rays. An analytical quantity is usually reported in turbidity units and determined by measurements of light diffraction. Material that can increase the turbidity (reduce clarity of water) are suspended clay, silt, sand, algae, plankton, microbes, and other substances.

Volume – The space occupied in three dimensions.

Voucher collection – A preserved archive of organisms that have been collected and identified. In addition to preserved specimens, the collection may involve photography or microscopy.

Water clarity – Measurement of how far an observer can see through water. The greater the water clarity, the further you can see through the water.

Water column – The water between the surface and the bottom of a river, lake, estuary, or ocean.

Water quality parameters – Any of the measurable qualities or contents of water. Includes temperature, salinity, turbidity, nutrients, dissolved oxygen, and others.

Watershed – The entire area of land whose runoff of water, sediments, and dissolved materials (e.g., nutrients, contaminants) drain into a river, lake, estuary, or ocean.

Wet deposition – See atmospheric deposition.

Wetlands – Lands that are often transitional areas between terrestrial and aquatic systems, with enough surface or groundwater to support a complex chain of life, including microorganisms, vegetation, reptiles, fish, and amphibians. Wetlands usually border larger bodies of water such as rivers, lakes, bays, estuaries and the open sea, and may serve as breeding grounds for many species. Examples include swamps, marshes, and bogs.

Whirl-pak bag – Sterilized, clear polyethylene bags used to collect water samples for analysis.

Wrack – Line of seaweed and organic material that can be seen when the high tide recedes.

Zooplankton – Aquatic microorganisms that are free floating or capable of minimal movement. Zooplankton feed primarily on phytoplankton and bacteria, are can be either adult microorganisms, or larval forms of fish or shellfish.

Index

Photos (l to r): The Ocean Conservancy, L. Monk, The Ocean Conservancy, K. Register

Index

A

B

C

D

E

F

G

H

I

K

L

M

N

O

P

Q

R

S

T

U

V

W

Z