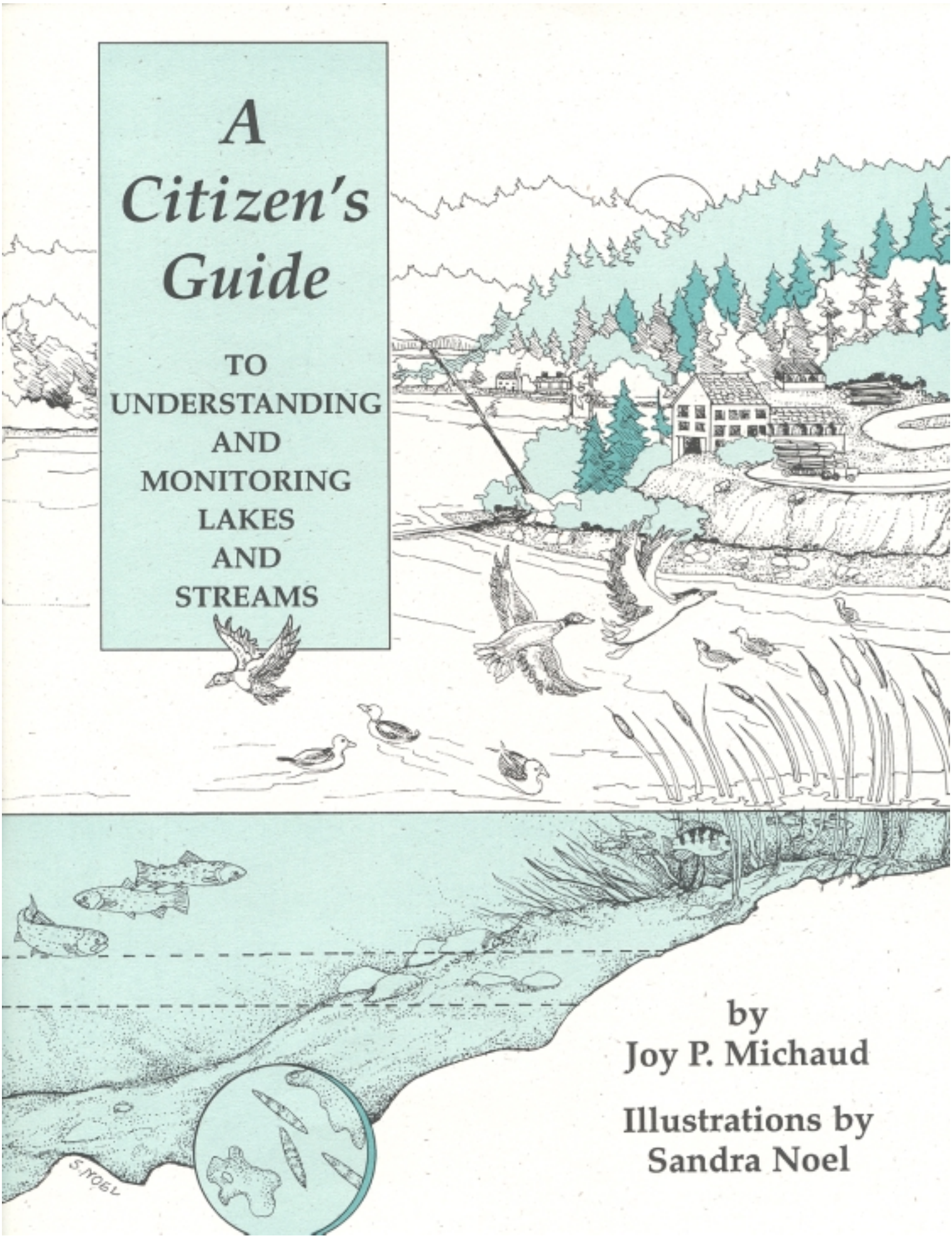
A Citizen's Guide

TO UNDERSTANDING AND MONITORING LAKES AND STREAMS



by
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to Understanding and Monitoring Lakes and -Streams

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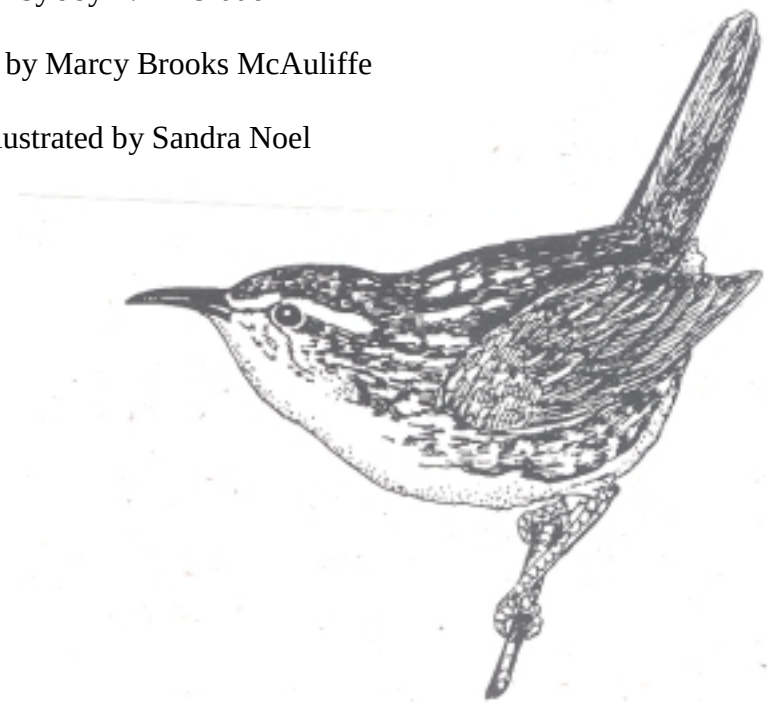

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A Word from the Author

When I first decided to take up the study of fresh waters, I envisioned spending hours along the banks of scenic, gurgling brooks and north country lakes. Imagine now my first sampling event. A cheese factor's waste system had failed and a huge quantity of waste had been released to a small creek. Our mission was to walk the length of the creek collecting dead fish carcasses, which we placed into large plastic bags and carried over our backs. Every half-mile we stopped to collect a water sample. The creek bottom and any protruding sticks or rocks were covered with long, gray strands of algae. The water itself was a milky-gray. It was a still, hot summer day and the odor of rotting fish in combination with the algae added a quite unpleasant aspect to the occasion.

Since that day I've been on sampling expeditions to numerous lakes and streams. Yet, these many years later I still distinctly remember Scotch Creek. I remember its many curves, its few pools, and a particularly nice section where it flowed through a meadow and had neat, undercut, grassy banks perfectly designed for the needs and whims of brook trout.

The point is, no matter how many lakes or streams I sample or how spoiled their condition, I maintain a personal interest in each. Each had its own character and left a separate impression on my memory. This is one of the great untold benefits of monitoring - it is not an experience that should be saved for a select few professionals.

Don't be put off by those of us who know the technical jargon and make it all sound incredibly complex and overwhelming. And don't be frustrated by other people's views of the value of your efforts. Lakes and streams belong to all of us, and we are all equally responsible for their protection.

Acknowledgements

Ibis work was funded through a Public Information and Education (PIE) grant from the Puget Sound Water Quality Authority. That really means the work - was funded through our tax dollars. Before that could happen, the citizens of Puget Sound had to be dedicated enough to protecting water quality to pay the price. Chances are if you are interested enough in water quality to pick up this guide and read this acknowledgement, you are likely one of those who has supported water quality protection efforts. And you deserve acknowledgement for this effort.

A number of people volunteered their time and expertise to review the first draft of this guide. These people provided excellent comments and ideas within a demanding time schedule. These people were: Jean Jacoby, a stream and lake ecologist employed by KCM consultants; Dave Hallock and Joe Joy, Water Quality Specialists with the Washington Department of Ecology; Emily Garlich a school teacher with the City of Shelton; and Ellen Gray with the Snohomish County Council and the Pilchuck Audubon Society.

Claire Dyckman, formerly with the Puget Sound Water Quality Authority, was the catalyst who recognized the need for a guide such as this and encouraged its funding.

Sandy Marvinney produced the layout using desktop publishing software. She and Sandra Noel, the graphic artist and designer, worked together to produce a handsome, readable document out of the paper scraps and floppy disks sent to them. They worked hard and long to create this document within a short time and still managed the last minute changes with their usual calm and proficiency. Marcy McAuliffe provided ideas and creative suggestions in addition to rewriting sentences and paragraphs, correcting punctuation errors and all the other tasks of a technical editor.

Last, thanks to -Sally, Jack, and Jean who listened to me, commiserated with me, and encouraged me on the many occasions when either one or all three were necessary.

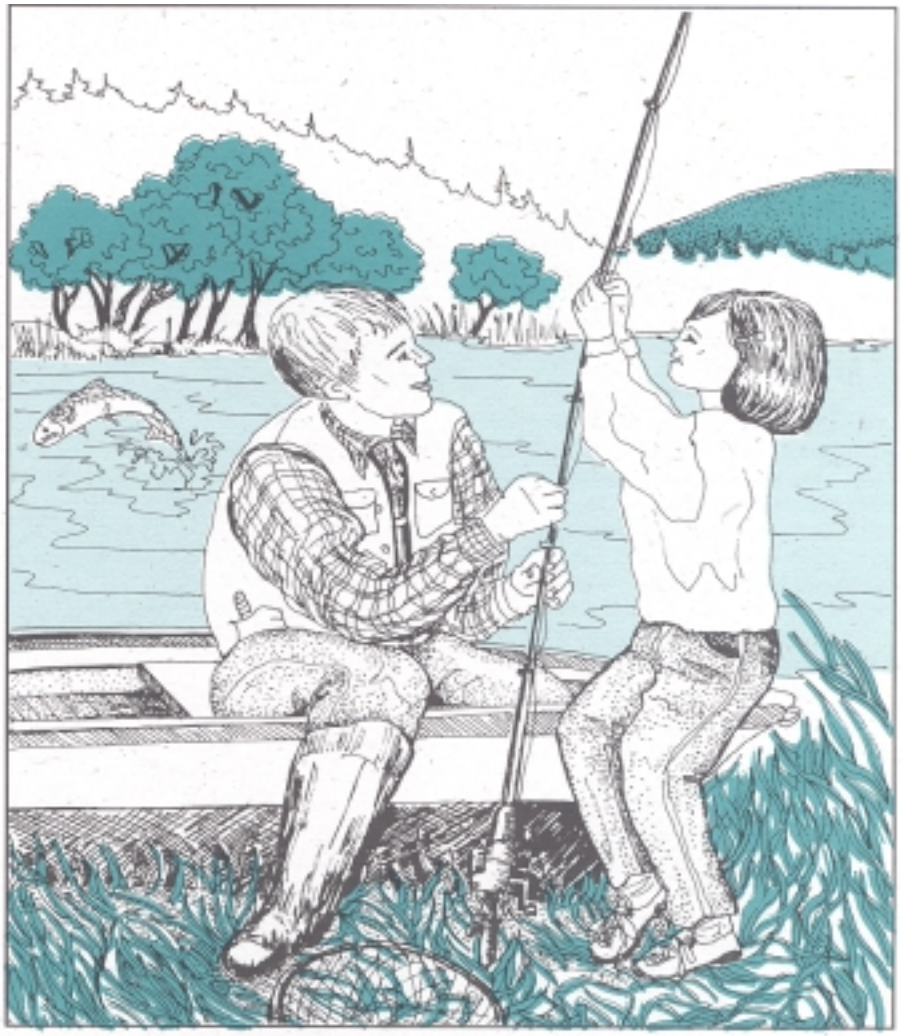
Introduction

The intent of this guide is to introduce citizens in the Puget Sound area to lake and stream water quality monitoring. The first chapter provides background information on who does monitoring in the Puget Sound region and why, and then describes some of the advantages and pitfalls of citizen monitoring. Because lakes and streams are very different systems, and because most readers will be interested in monitoring one or the other, each is described separately; Chapter Two covers lakes, Chapter Three covers streams. Each of these chapters contains an introduction to lake or stream ecology then describes different water quality measurements and why they are important. Chapter Four provides the necessary practical information on how to collect the samples and make the water quality measurements, or at least prepare the samples for later analysis. The last chapter describes how to take stream flow measurements, which can be an important part of both lake and stream studies.

As with all introductions to very complex subjects, one of the most difficult aspects of producing this guide was deciding how much information was enough and how much was too much. For each topic discussed, some compromise had to be reached. Some readers will find the guide too detailed and others not detailed enough. Furthermore, by necessity the guide contains many generalizations that by their very nature must then be wrong or inaccurate some of the time. Still, it is a good start. If you find the information is too detailed in places, skip over it. If you need more information, refer to the resources and references list included at the end of this guide.

Chapter One

Who Cares About Monitoring?



Is there a lake or stream that is especially important to you? Perhaps one near your home, or where you played as a child. Do you wonder whether it is being properly protected against pollution? Have you noticed any changes in it and wondered whether they were a sign of pollution? Are you concerned about water pollution, yet feel you don't understand enough about it to help? Having a clean, dependable water supply is important to almost every aspect of our lives, yet often we feel as though there is little we can do to help protect this essential resource. There are things *you* can do -- one is to become involved in a local volunteer monitoring program.

Before describing how lakes and streams work - which is integral to understanding how, where, when, and what to monitor - it will help to understand the different types of monitoring programs and know about who is doing what in terms of water quality monitoring in the Puget Sound area.

Water quality monitoring can take on many forms. The traditional method of water quality monitoring, where water samples are collected and analyzed, is the most common. There are other methods for assessing water quality. There is a type of visual monitoring, where people follow the shoreline and note such things as the condition of the bank, presence of shoreline vegetation, composition of the stream or lake bottom, and other physical characteristics that can be used to predict possible water quality problems. An increasingly popular method involves recording the abundance and diversity of insects and other organisms. Since these organisms each have different levels of tolerance to pollution, the number and type present can tell a great deal about the quality of the water. These two methods are indirect, or qualitative, ways of assessing water quality. They provide valuable information, are less costly than the traditional method, and can be easily suited to citizen monitoring programs. Although this guide describes the traditional method of water quality monitoring, much of the information presented is geared toward understanding how lakes and streams function. This information will be beneficial no matter what type of monitoring program is undertaken.

Different Monitoring Strategies

Some of the terms you may hear to describe traditional water quality monitoring program are reconnaissance surveys, baseline surveys, routine investigations, intensive surveys, ambient monitoring, and compliance monitoring. Each survey type reflects different objectives on the part of the investigator. A few of the major categories are described here to provide a general understanding of how they may differ.

Ambient Monitoring

The purpose of an ambient monitoring program is to describe existing conditions or long-term trends in water quality. Many water quality parameters are influenced by the change of seasons or by short-term weather patterns. In order to distinguish between short-term "blips" in the data and actual water quality trends, the parameters need to be measured at consistent intervals over a long period of time. Consequently, an ambient monitoring program usually will involve the monitoring of a few parameters on a routine basis (every 2 weeks or monthly) over a number of years. This type of monitoring lends itself well to citizen monitoring efforts. Citizens are permanently on hand, often have easy access to the monitoring sites, and are knowledgeable about the project area.

Baseline Monitoring

The purpose of baseline monitoring, as you may have guessed, is to describe baseline conditions in a lake or stream. Baseline conditions are those which exist before some event that affects water quality occurs, such as development in the watershed or addition of an industrial discharge. Comparing data collected before and after an event is one way of assessing its impact on water quality.

It is a fact of human nature that very little monitoring occurs in water bodies before there has been disturbance of some kind. Of course, another fact of life is that as the population continues to grow, our lakes and streams will be further affected. A baseline study on an already polluted stream still provides information; in 10 years, you can see whether the stream is more polluted or -- because of citizen involvement and watershed protection efforts -- less polluted.

Good baseline information is scarce, so there is ample opportunity for citizens to initiate monitoring programs of this type. If your local lake or stream appears to be in good shape, now might be the best time to begin a baseline monitoring program.

Compliance Monitoring

Monitoring designed to assess whether specific standards or requirements are being met is called compliance or regulatory monitoring. All of the surface waters in Washington State have been classified by the Department of Ecology as Class AA, A, B, or C. Each of these classes has a different set of water quality standards. Monitoring surface waters to determine whether they meet their assigned standards is considered compliance monitoring.

NOTE: Although the purpose of an ambient monitoring program may be to look for long-term water quality trends, the data can be reviewed at any time to determine whether the water body meets its designated class standards, and so could also be considered compliance monitoring.

Compliance monitoring is more commonly used in reference to permit investigations. All industrial or municipal discharges to waters of the state must meet specific standards as defined in their National Pollutant Discharge Elimination System (NPDES) permits. The dischargers themselves must monitor their own effluents to ensure they are meeting their permit requirements. In Washington State, the Department of Ecology also is required to perform periodic monitoring of the same discharges to ensure permit requirements are met. Due to the legal aspects associated with this type of monitoring, such as potential fines and lawsuits, compliance monitoring is not well suited for citizen monitoring.

Who Monitors What in Puget Sound

Many people wrongly believe that someone somewhere knows about their particular lake or stream, and is watching out for it. This is not the case. Most lakes and streams are not monitored on any regular basis, if at all. There is ample opportunity and need for citizens to choose a local target and begin their own programs -- with or without the involvement of an agency or organization. Some of the agency programs are described here to provide an idea of the diversity and extent of water quality monitoring in Washington State.

Puget Sound Water Quality Authority

The Puget Sound Water Quality Authority is responsible for implementation of the Puget Sound Ambient Monitoring Program (PSAMP). This program consists of collection of data on sediments, biological populations (e.g., fish and marine mammals), and habitats in addition to water quality type data. Monitoring by citizens is a required element of the PSAMP program and is supported through the Public Involvement and Education (PIE) Fund.

Washington Department of Ecology

The Department of Ecology's primary responsibility is to protect the waters of the State of Washington. Consequently, this agency does most of the water quality monitoring in the State. Its surface water sampling programs are described below.

- **Ambient Monitoring Program:** This is a long-term program of year-round monitoring. Stations are primarily located at the mouths of major rivers throughout Washington and at a number of key locations in Puget Sound and in a few coastal bays. Currently, 80 freshwater and 35 marine water stations are monitored.

- **Compliance Monitoring Program:** The purpose of this program is to ensure that permit holders meet their NPDES permit requirements. The emphasis is on direct sampling of the discharge (effluent), but some sampling also is done in the lake, stream, or marine water to which the effluent is discharged. Most discharges are located in developed -- urban or industrial -- sections of larger rivers and streams, consequently, compliance monitoring also is concentrated in these areas.
- **Investigative Studies:** Every year a number of lakes and streams or portions of streams are selected for short-term investigations that may last from one week to one year. These, too, occur primarily in waters where there are suspected problems. Typically 10 to 15 of these investigations occur each year.
- **Lake Monitoring:** Citizen volunteer organizations throughout Washington State monitor their lakes during the summer months. In 1990, Ecology staff collected samples at 25 of these lakes twice between May and September. The samples were analyzed for a wide range of parameters. The lake program also includes monitoring of 11 lakes in the Cascade mountain range that are sensitive to acid rain.

With the exception of the lakes program, the Department of Ecology itself does not utilize citizen volunteers in many of its efforts. However, the department provides the major source of funding to local governments and others who promote the use of citizen volunteers.

Washington Department of Health

The Department of Health (previously Department of Social and Health Services, DSHS) is responsible for monitoring bays and inlets in Puget Sound where shellfish are collected for commercial or private use. Shellfish harvesting is allowed only in waters that meet stringent federal water quality standards. It is the agency's responsibility to enforce these standards.

Another component of the sampling program is monitoring the occurrence of paralytic shellfish poisoning (PSP). This requires analysis of shellfish tissue. Citizen volunteers are assisting in this monitoring program by collecting shellfish samples from beaches throughout Puget Sound.

Local Government

Local governments have become increasingly involved in water quality monitoring efforts. Some local governments have extensive programs that have been in existence for years, while others have smaller, newer programs. Program size is somewhat related to population size, but also is influenced by availability of funding, the sources of pollution of most concern, and the priorities of local communities and elected officials. Consequently, there is a wide diversity in the monitoring programs and the degree to which citizens are involved.

Tribes

Most of the Puget Sound Tribes are intensively involved in water quality issues. This involvement often entails some monitoring efforts. As is the case with local governments, the extent of water quality monitoring varies a good deal between tribes, as does the use of citizen volunteers.

Watershed Management Plans

Development of watershed management plans is one of the requirements for implementation of the Puget Sound Water Quality Authority's Puget Sound Plan. The watershed plans are formulated by a committee of local residents for protection of their watershed. The idea is that by involving local residents the plans will have local support, will be tailored to the particular watershed, and will be more likely to offer realistic solutions to problems. Further, by participating in the planning process, a group of residents will become highly informed about water quality issues. Each of the plans must include a strategy for water quality monitoring. Many of the plans developed to date describe monitoring programs that use citizen volunteers. These plans are being implemented through local government, tribes, Conservation Districts, and other organizations through grants from the Department of Ecology. Becoming a member of one of these Watershed Management Committees is one of the best existing means to become involved in local issues.

Schools

An increasing number of elementary, junior, and senior high schools include environmental studies in their curriculum, and many of these programs cover water quality monitoring. Monitoring sites are often located close to the schools; monitoring may occur as a one-time event each school year, or may be done throughout the school year. Besides being educational, the information collected can be useful, especially if the same site is selected and monitored year after year.

Environmental Organizations and Citizen Protection Groups

Environmental organizations such as the National Audubon Society and the Sierra Club are becoming increasingly involved in water quality monitoring. Their local chapters provide a good network for promoting citizen involvement projects such as volunteer water quality monitoring programs. Many citizen groups also have formed to protect select areas. Some local examples include Citizens to Save Puget Sound, Friends of the Snohomish Delta, and Save Lake Sammamish. Many of these organizations and groups may not currently be involved in any monitoring projects, but provide an excellent launching point for such projects.

The Advantages of Citizen Monitoring

The most tangible benefits of citizen monitoring relate to convenience and expense. Sampling programs are always expensive. Costs are incurred during sample collection, analysis, and data interpretation. Although some citizen monitoring programs involve all three tasks, most focus on sample collection. Citizens whose homes are adjacent to a lake or stream or within its watershed are available to do routine sampling, to be the daily eyes and ears for the watershed, and to do extra monitoring during periods of concern.

For example, stream or watershed investigations usually are enhanced by storm event information -- that is, data collected while a storm is in progress. Even something as simple as documenting the height of the stream during a storm can be helpful. Since storm events cannot be scheduled ahead of time, it may be difficult for agency staff to obtain these data. Citizens living near the stream are often more able to collect this valuable information.

From a long-range perspective, the advantage of citizen monitoring is that it promotes development of a citizenry that is not only educated about water quality issues but also personally involved and committed. These people become strong advocates for water quality protection programs.

You may find that the greatest benefit is personal satisfaction and enthusiasm. Most of us have childhood memories of a certain lake or stream we played in. Chances are we still place a high personal value on that lake or stream. This same type of personal interest develops when you become involved in monitoring. Once you have muddied your boots in the water, collected a few samples, and taken some notes, the stream is no longer something you drive over on the way to work, and the lake is no longer just a place to fish or ski. They are instead familiar, interesting, complex, and integral parts of your life.

Concerns About Citizen Monitoring

Although citizens have taken on small monitoring roles for a number of years, it was only recently that their involvement became widespread. With this growth has come bigger roles and more intense interest in government actions. In the end, this citizen participation can have nothing but a positive effect on our ability to protect water quality. But in the meantime, a few problems have arisen, mainly concerning differences in expectations between government agencies and citizen monitoring groups.

From an agency perspective, citizen monitoring programs can be a valuable asset to their overall sampling program, a source of unpredictable uncontrollable workload, or both. By its very nature, citizen monitoring produces an active citizenry that is more likely to make phone calls, write letters, and demand action. While this advocacy is one of greatest benefits of citizen monitoring, it also puts responding agencies in a dilemma since they usually do not have the resources to respond immediately to the additional demands. This, in turn, causes frustration and disappointment on the part of the citizens.

A second concern is associated with agency treatment of the data collected by citizens. Unless the data collected by citizens can meet the same standards and were collected and analyzed by the same procedures as those used by the agency, the citizens' data set will be treated differently. As discussed in the following chapters, there is a myriad of procedures for collecting and analyzing samples. The procedure selected is dependent upon sampling objectives, expertise, available equipment, and, of course, money. The procedure used determines the quality of the data collected. If less exacting procedures are used, the resultant data are not bad or useless, just of lesser quality.

An Analogy ...

You may own a dog with many mixed bloodlines -- a mutt. You may claim that he is the world's best dog, the smartest, friendliest, cutest dog ever. And he may be. But, this is a relative comparison. Your dog is the "best" given what you expect and desire in a dog. Someone else may think the "best" dog can only be a purebred with a shelf full of trophies. Both views are right, the problem is that the objectives are different, so different criteria are used. It doesn't matter which criteria are used until the dogs meet. If you mix a mutt with a purebred, you get a mutt -- never a purebred. The same is true for monitoring data. A data set collected using less stringent methods may meet its objectives just as well as a data set collected using the most expensive personnel and equipment available meets its objectives. However, once you have mixed the two data sets, the quality of the resultant set is defined by the set that meets the less stringent standards.

Data sources that are not directly comparable because of differences in procedures cannot be treated equally in scientific investigations.

These concerns can be alleviated by making your monitoring objectives very clear at the onset. What is the purpose of your study? What do you want to know? What do you hope to accomplish? What would you like the final outcome to be?

How will the data be used by you or your group? Will you want to present the data to an agency or decision makers? Who will interpret the data? What are you expecting from agencies or other organizations? What are you expecting from local politicians and decision makers?

The answers to these questions will determine the type of monitoring program you design, the data quality required, the people who need to be involved, and their level of involvement. If your goal has less to do with water quality assessment than with convincing agencies or politicians to make a change, then keep the monitoring simple and concentrate your efforts in the political arena.

Once you have determined your objectives and expectations for the project, be sure everyone involved knows what they are.

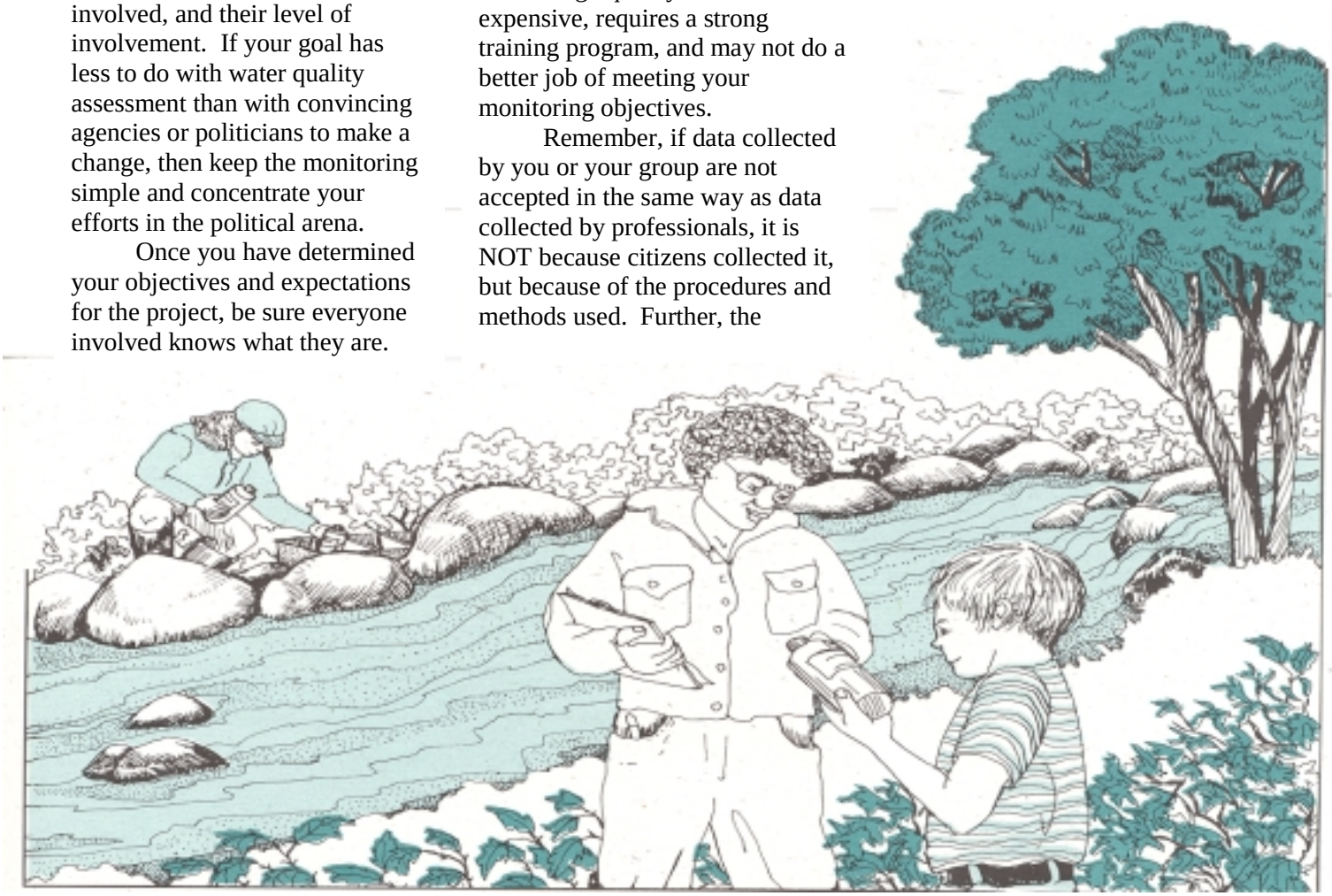
If you are expecting agency involvement or hoping that an agency will at least, look at the data for you (not a small task) then let them know. Ask for their assistance. Be sure the other citizens also understand the objectives. Be prepared to remind everyone frequently of what the objectives are. It's exciting to collect data or discover new problems, but easy to forget that your chosen sampling or analysis procedures place limits on the use of your data.

The Value of Your Efforts

Do not let all this information about data quality, analysis techniques, and agency support deter you. It is provided to help alleviate frustrations and misunderstandings. The point is, citizen volunteers can collect high quality data, but it is expensive, requires a strong training program, and may not do a better job of meeting your monitoring objectives.

Remember, if data collected by you or your group are not accepted in the same way as data collected by professionals, it is NOT because citizens collected it, but because of the procedures and methods used. Further, the acceptance of your data by an agency or organization does not necessarily give it any more credibility. And it certainly doesn't guarantee that the data will be used to make decisions or take actions. It is just as valuable to monitor for the purpose of learning about a stream or lake as it is to monitor for the purpose of identifying problems and demanding change.

Last, the role of citizen monitoring is changing. Throughout the country, citizens are taking on more responsibility for monitoring and protecting their environment. They are biting off bigger and more complex chunks as they see the need for their involvement increase. The role of volunteers is destined to become an increasingly valuable component of future environmental monitoring projects.

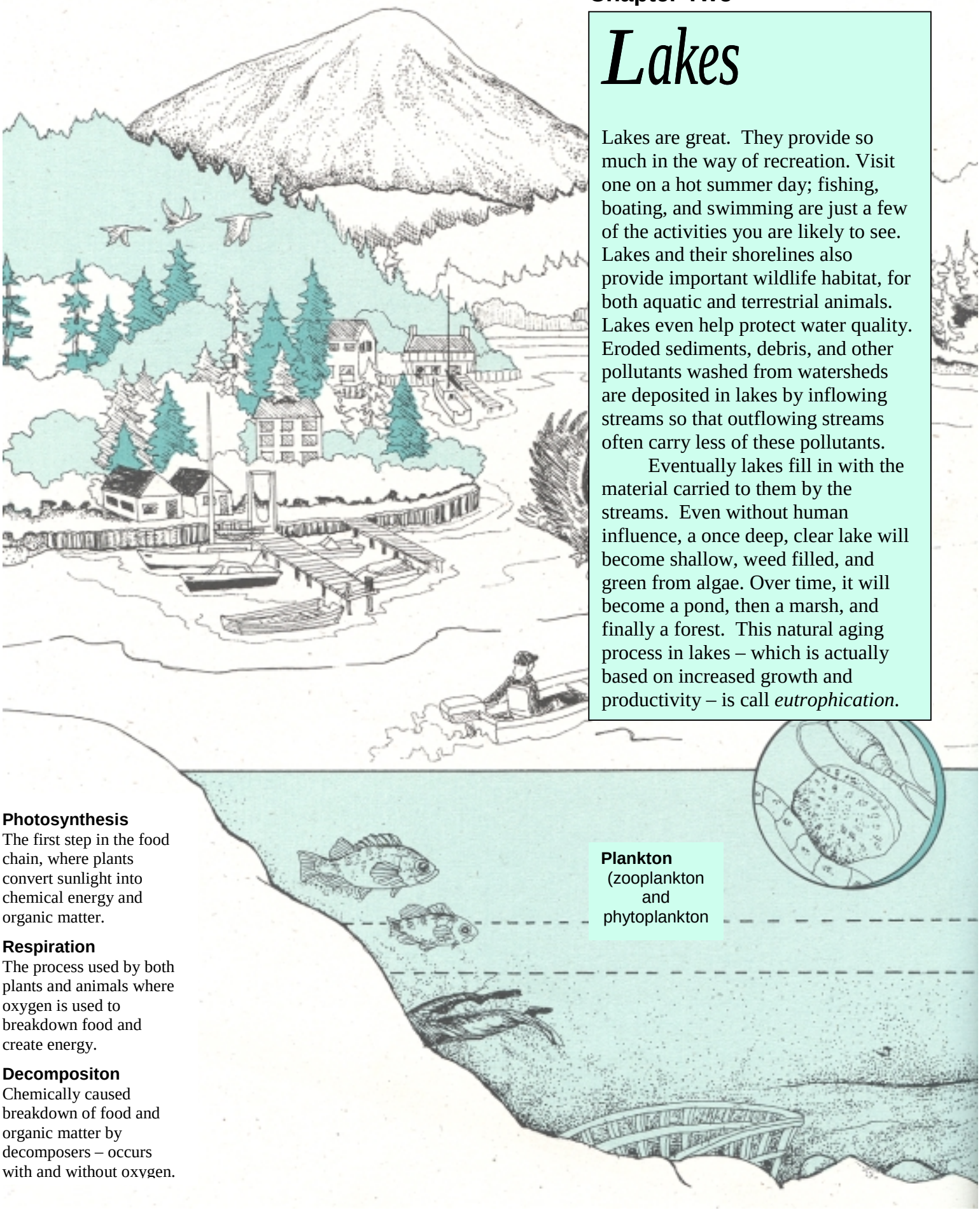


Chapter Two

Lakes

Lakes are great. They provide so much in the way of recreation. Visit one on a hot summer day; fishing, boating, and swimming are just a few of the activities you are likely to see. Lakes and their shorelines also provide important wildlife habitat, for both aquatic and terrestrial animals. Lakes even help protect water quality. Eroded sediments, debris, and other pollutants washed from watersheds are deposited in lakes by inflowing streams so that outflowing streams often carry less of these pollutants.

Eventually lakes fill in with the material carried to them by the streams. Even without human influence, a once deep, clear lake will become shallow, weed filled, and green from algae. Over time, it will become a pond, then a marsh, and finally a forest. This natural aging process in lakes – which is actually based on increased growth and productivity – is call *eutrophication.*



Plankton
(zooplankton and phytoplankton

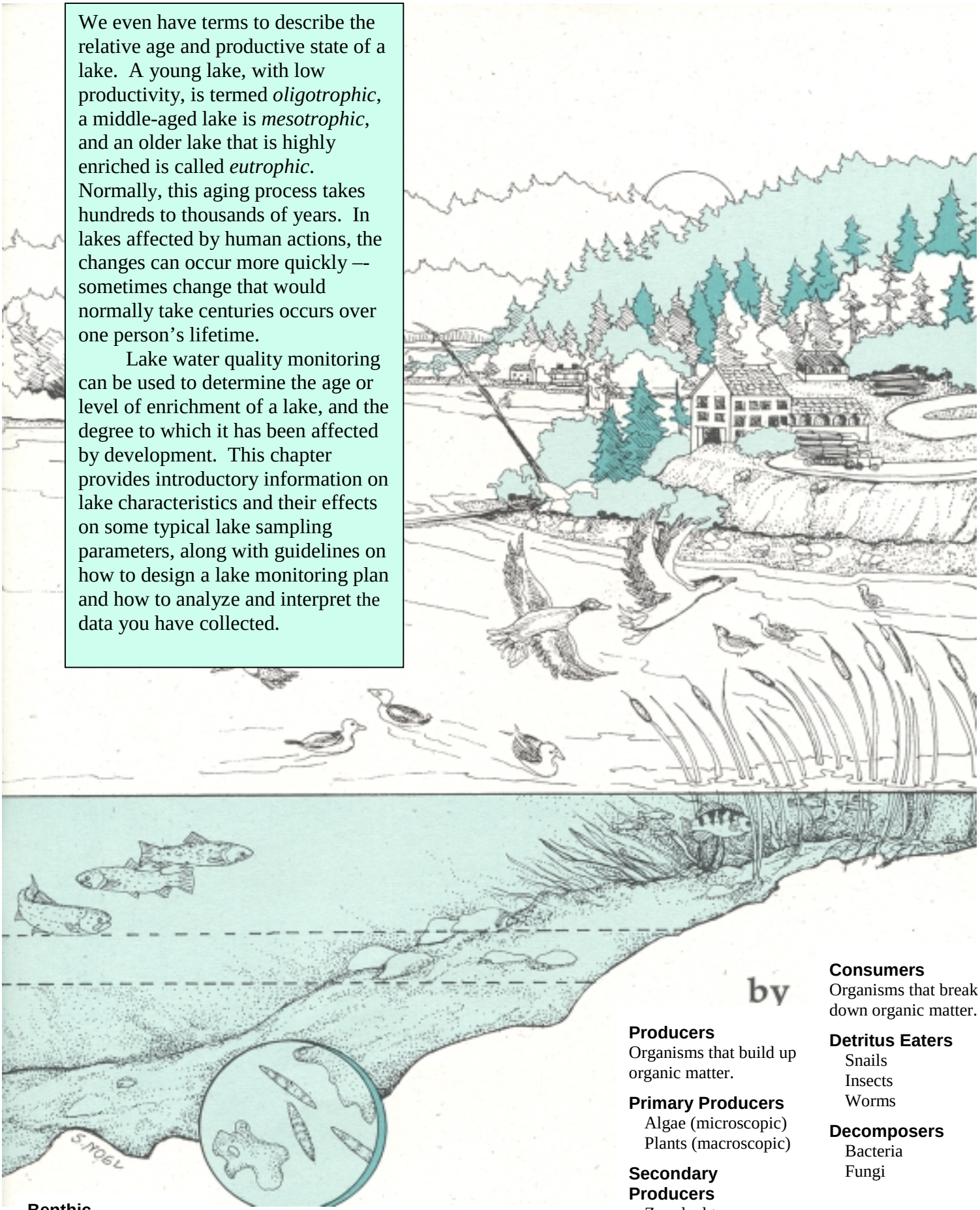
Photosynthesis
The first step in the food chain, where plants convert sunlight into chemical energy and organic matter.

Respiration
The process used by both plants and animals where oxygen is used to breakdown food and create energy.

Decompositon
Chemically caused breakdown of food and organic matter by decomposers – occurs with and without oxygen.

We even have terms to describe the relative age and productive state of a lake. A young lake, with low productivity, is termed *oligotrophic*, a middle-aged lake is *mesotrophic*, and an older lake that is highly enriched is called *eutrophic*. Normally, this aging process takes hundreds to thousands of years. In lakes affected by human actions, the changes can occur more quickly –- sometimes change that would normally take centuries occurs over one person's lifetime.

Lake water quality monitoring can be used to determine the age or level of enrichment of a lake, and the degree to which it has been affected by development. This chapter provides introductory information on lake characteristics and their effects on some typical lake sampling parameters, along with guidelines on how to design a lake monitoring plan and how to analyze and interpret the data you have collected.



Benthic Microorganisms
(bacteria and fungi)

Producers
Organisms that build up organic matter.

Primary Producers
Algae (microscopic)
Plants (macroscopic)

Secondary Producers
Zooplankton
Plant eating fish

Consumers
Organisms that break down organic matter.

Detritus Eaters
Snails
Insects
Worms

Decomposers
Bacteria
Fungi

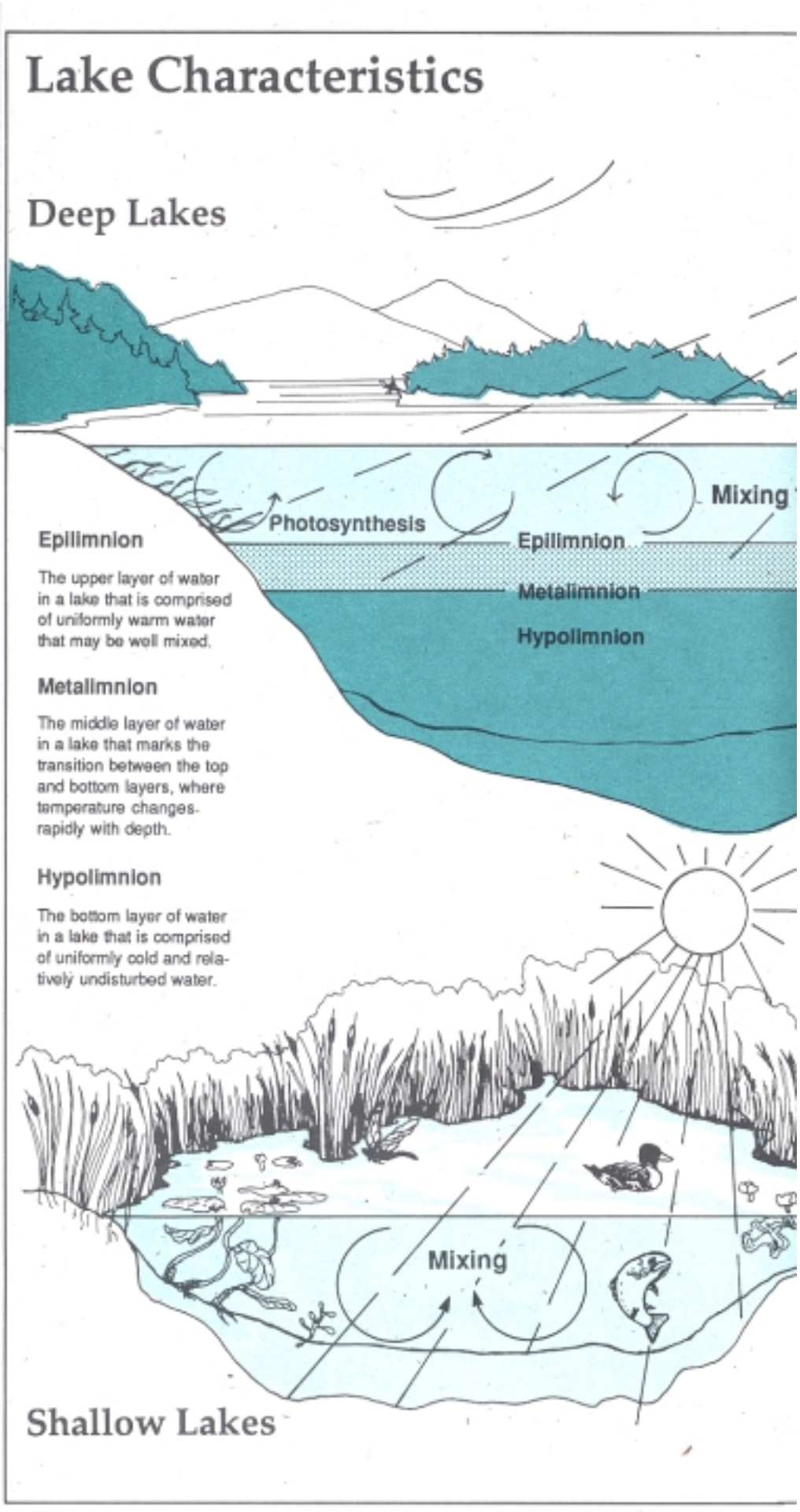
The Physical Character of Lakes

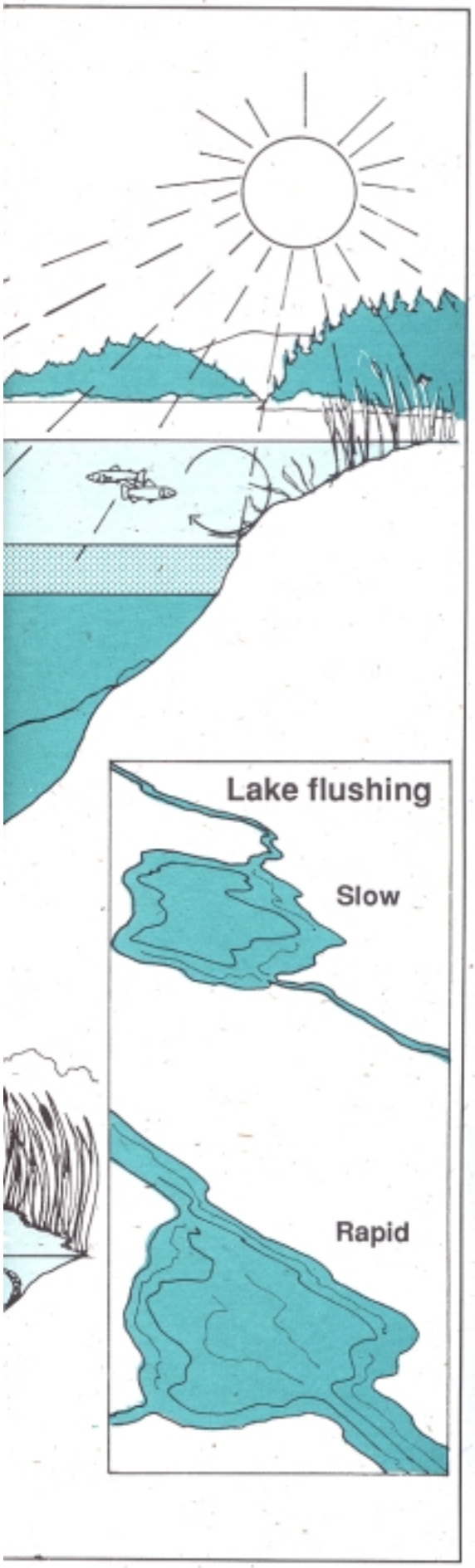
No two lakes are exactly alike. They may differ in size, depth, number and size of inflowing and outflowing streams, and shoreline configuration. Each of these physical factors in turn influences the lake character. Some characteristics affected include the species of fish in the lake, the likelihood the shoreline will be weed covered or that algae will turn the lake green in the summer, and whether the lake water is warm enough for swimming or suitable as a drinking water source. Physical factors also influence decisions about sampling locations, water quality monitoring parameters, and how to interpret the data collected.

Lake Depth

In a deep lake, water near the surface may be very different physically, chemically, and biologically from water near the bottom. The top portion of the lake is mixed by the wind and warmed by the sun. Because of the available light and warmer temperatures, many organisms live there. The more organisms there are photosynthesizing, breathing, eating, and growing, the higher the growth rate or productivity. The bottom portion of a deep lake receives little or no light. The water is colder; it is not mixed by wind; and decay of dead organic matter, called decomposition, is the main physical, biological, and chemical activity.

A shallow lake is more likely to be homogeneous – the same from top to bottom. The water is well mixed by wind, and physical characteristics such as temperature and oxygen vary little with depth. Because sunlight reaches all the way to the lake bottom, photosynthesis and growth occur throughout the water column. As in a deep lake, decomposition in a shallow lake is higher near the bottom than the top for the simple reason that when plants and animals die they sink. It also is likely that a larger portion of the water in a shallow lake is influenced by sunlight, and that photosynthesis and growth are proportionately higher.





Lake Size

Lakes range in size from little more than ponds to reservoirs over 50 miles long. As you can imagine, a pond and a reservoir are quite different systems. Although there are few hard and fast rules that govern lake size comparisons, the size does affect a number of important relationships. Some examples are the ratio of lake surface area to miles of shoreline, the percentage of the total water volume that is influenced by sunlight, and the ratio of the size of the watershed to size of the lake. These relationships affect how lakes function. A small lake with a greater ration of shoreline to water volume may be more susceptible to damage from shoreline or watershed activities.

Inflows and Outflows

The size and number of inflowing and outflowing streams in a lake determine how long it takes for a drop of water entering a lake to leave it – a process called *flushing*. Some lakes flush in days while other take years. You may know of a lake that is actually just a widening in the river, where the inflowing stream constitutes a large portion of the total lake volume. Such a lake flushes relatively rapidly. In other lakes, the inflow is not even visible; all of it comes from groundwater seeps and precipitation. In the former case, quality of the incoming water is the single most important factor influencing lake water quality. In the latter case, internal lake processes and groundwater determine water quality. In terms of pollution, the more rapidly the lake flushes the better because pollutants are flushed from the lake before they can cause too much damage. A more rapidly flushing lake also may respond sooner to pollution control activities in the watershed.

Shoreline Configuration

Another important lake characteristic is the shape of the shoreline. Shallow bays and inlets tend to be warmer and more productive than other parts of a lake. A lake with many of these features will be different than, say, a bowl-shaped lake with a smooth, round shoreline. This difference becomes important when setting up a monitoring plan. In the latter case, one mid-lake sampling station may adequately represent the lake. In a lake strongly influenced by shallow bays or inlets, water quality is likely to be greatly affected by location, and multiple sampling stations probably will be necessary.

Lake Water Quality Parameters

The parameters that are most frequently tested in lake water are discussed in this section. These include temperature, dissolved oxygen, pH, Secchi disk depth, nutrients, total suspected solids and turbidity, chloraphyll a, and fecal coliform bacteria. For each parameter, you will learn why it is important, why measured values differ over time, and how pollution could affect the measurement. Since most of these parameters are related to each other, the relationship is described twice, once under the discussion of each parameter. For example, there is a relationship between temperature and dissolved oxygen. This relationship is described in both the discussion on temperature and the discussion on dissolved oxygen. If you find it difficult to understand the discussion under one parameter, move on to the next; with luck you will find the next discussion helps clarify the first. Chapter Four describes the different methods for analysis of each parameter.

State Water Quality Standards

Water Quality standards have been established for all surface waters in Washington State. All lakes are grouped together in one class – *Lake Class* – and must meet the requirements set forth for this class by the Washington Administrative Code (WAC) 173-201-045. The State standard is described for each parameter discussed in this chapter.

Temperature

Why Is It Important?

Temperature exerts a major influence on biological activity and growth. To a point, the higher the water temperature, the greater the biological activity. Temperature also governs the kinds of organisms that can live in your lake. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are none.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen than cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures.

Reasons for Natural Variation

The most obvious reason for temperature change in lakes is the change in seasonal air temperature. Daily variation also may occur, especially in the surface layers, which are warmed during the day and cooled at night.

In deeper lakes during summer, the water separates into layers of distinctly different temperature. This process is called *thermal stratification*. The surface water is warmed by the sun, but the bottom of the lake remains cold. You may have experienced this difference when diving into a lake. Once the stratification develops, it tends to persist until the air temperature cools again in fall. Because the layers don't mix, they develop different physical and chemical characteristics. For example, dissolved oxygen concentration, pH, nutrient concentrations, and species of aquatic life in the upper layer can be quite different from those in the lower layer. It is almost like having two separate lakes.

When the surface water cools again in the fall to about the same temperature as the lower water, the stratification is lost and the layers mix. This process is called fall *turnover*. (A similar process also may occur during the spring as colder surface waters warm to the temperature of bottom waters and the lake mixes. This is called spring turnover.) The lake mixing associated with a turnover often corresponds with a large increase in turbidity. Watch for this change in your lake this fall.

Because the sun can heat a greater proportion of the water in a shallow lake than in a deep lake, a shallow lake may warm up faster and to a higher temperature. Lake temperature also is affected by the size and temperature of inflows (e.g., a glacial fed stream of springs or a lowland creek) and by how quickly water flushes through the lake. Even a shallow lake may remain cool if fed by a comparatively large, cold stream.

Expected Impact of Pollution

Thermal pollution (artificially high temperatures) almost always occurs as a result of discharge of municipal or industrial effluents. Except in very large lakes, it is rare to have an effluent discharge. In urban areas, runoff that flows over hot asphalt and concrete pavement before entering a lake will be artificially heated and could cause lake warming, although in most cases this impact is too small to be measured. Consequently, direct, measurable thermal pollution is not common. However, since streams and rivers constitute a major source of flow to some lakes, these lakes may be indirectly impacted by thermal pollution via inflows,

Temperature is reported'in degrees on the Celsius temperature scale (^{o}C). There is no numerical State water quality standard for lake temperatures. The standard reads there will be "no measurable change from natural conditions." Temperatures for three Western Washington lakes are shown below to provide

Temperature (^{o}C) Measured in the Top Layer (Epilimnion) and Bottom Layer (Hypolimnion) of Three Western Washington Lakes In June and September 1989.

	Summit Lake		Blackman Lake		Black Lake	
	Top	Bot	Top	Bot	Top	Bot
June	19.7	7.5	21.4	11.8	23.0	13.6
September	20.0	8.0	19.1	15.9	21.1	17.2

Revised from: Brower, C. and W. Kendra. Water Quality Survey of 25 "citizen-Volunteer" Lakes from Washington State. Olympia, WA. Washington Department of Ecology, March 1990.

examples of the range you may expect to measure. The three lakes shown represent an oligotrophic lake (Summit Lake, Thurston Co.), a mesotrophic lake (Blackmans Lake, Snohomish Co.) and a eutrophic lake (Black Lake, Thurston Co.). These same lakes are used throughout this chapter to provide values for comparison purposes.

Dissolved Oxygen

Why Is It Important?

Like terrestrial animals, fish and other aquatic organisms need oxygen to live. As water moves past their gills (or other breathing apparatus), microscopic bubbles of oxygen gas in the water, called dissolved oxygen (DO), are transferred from the water to their blood. Like any other gas diffusion process, the transfer is efficient only above certain concentrations. In other words, oxygen can be present in the water, but at too low a concentration to sustain aquatic life. Oxygen also is needed for many chemical reactions that are important to lake functioning.

Reasons for Natural Variation

Oxygen is produced during photosynthesis and consumed during respiration and decomposition. Because it requires light, photosynthesis occurs only during daylight hours. Respiration and decomposition, on the other hand, occur 24 hours a day. This difference alone can account for large daily variations in DO concentrations. During the night, when photosynthesis cannot counterbalance the loss of oxygen through respiration and decomposition, DO concentrations steadily decline. They are lowest just before dawn, when photosynthesis resumes.

Other sources of oxygen include the air and inflowing streams. Oxygen concentrations are much higher in air, which is about 21 percent oxygen, than in water, which is a tiny fraction of 1 percent oxygen. Where the air and water meet, this tremendous difference in concentration causes oxygen molecules in the air to dissolve into the water. More oxygen dissolves into water when wind stirs the water, as the waves create more surface area, more diffusion can occur. A similar process happens when you add sugar to a cup of coffee - the sugar dissolves. It dissolves more quickly, however, when you stir the coffee. Rivers and streams also deliver oxygen to lakes, especially if they are turbulent and thus well aerated when they reach the lake. Consequently, natural variation of DO concentration in lakes is also caused by weather and changes in inflowing streams (e.g., higher, more turbulent flow during winter months).

Another physical process that affects DO concentrations is the relationship between water temperature and gas saturation. Cold water can hold more gas -- that is DO -- than warmer water. Warmer water becomes "saturated" more easily with oxygen. As water becomes warmer it can hold less and less DO. So, during the summer months or in the warmer top portion of a lake, the total amount of oxygen present may be limited by temperature.

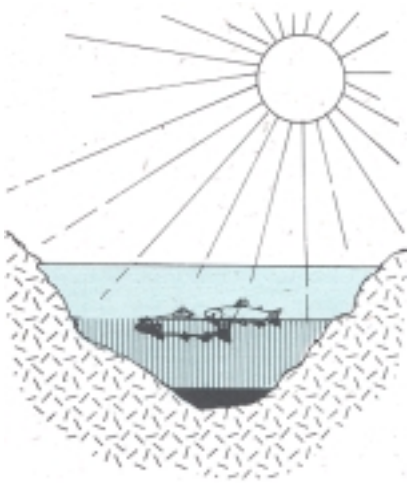
The Relationship Between Temperature and Oxygen Solubility

Temperature (^{o}C)	Oxygen Solubility (mg/L)
0	14.6
5	12.8
10	11.3
15	10.2
20	9.2
25	8.6
100 boiling	0

Dissolved oxygen concentrations may change dramatically with lake depth. Oxygen production occurs in the top portion of a lake, where sunlight drives the engines of photosynthesis. Oxygen consumption is greatest near the bottom of a lake, where sunken organic matter decomposes. In deeper, stratified, lakes, this difference may be acute -- plenty of oxygen near the top but practically none near the bottom: If the lake is shallow and easily mixed by the wind, the DO concentration may be fairly , consistent throughout the water column.

Putting the Squeeze on Fish . . .

Mid-summer, when strong thermal stratification develops in a lake, may be a very hard time for fish. Water near the surface of the lake – the epilimnion – is too warm for them, while water near the bottom – the hypolimnion – has too little oxygen. Conditions may become especially serious during a spate of hot, calm weather, resulting in the loss of many fish. You may have heard about summertime fish kills in local lakes that likely result from this problem.



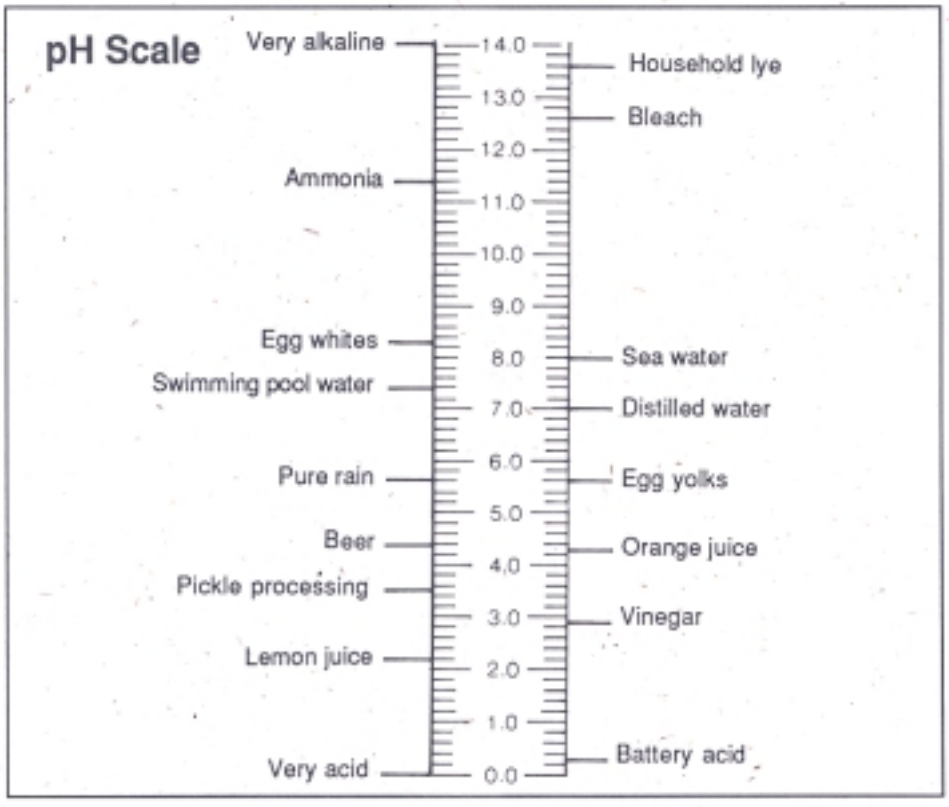
Dissolved Oxygen Concentrations (mg/L) Measured in the Top Layer (Epilimnion) and Bottom layer (Hypolimnion) of Three Lakes in June and September 1989.

	Summit Lake		Blackman Lake		Black Lake	
	Top	Bot	Top	Bot	Top	Bot
June	9.7	6.3	10.3	0.4	9.8	2.0
September	11.8	1.6	8.9	0.2	__	0.1

Seasonal changes also affect dissolved oxygen concentrations. Warmer temperatures during summer speed up the rates of photosynthesis and decomposition. When all the plants die at the end of the growing season, their decomposition results in heavy oxygen consumption other seasonal events, such as changes in lake water levels, volume of inflows and outflows, and presence of ice cover, also cause natural variation in DO concentrations.

Expected Impact of Pollution

To the degree that pollution contributes oxygen-demanding organic matter (like sewage or lawn clippings) or nutrients that stimulate growth of organic matter, pollution causes a decrease in average DO concentrations. If the organic matter is formed in the lake, for example by algae growth, at least some oxygen is produced during growth to offset the eventual loss of oxygen during decomposition. However, in lakes where a large portion of the organic matter is brought in from outside the lake, the balance between oxygen production and oxygen consumption becomes skewed and low DO may become even more of a problem.



pH

Why Is It Important

The pH of a sample of water is a measure of the concentration of hydrogen ions. The term pH was derived from the manner in which the hydrogen ion concentration is calculated – it is the negative logarithm of the hydrogen ion (H^+) concentration. What this means to those of us who are not mathematicians is that at higher pH, there are fewer free hydrogen ions, and that a change of one pH unit reflects a tenfold change in the concentration of the hydrogen ion. For example, there are 10 times as many hydrogen ions available at a pH of 7 than at a pH of 8. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH less than 7 are acidic; substances with pH greater than 7 are basic.

The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH also determines whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble.

Reasons for Natural Variation

Photosynthesis uses up hydrogen molecules, which causes the concentration of hydrogen ions to decrease and therefore the pH to increase. For this reason, pH may be higher during daylight hours and during the growing season, when photosynthesis is at a maximum. Respiration and decomposition processes lower pH. Like dissolved oxygen concentrations, pH may change with depth in a lake, due again to changes in photosynthesis and other chemical reactions.

Fortunately, lake water is complex; it is full of chemical "shock absorbers" that prevent major changes in pH. Small or localized changes in pH are quickly modified by various chemical reactions, so little or no change may be measured. This ability to resist change in pH is called *buffering capacity*. Not only does the buffering capacity control would-be localized changes in pH, it controls the overall range of pH change under natural conditions. The pH scale may go from 0 to 14, but the pH of natural waters hovers between 6.5 and 8.5.

Expected Impact of Pollution

When pollution results in higher productivity (e.g., from increased temperature or excess nutrients), pH levels increase, as allowed by the buffering capacity of the lake. Although these small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the lake and may aggravate nutrient problems. For example, a change in pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen.

The Case of Acid Rain

As important exception to the buffering of pH changes in lakes is the case of lakes affected by acid rain. Lakes that have received too much rain with a low pH (acid rain), lose their buffering capacity. At a certain point, it takes only a small bit of rain for the pH to change. After that point, change occurs relatively quickly. Acid rain is not considered to be a significant problem in the Puget Sound lowlands.

Values for pH are reported in standard pH units, usually to one or two decimal places depending upon the accuracy of the equipment used. Since pH represents the negative logarithm of a number, it is not mathematically correct to calculate simple averages or other summary statistics. Instead, pH should be reported as a median and range of values. There is no numerical State water quality standard for pH in lakes. The standard reads there will be "no measurable change from natural conditions." (A pH of 5-6 or lower has been found to be directly toxic to fish, according to the EPA.)

Generally, during the summer months in the upper portion of a productive or eutrophic lake, pH will range between 7.5 and 8.5. In the bottom of the lake or in less productive lakes, pH will be lower, 6.5 to 7.5 perhaps. This is a very general statement to provide an example of the differences you might measure.

Secchi Disk Depth

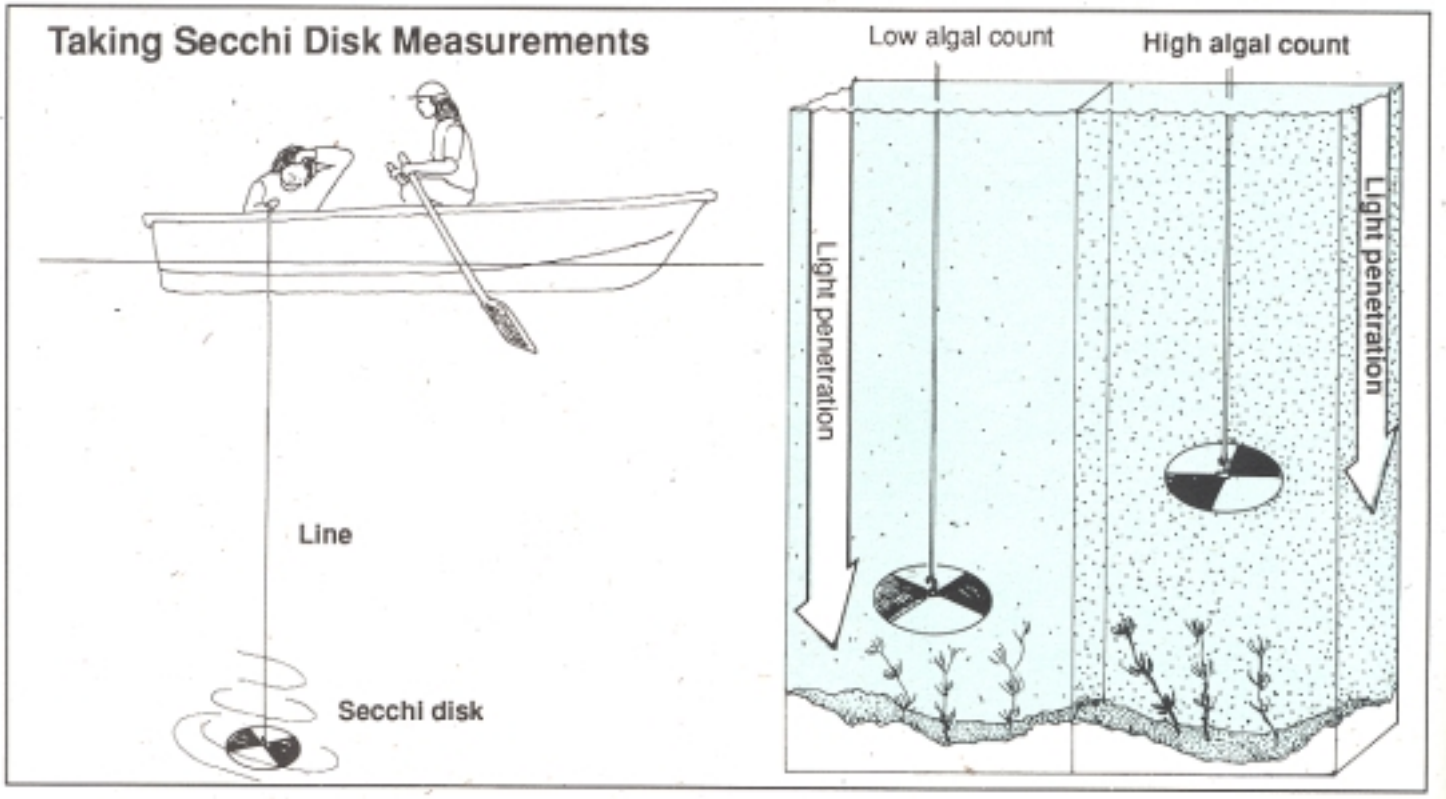
Why Is It Important?

A Secchi disk is a circular plate divided into quarters painted alternately black and white. The disk is attached to a rope and lowered into the water until it is no longer visible. Secchi disk depth, then, is a measure of water clarity. Higher Secchi readings mean more rope was let out before the disk disappeared from sight and indicates clearer water. Lower readings indicate turbid or colored water. Clear water lets light penetrate more deeply into the lake than does murky water. This light allows photosynthesis to occur and oxygen to be produced. The rule of thumb is that light can penetrate to a depth of 1.7 times the Secchi disk depth.

Clarity is affected by algae, soil particles, and other materials suspended in the water. However, Secchi disk depth is primarily used as an indicator of algal abundance and general lake productivity. Although it is only an indicator, Secchi disk depth is the simplest and one of the most effective tools for estimating a lake's productivity.

Reasons for Natural Variation

Secchi disk readings vary seasonally with changes in photosynthesis and, therefore, algal growth. In most lakes, Secchi disk readings begin to decrease in the spring, with warmer temperature and increased growth, and continue decreasing until algal growth peaks in the summer. As cooler weather sets in and growth decreases, Secchi disk readings increase again. (However, cooler weather often means more wind. In a shallow lake, the improved clarity from decreased algal growth may be



partly offset by an increase in concentration of sediments mixed into the water column by wind.) In lakes that thermally stratify, Secchi disk readings may decrease again with fall turnover. As the surface water cools, the thermal stratification created in summer weakens and the lake mixes. The nutrients thus released from the bottom layer of water may cause a fall algae bloom and the resultant decrease in Secchi disk reading.

Rainstorms also may affect readings. Erosion from rainfall, runoff, and high stream velocities may result in higher concentrations of suspended particles in inflowing streams and therefore decreases in Secchi disk readings. On the other hand, temperature and volume of the incoming water may be sufficient to dilute the lake with cooler, clearer water and reduce algal growth rates. Both clearer water and lower growth rates would result in increased Secchi disk readings.

The natural color of the water also affects the readings. In most lakes, the impact of color may be insignificant. But some lakes are highly colored. Lakes strongly influenced by bogs, for example, are often a very dark brown and have low Secchi readings even though they may have few algae.

Expected Impact of Pollution

Pollution tends to reduce water clarity. Watershed development and poor land use practices cause increases in erosion, organic matter, and nutrients, all of which cause increases in suspended particulates and algae growth.

Secchi Disk Readings (meters) Taken in Three Lakes in June and September 1989.

	Summit Lake	Blackmans Lake	Black Lake
June	7.0	2.9	2.3
September	6.8	3.7	0.9

Secchi disk depth is usually reported in feet to the nearest tenth of a foot, or meters to the nearest tenth of a meter. Secchi disk depths for three Western Washington lakes are shown here to provide examples of the range you may expect to measure, There is no State water quality standard for Secchi depth.

Secchi disk readings can be used to determine a lake's trophic status. Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state. Information on calculating trophic status is included in the interpretation section at the end of this chapter.

Nutrient Concentrations

Why Are They Important?

Nutrients in lakes serve the same basic functions as nutrients in a garden. They are essential for growth. In a garden, growth and productivity are considered beneficial, but this is not necessarily so in a lake. The additional algae and other plant growth allowed by the nutrients may be beneficial up to a point, but may easily become a nuisance.

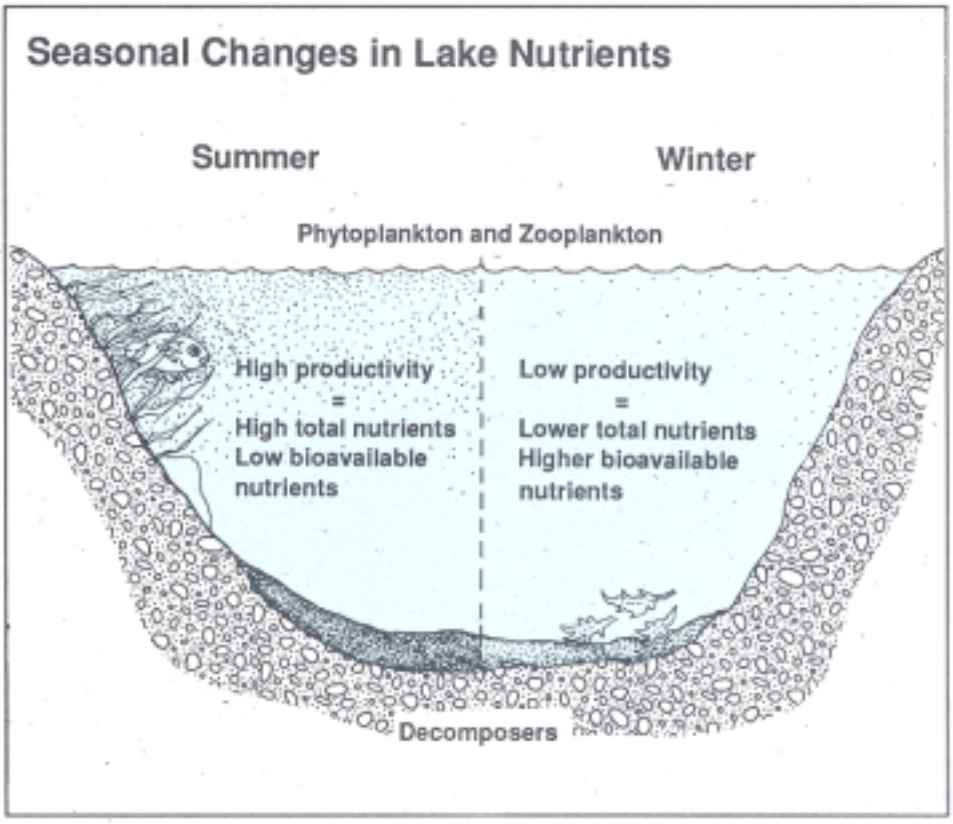
The main nutrients of concern are phosphorus and nitrogen. Both elements are measured in several forms. Phosphorus can be measured as total phosphorus (TP) or as soluble reactive phosphate (SRP). SRP is also sometimes called phosphate (PO_4) or orthophosphate (ortho-P). SRP represents the fraction of TP that is available to organisms for growth.

Nitrogen can be measured as total nitrogen (TN), total Kjeldahl nitrogen (TYN),,nitrate-nitrogen (NO), nitrite-nitrogen (NO_2) [these are usually measured.as nitrate-nitrite-nitrogen (NO_3- $N0_2$)], or ammonia-nitrogen (NH). TN is similar to TP and is used to represent the total amount of nitrogen in a sample. TKN represents the fraction of TN that is-unavailable, for growth or bound up in organic form; it also includes NH_4. The remaining fractions, NO_3-NO_2 and NH_4 represent bioavailable forms of nitrogen. If they are summed, they can be compared to the SRP fraction of phosphorus.

One chemical form of an element can be converted into another. The conditions under which the conversion occurs are influenced by many factors, such as, pH, temperature, oxygen concentration, and biological activity.

The total concentration of a nutrient (e.g., TP or TN) is not necessarily the most useful measurement. For example, if a sample is analyzed for TP, all forms of the element are measured, including the phosphorus "locked up" in biological tissue and insoluble mineral particles. It may be more useful to know the concentration of phosphorus that is actually available for growth. SRP better reflects bioavailability.

Although there are many different forms of nutrients that can be measured, there are only three commonly used combinations. They are (1) measure all forms of both elements -- TP, SRP,.TN, NO_3-NO_2, NH_4; (2) measure only total nutrients - TP and TN; or (3) measure only available nutrients -- SRP and NO_3-NO_2 and NH_4. (In the first example, TKN could be measured instead of TN. Depending upon which form is measured, the other can be estimated by difference.)



Reasons for Natural Variation

The concentration of nutrients and the forms they are found in change continually. How and why they change is a very complex field of study. The total input of nutrients varies through time, depending upon land use and other factors. During the summer, nutrient input may increase due to fertilization of cropland, lawns, and gardens. During the winter, high rainfall causes increased washoff of organic matter such as leaves, twigs, grass, and other debris. Because decomposition of this organic matter releases nutrients, it constitutes an important source of nutrient loading.

Whether the increase in total nutrient concentrations results in higher available nutrient concentrations, and therefore an immediate increase in growth or productivity, depends upon the original form of the nutrient and physical conditions. If nutrients enter as organic matter that first needs to be decomposed before it can be utilized for growth, temperature becomes important because of its effect on the rate of decomposition. (During warmer months, nutrients entering the system as intact organic matter would be decomposed relatively quickly as compared with cold, wet-weather months when decomposition is slow.)

These dynamics are further complicated by the fact that increased growth leads to greater numbers of organisms, which need even more nutrients. So, as nutrients become available they are immediately utilized. In this case, an increase in total nutrients would not be reflected by any measurable increase in available nutrient fractions. In short, clear or simple relationships between increases in organic matter or other sources of nutrients and resultant increases in either total or available nutrient concentrations become obscure.

Nutrient concentrations also may vary with depth in a lake. Near the top of the lake, where light stimulates algae growth, total nutrient concentrations may be higher than those deeper in the lake. These high

total concentrations reflect the increased concentration of organic matter -- algae. But because the organisms are utilizing most of the nutrients that are produced, available nutrient concentrations may be low. Since decomposition of organic matter -- formation of available nutrients from total nutrients occurs to a larger extent near the bottom of a lake, available nutrient concentrations may be higher at depth.

Expected Impact of Pollution

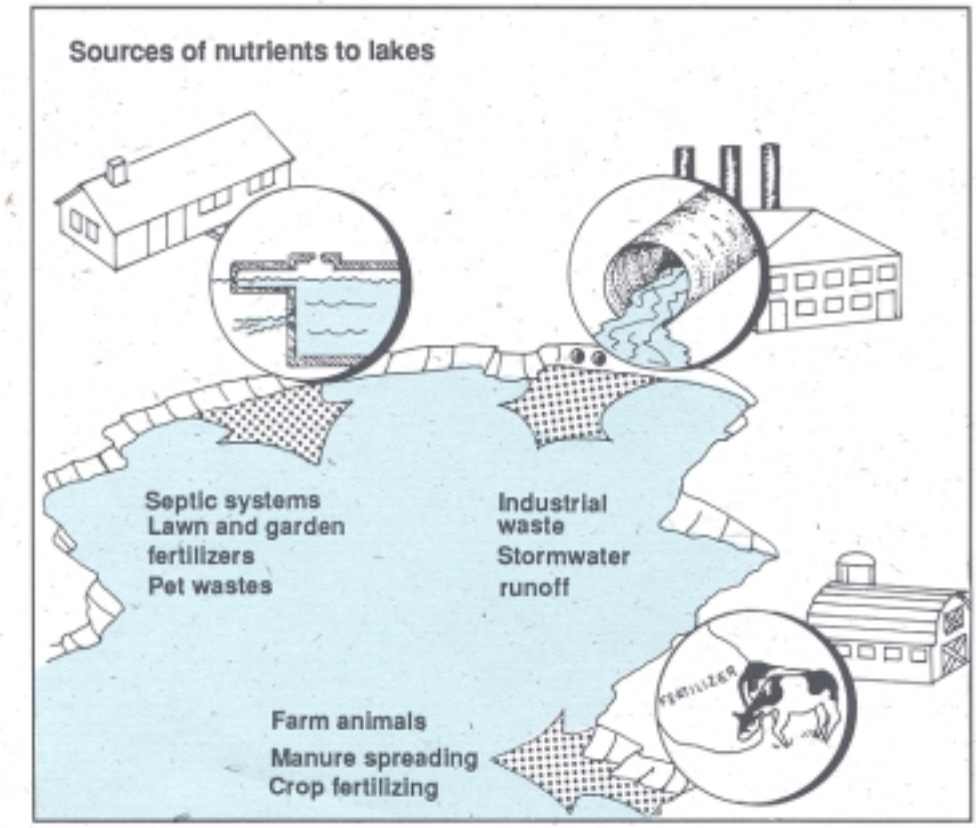
Most sources of pollution to lakes contribute nutrients in one form or another. These sources include stormwater runoff, which may carry fertilizers from lawns and cropland as well as organic matter such as leaves, grass, and insects; waste products from farm animals and domestic pets; failing lakeside septic systems; and effluent from industrial and municipal wastewater treatment plants. As the number or size of pollutant sources increases, average nutrient concentrations also increase.

Nutrient Concentrations (µg/L) Measured in the Top Layer (Epilimnion) and Bottom Layer (Hypolimnion) of Three Lakes in September 1989.

	Summit Lake		Blackman Lake		Black Lake	
	Top	Bot	Top	Bot	Top	Bot
TP	6	12	22	35	46	146
SRP	5	5	9	4	11	75
TN	150	170	440	420	750	490
NO_3-NO_2	3	10	3	3	3	--
NH_4	5	5	18	9	5	168

Nutrient concentrations are reported in units of milligrams of nutrient per liter of water -- mg/L, or micrograms per liter of water - µg/L. Milligrams per liter is equivalent to parts per million (ppm); micrograms per liter is equivalent to parts per billion (ppb). There is no State water quality standard for nutrients. Nutrient concentrations for three Western Washington lakes are shown above to provide examples of the range you may expect to measure.

Total phosphorus concentrations can be used to determine a lake's trophic status. Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state. Information on calculating trophic status is included in the interpretation section at the end of this chapter.



Total Suspended Solids and Turbidity

Why Is It Important?

Total suspended solids (TSS) concentrations and turbidity both indicate the amount of solids suspended in the water, whether mineral (e.g., soil particles) or organic (e.g., algae). However, the TSS test measures an actual weight of material per volume of water, while turbidity measures the amount of light scattered from a water sample (more suspended particles cause greater scattering). This difference becomes important when trying to calculate total quantities of material within or entering a lake. Such calculations are possible with TSS values, but not with turbidity readings.

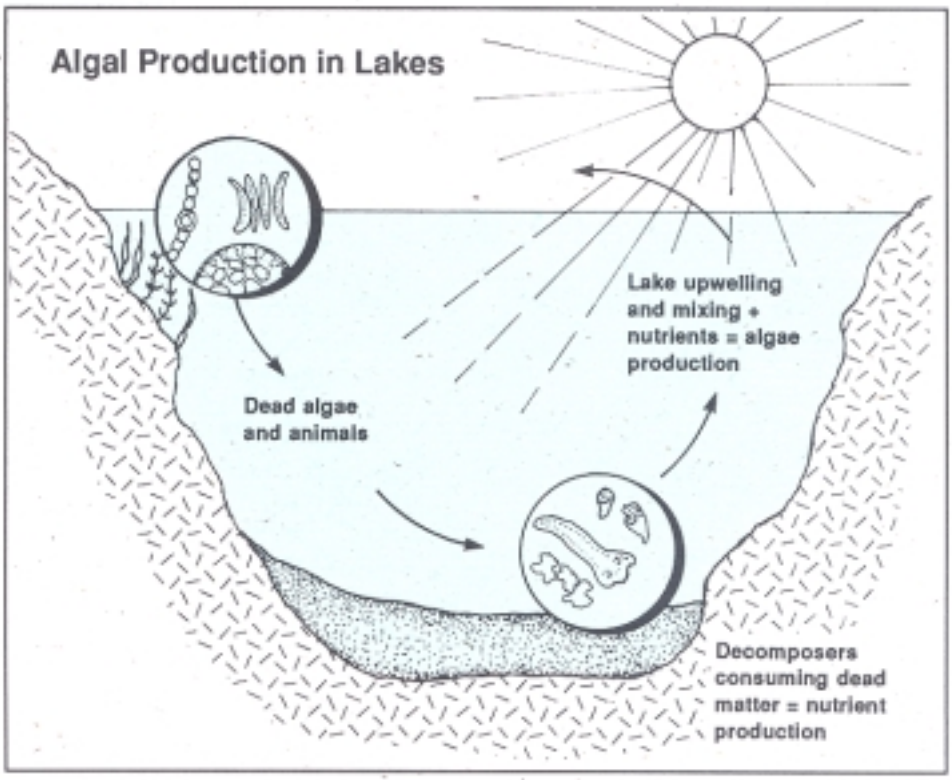
High concentrations of particulate matter affect light penetration and productivity, recreational values, and habitat quality, and cause lakes to fill in faster. Particles also provide attachment places for other pollutants, notably metals and bacteria.

Reasons for Natural Variation

TSS and turbidity values vary for two main reasons -- one physical, the other biological. Heavy rains and fast-moving water are erosive. They can pick up and carry enough dirt and debris to make even an unpolluted inflowing stream look muddy. So, heavy rainfall may cause higher TSS concentrations or turbidity, especially where the stream flows into the lake. In lakes, the most important reason for variation in these parameters is caused by seasonal changes in algae growth. Warm temperatures, prolonged daylight, and release of nutrients from decomposition may cause algae blooms that increase turbidity or TSS concentrations.

Expected Impact of Pollution

Pollution or general human activities usually result in higher TSS concentrations or turbidity. For example, loss of vegetation due to development exposes more soil to erosion, allows more runoff to form, and simultaneously reduces the watershed's ability to filter the nutrients and organic matter from runoff before it reaches the inflowing streams. Although much of the particulate matter may settle to the lake bottom, the addition of nutrients will eventually cause increased algae growth.



TS S concentrations are reported in units of milligrams of suspended solids per liter of water -- mg/L Turbidity is reported as nephelometric (NTU), or Jackson turbidity units (JTU), depending on the instrument used to perform the measurement. The State water quality standard is based on turbidity as measured by a nephelometer. The standard states, "turbidity shall not exceed 5 NTU over background coniditions." Turbidity measurements for three Western Washington lakes are shown here for comparison purposes. TSS measurements are not available.

Turbidity (NTUs) Measured in the Top Layer (Epilimnion) of Three Lakes in June and September 1989.

	Summit Lake	Blackmans Lake	Black Lake
June	0.8	0.8	1.7
September	0.7	1.6	12.5

Chlorophyll a

Why Is It Important?

Chlorophyll is the green pigment in plants that allows them to create energy from light -- to photo-synthesize. By measuring chlorophyll, you are indirectly measuring the amount of photosynthesizing plants found in a sample. In a lake water sample, these plants would be algae or phytoplankton. Chlorophyll is a measure of all green pigments whether they are active (alive) or inactive (dead). Chlorophyll a is a measure of the portion of the pigment that is still active; that is, the portion that was still actively respiring and photosynthesizing at the time of sampling.

As described in the previous discussions on DO, pH, nutrients, and Secchi disk depth, the amount of algae found in a lake greatly affects the lake's physical, chemical, and biological makeup. Algae produce oxygen during daylight hours but use up oxygen during the night and again when they die and decay.

Decomposition of algae also causes the release of nutrients to the lake, which may allow more algae to grow. Their processes of photosynthesis and respiration cause changes in lake pH, and the presence of algae in the water column is the main factor affecting Secchi disk readings. Algae, of course, also can cause aesthetic problems in a lake; a green "scum," swimmers itch, and rotting scent are common problems associated with high algae concentrations.

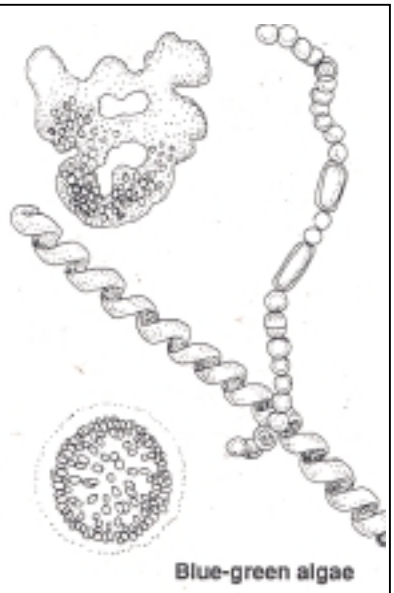
Reasons for Natural Variation

Sunlight, temperature, nutrients, and wind all affect algae numbers and, therefore chlorophyll a concentration. During the spring when water begins to warm, the days are sunnier, and nutrients are still plentiful, the first outbreak or "bloom" of algae may occur. As the days become increasingly warmer and sunnier, algae will continue to grow; however, they may soon outgrow the available supply of nutrients. Consequently, the total amount of algae growth may be - limited.

Wind also can impact algae populations. A good strong wind may mix the lake, causing an immediate decrease in algae concentrations as they become mixed throughout the water column. On the other hand, the wind also may cause a release of nutrients into the lake system by stirring up nutrient-laden bottom sediments. Then, after the wind dies down, the number of algae and the chlorophyll concentration may increase.

Algae Toxicity

Some algae produce a poisonous toxin. Typically, the amount of toxin produced is too small to have a serious impact. However, if populations of these algae get very dense, the concentration of the toxin can become seriously high. Dogs and farm animals have been known to die from drinking water that contained too many of these algae and their toxin. The algae of concern in this case is a group called the "blue-green" – named after their particular pigment color. Sometimes, you can identify a "bloom" of blue-greens in your lake or pond by the oily, bluish-green sheen they produce in the water.


Blue-green algae

As summer turns to fall and temperature and sunlight decrease, algae concentrations will decrease as well. Often, in deeper lakes where temperature stratification has occurred (see discussion on temperature, page 10), there will be a fall algae bloom when the lake mixes again and nutrients are released to the entire water column.

Algae populations, and therefore chlorophyll a concentrations, vary greatly with lake depth. Algae must stay within the top portion of the lake where there is sunlight to be able to photosynthesize and stay alive. As they sink below the sunlit portion of the lake, they die. Therefore, few live algae (as measured by chlorophyll a) are found at greater depths. Some algae, notably blue-greens, have internal "flotation devices" that allow them to regulate their depth and so remain within the top portion of the lake to photosynthesize and reproduce.

Expected Impact of Pollution

As previously described, the most common concern associated with pollution or development of a lake's watershed is the increase in nutrients to the lake. Since the lack o f nutrients is often what limits the number of algae that can grow in a lake, the increase in nutrients caused by pollution usually results in more algae. The populations will continue to increase, causing the aesthetic problems described above.

Chlorophyll a is reported in µg/L. There is no State water quality standard for chlorophyll a. Chlorophyll a concentrations for three Western Washington lakes are shown below to provide examples of the range you may expect to measure.

Chlorophyll a concentrations can be used to determine a lake's trophic status. Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state. Information on calculating trophic status is included in the interpretation section at the end of this chapter.

Chlorophyll a Concentrations (µg/L) Measured in the Top Layer (Epilimnion) of Three Lakes in June and September 1989.

	Summit Lake	Blackmans Lake	Black Lake
June	1.5	3.3	7.6
September	1.5	3.9	56.2

Fecal Coliform Bacteria Concentrations

Why Is It Important?

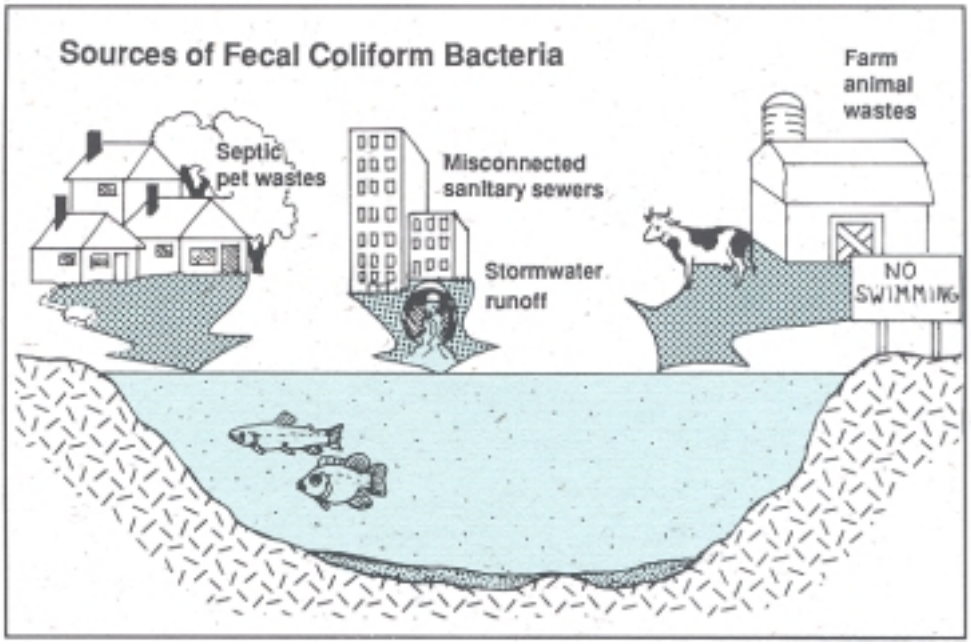
Fecal coliform bacteria are microscopic animals that live in the intestines of warm-blooded animals. They also live in the waste material or feces excreted from the intestinal tract. When fecal coliform bacteria are present in high numbers in a water sample, it means that the water may have received fecal matter from one source or another. Although not necessarily agents of disease, fecal coliform bacteria indicate the potential presence of disease-carrying organisms, which live in the same environment as the fecal coliform bacteria.

Reasons for Natural Variation

Unlike the other conventional water quality parameters, fecal coliform bacteria are living organisms. They multiply quickly when conditions are favorable for growth and die in large numbers when they are not. Because bacterial concentrations are dependent upon specific conditions for growth and these conditions change quickly, fecal coliform bacteria counts are not easy to predict. For example, although winter rains may wash more fecal matter from urban areas into a lake, cool water temperatures may cause many of the organisms to die. Direct exposure to sunlight is also lethal to bacteria, so dieoff may be high even in the warmer water of summertime.

Expected Impact of Pollution

A lake heavily polluted by nutrients-may have very low concentrations of fecal coliform bacteria. It depends on the source of pollution. Urbanization of watersheds may generate new sources of fecal coliform bacteria,



even as "old" sources disappear -- for example, when agricultural land fertilized by cow manure is converted into residential developments. In this case, pet wastes, failing septic systems, and interconnections with leaking sanitary sewers may replace cow manure as a fecal coliform source. Stormwater runoff in urbanized areas has been found to be surprisingly high in fecal coliform bacteria concentrations. The presence of disintegrating storm and sanitary sewers, misplaced sewer pipes, and good breeding conditions are common explanations for the high levels measured.

Most states have strict standards for fecal coliform bacteria concentrations, primarily for reasons of public health. The abundance of fecal coliform bacteria is measured as the number of "colonies" in 100 mL of water -- #/100 mL. The Washington State standard for lakes reads "fecal coliform organisms shall not exceed a geometric mean value of 50 organisms/100 mL, with not more than 10 percent of the samples exceeding 100 brganisms/100 mL."

The equation below describes how to calculate a geometric mean.

Geometric Mean = $\sqrt[n]{X_1 X_2 X_3 \ldots X_n}$

If the lake is used for a drinking water supply, more stringent standards apply. The standards differ depending upon the method used and the number of samples collected. Suffice to say that for drinking water, coliform numbers should be one or less.

Fecal coliform concentrations for three Western Washington lakes are shown here to provide examples of the range you may expect to measure. This group of lakes displays a fairly narrow range in measured bacteria concentrations. Large variations (tenfold or more) within a lake are not unusual, given the rate at which bacteria multiply and die.

Fecal Coliform Bacteria Concentrations (#/100 mL) Measured in the Top Layer (Epilimnion) of Three Lakes in June and September 1989.

	Summit Lake	Blackmans Lake	Black Lake
June	1	36	0
September	0	37	1

A Typical Lake Monitoring Program

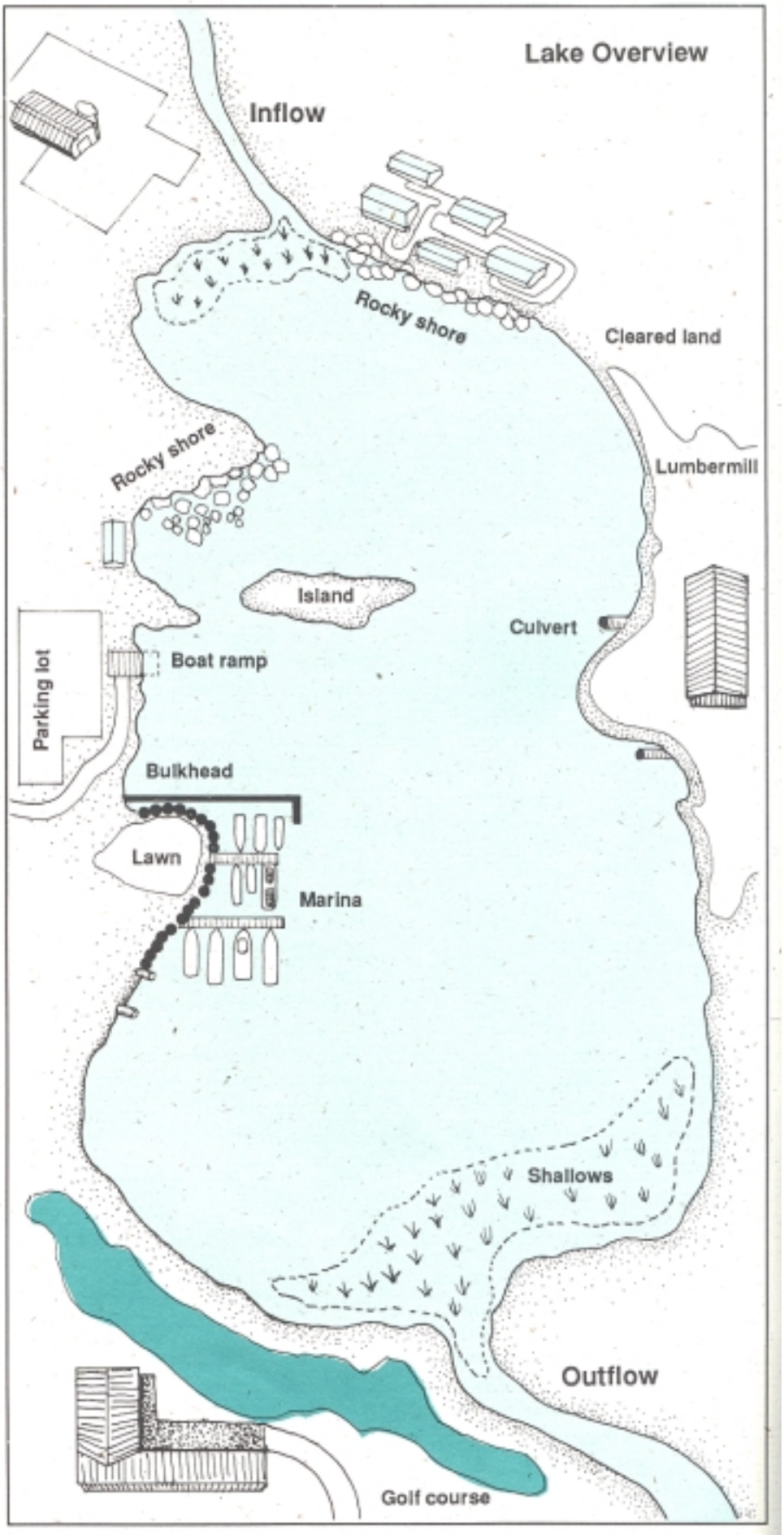
Getting Started

The first step in beginning any monitoring program is to think about your objectives or purpose for monitoring as discussed in Chapter One. Your monitoring plan may not be anything like someone else's plan if your goals and objectives are different. Some typical objectives for citizen monitoring include characterizing the entire lake, learning about how lakes function, or assessing general lake water quality trends.

Once you have defined your purpose for sampling, you can figure out where to collect the samples, what analyses to perform, and when to do the work. The complexity of your program also will be affected by the number of volunteers and your budget.

It is often useful to begin a lake monitoring program by obtaining or drawing a rough map of the lake. Show the inflows and outflows; mark the shallow portions of lake and known deep "holes;" and show any aquatic plant beds, rocky shorelines, or other physical differences you may have noticed. Note the prevailing wind direction. You also may want to locate or record such things as the presence of stormwater runoff pipes or culverts, types of shoreline vegetation (lawns, native vegetation, or agricultural land), and adjacent land use.

Depending upon the location and development pressure around your lake, it may be interesting to revise this map periodically to provide ongoing documentation of factors that will influence lake water quality.



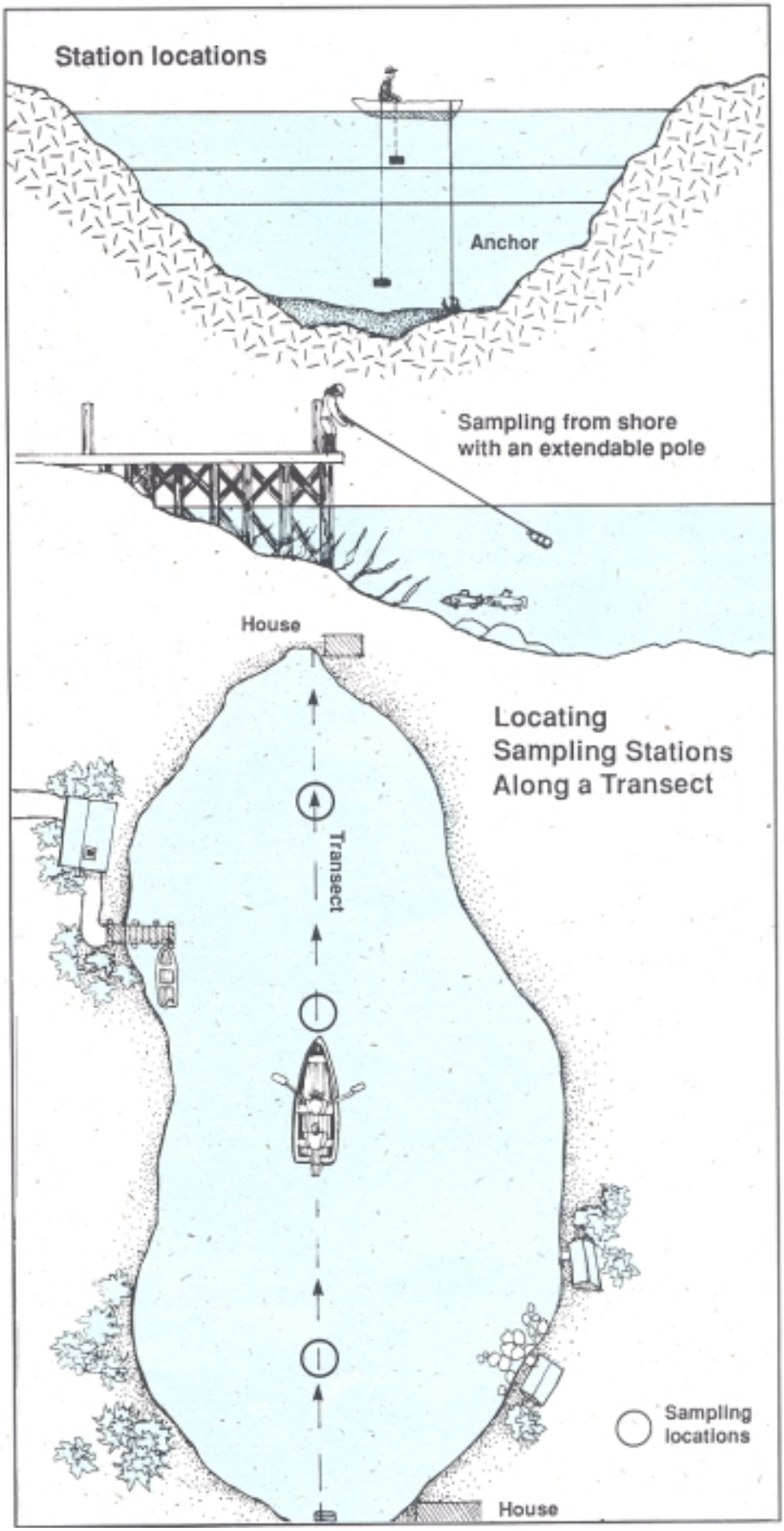
Selecting Sampling Locations

The selection of sampling stations is directly dependent upon your monitoring objectives. If your objective is to characterize the entire lake, and it happens to be a large lake with a number of shallow bays, inflowing streams, or other distinguishing characteristics, then it is likely a number of stations will be needed to provide an adequate characterization. If your objective is to learn how lakes function, stations in physically diverse locations (bays and open water) and at different depths should be selected. Conversely, if tracking water quality trends is your objective, it could be argued that one station could be used to represent any lake.

Avoid sampling near shore, near inflows, or in the downwind direction. Prevailing winds blow algae, zooplankton, and debris down the lake and toward the shoreline; samples collected in these areas are less representative of the lake's overall water quality. If a boat is not available, choose a location about midway down the shoreline and sample off a long pier, using a pole to collect the sample as far from the shoreline as possible.

In deep lakes, sampling at two depths (near surface and near bottom) is a good idea. In a large lake, if you have sufficient volunteers and money for more than one station, choose additional stations according to your interests or physical aspects of the lake. For example, you may want to compare the mid-lake station to a shallow bay. If the lake is long, you could establish stations in a transect along the midsection. Addition of a station at the mouth of important inflowing streams will help you figure out how much they contribute to pollution in the lake.

You will always want to return as near as possible to the same location in the lake. Obviously, if you are sampling from shore this location



is easy to document and remember. However, if you are sampling from a boat, it can be a little more difficult. Identify landmarks along the shore and line the boat up with them and document the location. An example field note – "Line the boat up on a visual transect between the small yellow house on the northern shore and the-gray barn on the southern shore, and follow along this transect until the inflow at the eastern tip of the lake is directly across from the boat. Drop the anchor here." (By the way, it is important to use an anchor so you don"t float away from the station during the sampling.)

Selecting Parameters

Water quality parameters, too, should be selected to meet project objectives, number of volunteers, and available money. Field measurements such as pH, temperature, dissolved oxygen, and Secchi depth are inexpensive to measure once the initial equipment or chemical reagents have been purchased. This information alone is enough to do a general water quality assessment, determine trophic state, provide plenty of educational information, and even describe water quality trends if data are collected for a long enough period. Including additional parameters such as nutrient analyses and chlorophyll a just provides more in-depth information for meeting these same objectives. Since these parameters can be more expensive to analyze -- depending upon the measurement method used -- a decision on whether to measure them and at how many stations will be money-dependent. If only a few, nutrient or chlorophyll a samples can be collected, pick the stations that best meet your monitoring objectives. Information on how to collect samples for each of these measurements and different methods for analysis are described in Chapter Four.

When to Sample

Again, the monitoring objectives will be the primary factor influencing when to sample. The following assumes your monitoring objectives are fairly general.

The most critical time period in a lake is typically during the growing season. For general water quality assessment purposes, it is sufficient to monitor from April or May through September or October, either monthly or preferably, every 2 weeks. For general purposes, there is little benefit in monitoring more than every 2 weeks and, in fact, for some, parameters there are statistical reasons for not doing so. If you choose to sample a lake throughout the year, even research professionals typically sample only monthly during the winter.

Samples also should be collected at about the same time of day each time you sample. This allows for some consistency in daylight hours and in all the indirect effects daylight has on the different lake processes.

Example Lake Monitoring Strategies

Educational Monitoring

In this example, the purpose of the monitoring program is not to identify or rate water quality problems, but to learn about how lakes function. The monitoring program is designed to emphasize the changes or differences between stations or through the year. DO, temperature, pH, and Secchi depth are good parameters to start with. If money were available to measure nutrients, TP and SRP would probably be the best choices. These parameters should all change noticeably with season, depth, and probably station. If the lake is deep and more than one station can be sampled, sampling at two depths likely will be more informative than sampling at two stations. Additional stations might be added to show the effect of shallow bays, inflowing streams, or other characteristics. Sampling could occur on a one-time basis or a few times through the summer and maybe once during the winter depending of course, upon how much time you wish to spend.

General Lake Characterization

Here the objective is to collect information from all portions of the lake as a kind of baseline study to better understand the lake. Many stations would be selected to characterize each of the different parts of the lake. The inflow, outflow, small bays, weed beds, a transect of stations along the mid-section of the lake, and at two or more depths at each station are a few ideas on what stations you might select. All the parameters described would be needed for a thorough characterization. Sampling through one season would probably provide enough information to generally characterize how the different portions of the lake function. Because of the general nature of this objective, there would be little merit in continuing a sampling program such as this for very long. Perhaps after the first season a few sampling sites would be excluded and the parameters sampled would be pared down to create a less costly, more focused long-term sampling program.

Water Quality Assessment

In this case, the objective is to determine or even rate the water quality of the lake. DO, pH, temperature and Secchi depth would of course be sampled because they are easy and inexpensive. TP, SRP, and perhaps chlorophyll a would be

sufficient to allow you to rate the water quality in most cases. For many scientific purposes, TN, NO_3,-NO_2, and NH_4, data would be a great advantage. Sampling at one station and two depths would likely allow an adequate general assessment. If the ultimate objective was to use this assessment data to monitor water quality trends, the sampling program would last for a number of years and then be reinstated every few years to continue the trend monitoring.

Most monitoring programs that are not purely educational actually fall somewhere between the general characterization approach and the water quality assessment approach. Typically, at least two stations are monitored (more in a bigger lake), and all the parameters listed are monitored, at least at the two most important stations or depths. At less important stations, just the field measurements (DO, pH, temperature, and Secchi depth) are usually taken.

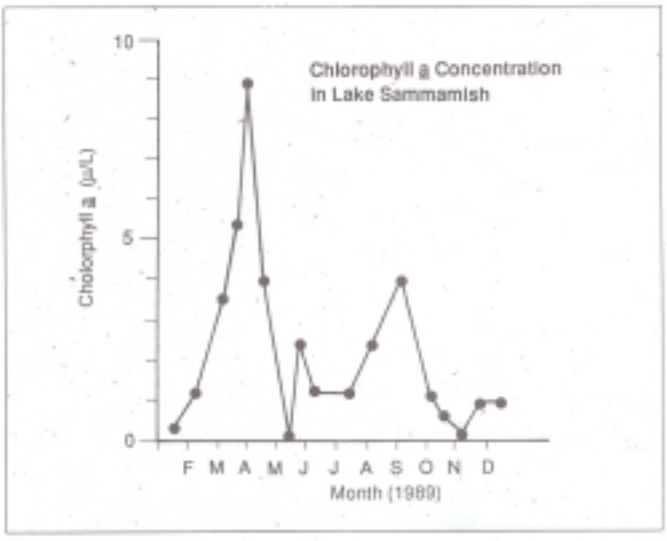
How to Report and Analyze Lake Water Quality Data

Data analysis and interpretation can be as simple as comparing measurements to State standards, or be very complex involving advanced statistics and a thorough understanding of lake dynamics. The following section describes some simple, straightforward approaches to looking at the data you have collected and even making some preliminary determinations on what it all might mean. The first step in assimilating and reporting data is to create a summary table of your data, showing the average and range for each parameter measured. This will make it easy to compare the data to water quality standards or data from other lakes.

You can learn the most about your lake by looking at how a measurement changes over time (like over a growing season) and how one measurement changes with respect to another. It's easiest to see these changes by plotting the numerical values on graph paper.

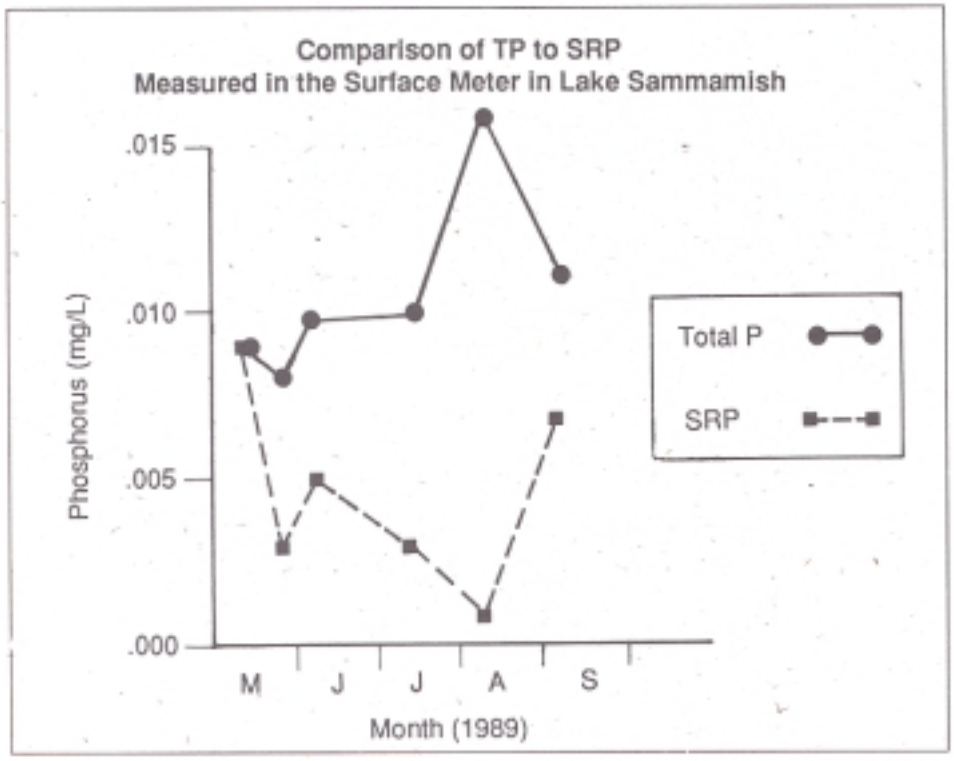
The horizontal axis (x-axis) is used for the *independent* variable. It is called independent because it is not affected by the variable shown on the vertical axis (y-axis). Typical x-axis variables include time, date, and distance. The y-axis is used for the *dependent* variable, which changes over time or date or distance. Typical y-axis variables include the parameters measured in your sampling program, such as dissolved oxygen, total phosphorus concentrations, Secchi , depths, and temperature. Choose the scale of each axis to match the range of numbers -you have measured.

Any of the parameters measured can be plotted to compare changes over time or between stations. The data for the sample plots shown were collected from Lake Sammamish during the summer of 1989. The first plot is a simple depiction of the change in one parameter -- chlorophyll a -- through the year. Although not discussed in this guide, the high early spring peak in chlorophyll a is fairly typical. The available nutrient supply is very high at this time because of the low winter productivity. Consequently, as soon as sunlight increases in the spring, conditions are just right for a large bloom such as the one shown. In this lake, chlorophyll a levels remained low until late summer, when another smaller peak in concentrations was measured.



The second graph on the following page compares TP and SRP concentrations measured in the top meter of the lake. Notice that the TP concentration increased through most of the summer (until August), while SRP decreased. This corresponds to the process described earlier where increased growth and productivity during summer result in higher total nutrient (TP) concentrations but lower amounts of available nutrients (SRP) because available nutrients are being utilized, almost immediately for continued growth.

If you have sampled at more than one station or depth, the next-level of comparison is to plot the results on the same graph use different symbols for each station or depth -- circles for one and a square for the other. When connecting the points, use different styles of line for each station or depth -- like a solid line for one and a dotted line for the other. Different colors serve the same purpose as different shapes and line styles. The third plot compares DO measured in the top meter of Lake Sammamish to that measured at 20 meters depth. This provides a good example of the effects of stratification in a lake. As shown, sometime in late May the concentration of DO began to differ at the two depths -- a sign the lake was stratifying. As the summer progressed, the difference became more acute, as photosynthesis and aeration near the surface created oxygen while chemical and biological processes near the bottom used it up. By July and August, DO near the bottom of the lake was too low to support many fish and other aquatic life.



You may even want to compare different parameters to each other. If the reporting units and expected range of values are the same, you can use the regular y-axis for both parameters. If the units and expected range are different, use a y-axis on the left for one of the parameters and draw another y-axis on the right for the other parameter. The parameters that are commonly compared for lake data are total phosphorus and total nitrogen, total phosphorus and available phosphorus, and total phosphorus and Secchi depth. It also is interesting to compare the change in temperature, DO, and pH with depth in a lake.

After you have made the plots, go back to the beginning of this chapter and review each of the parameters and their reasons for variation. Try to explain the variations in your plots by what you now know about how each of the parameters functions.

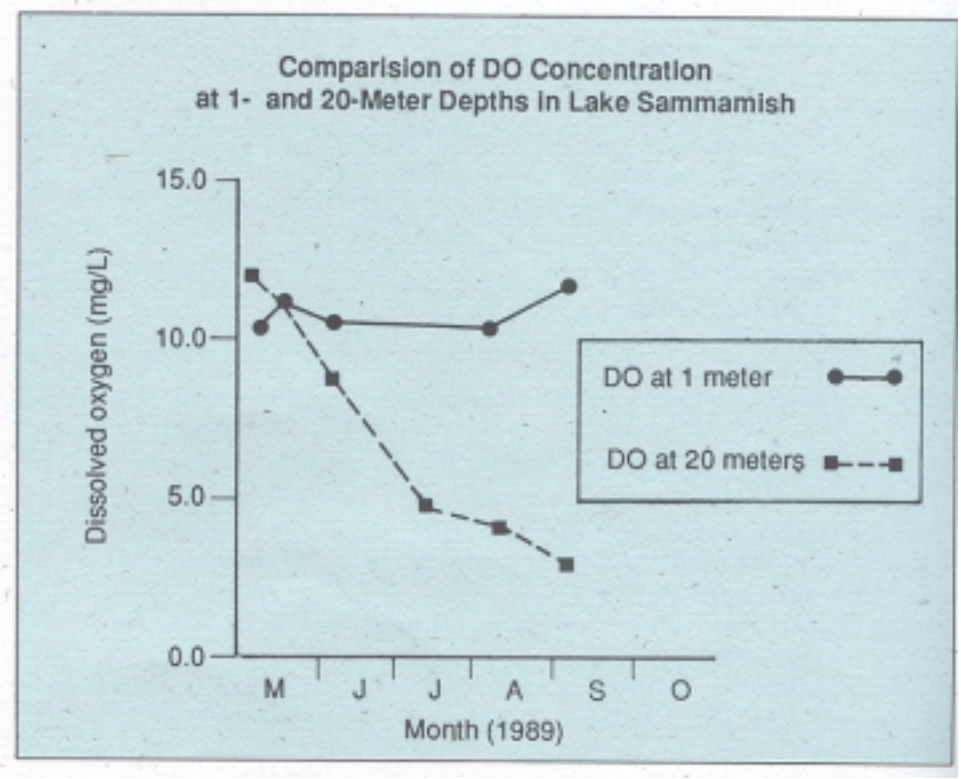
An additional and relatively easy data analysis technique is to calculate your lake's trophic state index (TSI). TSI provides a simple means of determining and comparing lake productivity.

Determining a Lake's Tropic Status

Since lake water quality has so much natural variation, it is not possible to set water quality standards for lakes. It can be much more valuable to compare changes in one lake's quality over the years or to compare between lakes, than to have simple limits for "good" and "bad" lakes. A method has been devised for "rating" lakes. This method is called the trophic state index (TSI) or the Carlson index (after the scientist who devised it).

Calculating TSI

TSI can be calculated by using the Secchi disk depth, the total phosphorus concentration at the surface of the lake, or the chlorophyll a concentration at the surface. Either one day's values or, preferably, average values over the summer can be used. The equations used to calculate TSI are given on the following page.



Using Secchi disk depth:

TSI = 60 - 14.41 (In SD)

Where SD is the Secchi depth in meters, and ln stands for the natural log of a number.

Using total phosphorus:

TSI = 14.42 (In TP) + 4.15

Where TP is the total phosphorus concentration measured in the surface water in µg/L, and ln stands for the natural log of -a number.

Using chlorophyll a:

TSI = 9.81 (In Chla) + 30.6

Where-chla is the chlorophyll a concentration, in µg/L, and ln stands for the natural log of a number.

Once you have calculated the TSI, you can compare the results to other lakes or recalculate the value each year to see whether there appears to be any upward or downward trend in your lake. Again, because of the large natural variation for these parameters, it would take a number of years of data to determine whether any trend existed.

You should be aware that you will not calculate the same TSI value with each of the parameters. In other words, if TSI is calculated using Secchi disk depth, the same result may not be obtained when calculating it with TP.

Comparison of Trophic State Index to Water Quality Parameters and Lake Productivity

Trophic State	TSI	Secchi Disk (m)	Total Phosphorus (µg/L)	Chlorophyll a (µg/L)
Eutrophic	0	64	0.75	0.04
	10	32	1.50	0.12
	20	16	3	0.34
	30	8	6	0.94
Mesotrophic	40	4	2	2.60
	50	2	24	6.40
	60	1	48	20
Eutrophic	70	0.500	96	56
	80	0.250	192	154
	90	0.120	38	427
	100	0.062	768	1,183

(NOTE: The original source of this table with the equations is Carlson, R.E., 1977. A Trophic State Index for Lakes, *Limnology and Oceanography*, 22:361-369.)

According to the scientist who developed this index, chlorophyll a is the best indicator to use if using data from the summer months, while TP is the best during the rest of the year. Of course, if Secchi disk data is all you have – that's what you will use.

The table above provides a comparison of each of the parameters and the resultant TSI. The higher the TSI value, the "older" or more productive the lake is. Roughly speaking, lakes with TSI values between 0 and 40 are considered to be oligotrophic, those between 40 and 60 are mesotrophic, and those between 60 and 100 are eutrophic.

A great deal of information was covered in this chapter. If you've read it from end to end you are probably feeling a little overwhelmed by now. Take a break and let your mind assimilate some of the information. Unless you are also interested in stream monitoring, you should read Chapter Four next. Chapter Four explains how to go about collecting the samples and different analysis methods for the different water quality parameters. You may want to return to this chapter now and again to refresh your memory -- with luck you'll find that each time you read it you will understand some concept a little better.

Streams

One of the greatest things about streams is their endless variety. Some flow through riffle after riffle of deep forest, their banks dotted with moss-covered stones. Others flow through meadows, with deep pools and neatly undercut banks. Still others flow through cement culverts, along parking lots, and past the lawns and driveways of urbanized America. Of course, one stream may journey through all of these environments.

Streams are valuable recreation areas. For most adults the recreational value of streams may be limited to those with boating access or good fishing. But for children, any stream, even in the most industrialized portion of its length, represents the year-round playground of choice.

Streams are the workhorse of the local watershed. Carving through rock and streambanks, they create sediment

Shredders

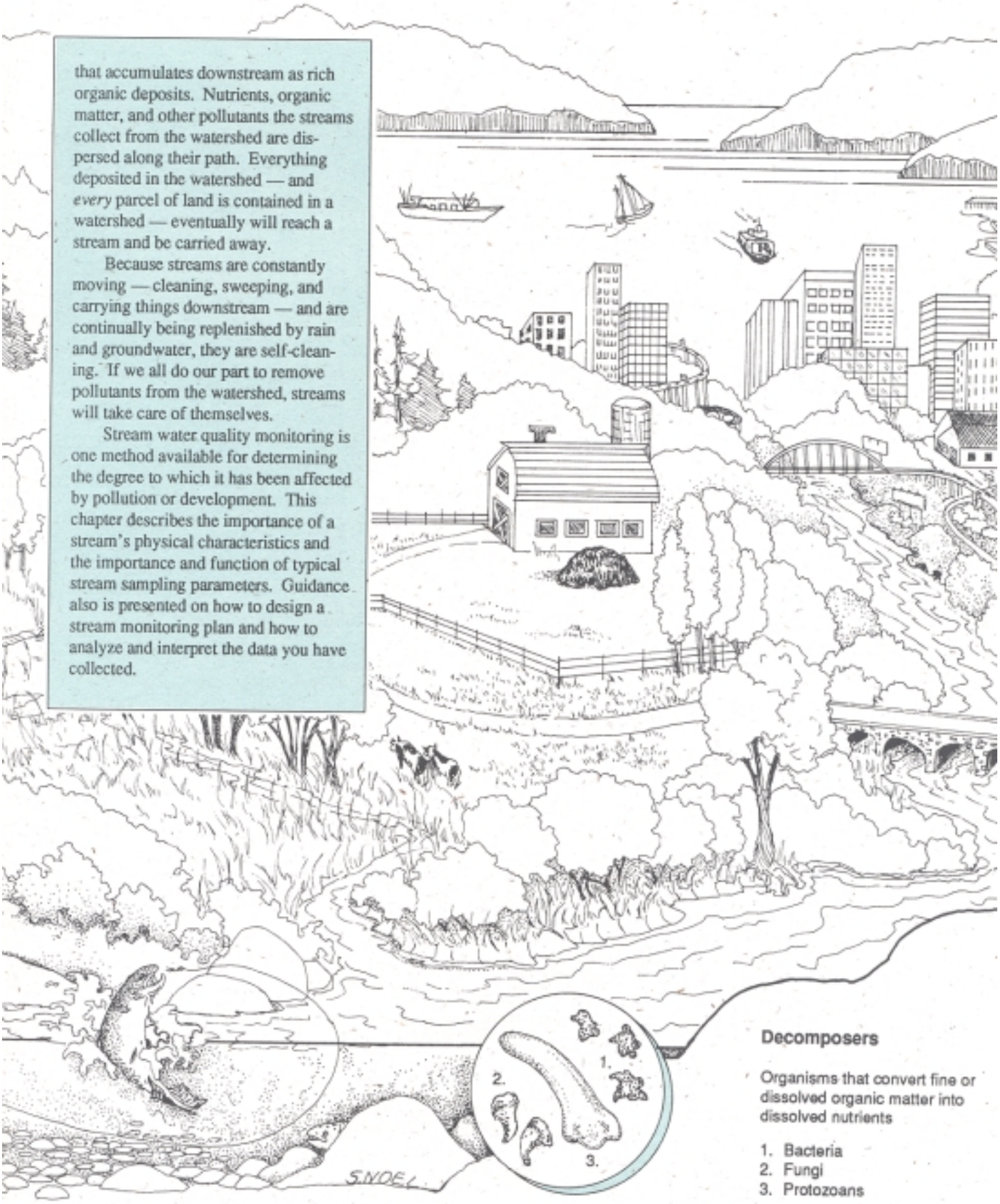
Organisms that convert coarse organic particles such as leaves and twigs into fine or dissolved organic matter.

1. Stonefly nymph
2. Mayfly nymph
3. Caddisfly nymph

that accumulates downstream as rich organic deposits. Nutrients, organic matter, and other pollutants the streams collect from the watershed are dispersed along their path. Everything deposited in the watershed — and *every* parcel of land is contained in a watershed — eventually will reach a stream and be carried away.

Because streams are constantly moving — cleaning, sweeping, and carrying things downstream — and are continually being replenished by rain and groundwater, they are self-cleaning. If we all do our part to remove pollutants from the watershed, streams will take care of themselves.

Stream water quality monitoring is one method available for determining the degree to which it has been affected by pollution or development. This chapter describes the importance of a stream's physical characteristics and the importance and function of typical stream sampling parameters. Guidance also is presented on how to design a stream monitoring plan and how to analyze and interpret the data you have collected.



Decomposers

Organisms that convert fine or dissolved organic matter into dissolved nutrients

1. Bacteria
2. Fungi
3. Protozoans

CHAPTER THREE

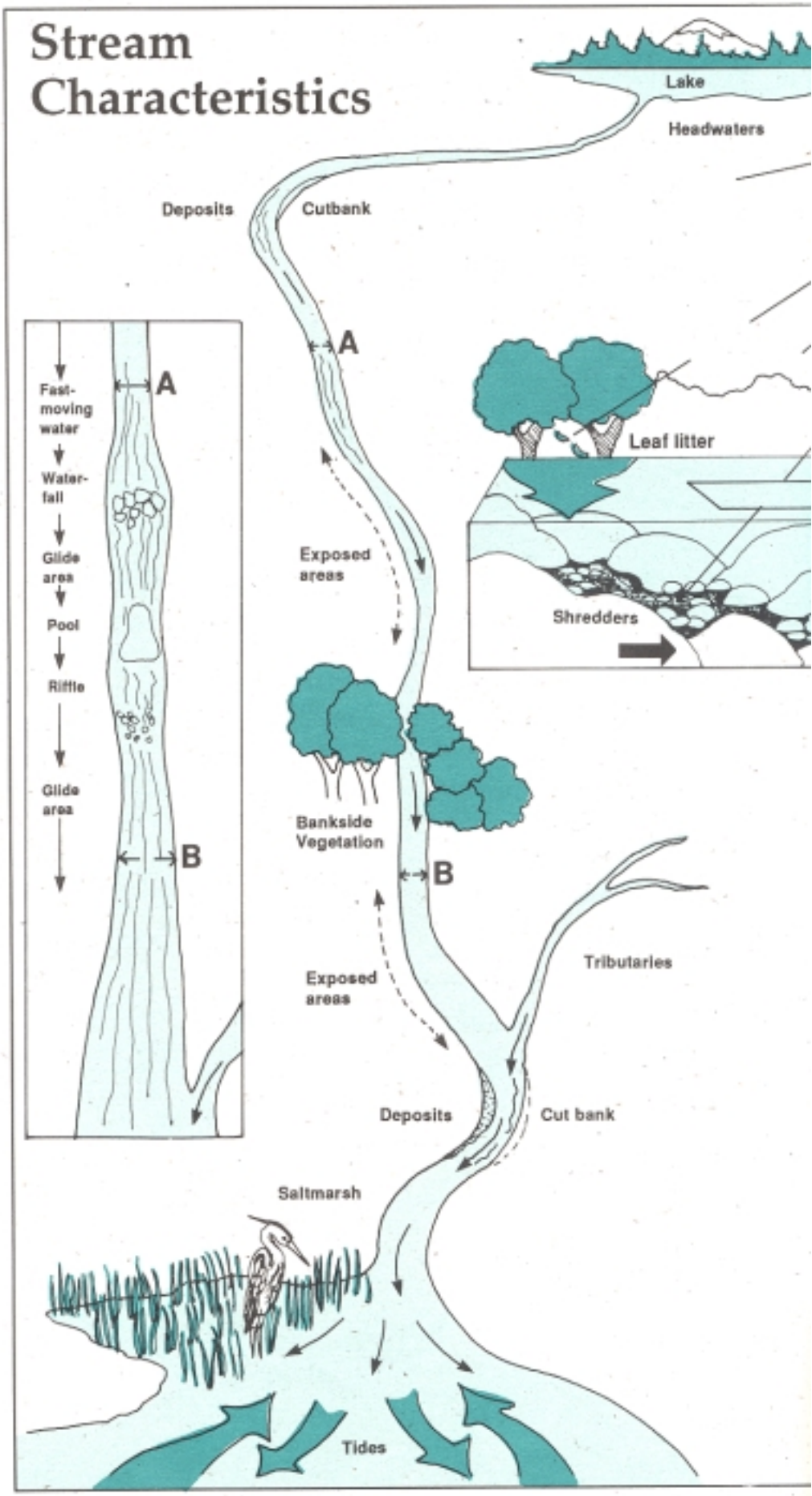
The Physical Character of Streams

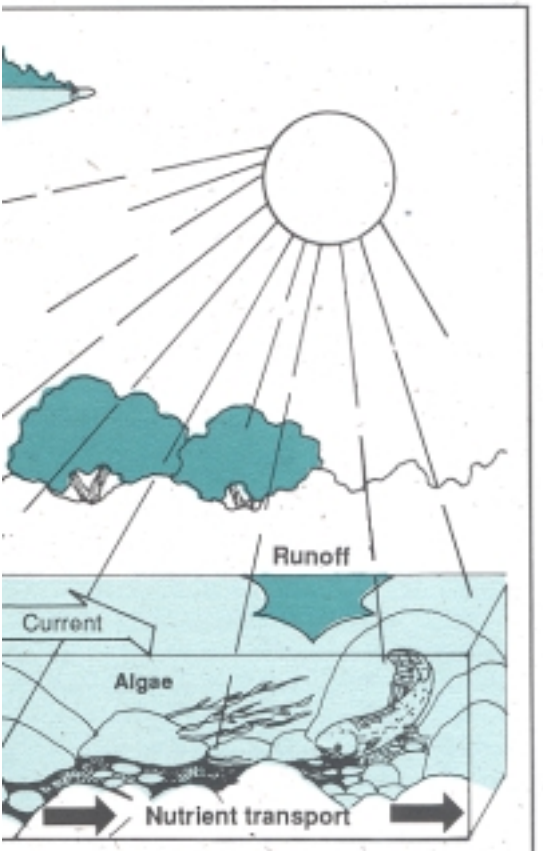
No two streams are exactly alike – not even two segments of the same stream are exactly alike. Consider all the things that make a stream reach what it is: water velocity, depth, width, pools, riffles, vegetation, and the shape and nature of the shoreline. All of these physical characteristics influence water quality and the type and variety of habitat that is available to support aquatic life.

Stream Velocity

Stream velocity is a measure of the water's speed. A fast-moving stream is usually more turbulent than a slow-moving stream. The speed and extra turbulence give the water the force to scour the stream bottom and banks and pick up sediment and other material. The faster the stream is moving, the larger the materials it can pick up and carry with the current. In fact, algae and other organisms can't live in a stream or stream section that is moving too fast because of this strong scouring force.

Stream velocity changes with season; in the Puget Sound Region this generally means faster during the winter and slower during the summer. Velocity also changes within stream segments; where the streambank widens or the channel deepens, the velocity decreases. Velocity also varies across the width of a stream. This is especially true when the stream is following a curve; the velocity is much greater on the outside of the curve than on the inside. The difference is often so great that while the force on the outside of the curve is strong enough to be cutting away at the bank, the force on the inside is so small that material is deposited along the bank.



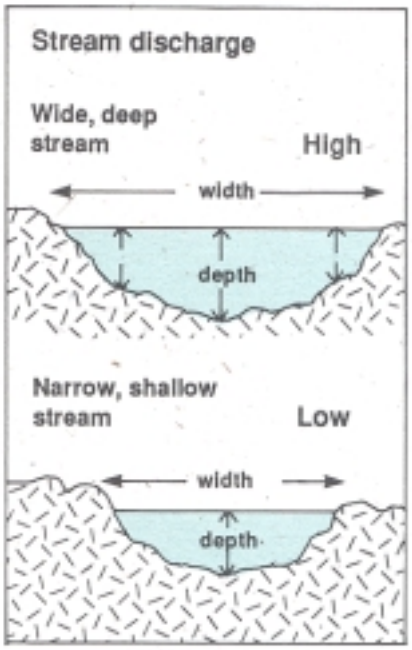


Stream Depth

Stream depth determines the formation of pools, riffle, and glide areas. A pool forms in deeper segments while riffles form in shallow areas. A glide is the smooth, fast-moving area that often separates pools from riffles. Depth determines how much sunlight reaches the stream bottom, which in turn determines whether organisms that require light, such as algae, can grow there. The shallower a stream, the greater the proportion of water that is exposed to the air and sun. Exposure to the air where water can pick up more oxygen is good, but too much exposure to the sun can be harmful if water temperatures increase too much. Stream depth also varies with season, so that a segment that was a pool or glide during the winter may become a riffle during summer.

Stream Width

The narrower a stream, the greater the influence of streamside vegetation. A narrow stream may have a full canopy of trees or shrubs above it, as compared to a wide stream where the trees and other vegetation influence only the very edge. Bankside vegetation keeps temperatures cooler by creating shade, and provides places for fish and other organisms to hide.



Stream Discharge

Stream discharge refers to the total volume of water in the stream. It is a function of the cross-sectional area of the stream (width and depth), and the velocity. A wide, deep stream will have a greater discharge than a shallow, narrow stream, assuming their flow velocity is the same. Conversely, two streams of similar size may have quite different discharges if the flow velocity differs.

Shoreline Shape and Character

Some streams have sharp curves, others are straight. Some have high steep banks, others have gently sloping banks. Bankside characteristics range from exposed dirt, to rock, to thick vegetation. The shape and character of the shoreline affects how water moves past it, what vegetation grows there, and the type of habitat available. The change in the speed and force of water as it cuts around a curve further forms the shoreline and influences the pattern of riffles, pools, and glides. A straight or channelized stream is less stable and more prone to flooding than a curving, meandering stream because of this distribution of energy.

Stream Water Quality Parameters

This section discusses the water quality parameters volunteers frequently test: temperature, dissolved oxygen, pH, nutrients, total suspended solids and turbidity, and fecal coliform bacteria. For each parameter you'll learn why it's important, why measured values differ from one time to another, and how pollution could affect the measurement. Most of the parameters described are related to each other and the relationship is described in the section on each of the parameters. For example, there is a relationship between temperature and dissolved oxygen. This relationship is described in both the discussion on temperature and the discussion on dissolved oxygen. If you find it difficult to understand the discussion under one parameter, move on to the next; with luck you will find the next discussion helps to clarify the first. Chapter Four describes the different methods for analysis for each of these parameters.

State Water Quality Standards

Water quality standards have been established for all surface waters in Washington. Rivers and streams are rated in one of four classes: Class AA – Extraordinary, Class A – Excellent, Class B – Good, and Class C – Fair. Different water quality standards apply to the different classes as set forth by the Washington Administrative Code (WAC) 173-201-045. For each of the parameters discussed, the applicable standard is described in this chapter.

Temperature

Why Is It Important?

Temperature is important because it - governs the kinds of aquatic life that can live in a stream. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. If temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are none.

Temperature also is important because it influences water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen than cool water, so it may be "saturated" with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures.

Reasons for Natural Variation

In addition to seasonal variations in stream temperature caused by changing air temperatures, many other physical aspects of a stream cause natural variation in temperature. The origin of the stream – whether it flows from a glacier, a lowland lake, or a spring or wetland – determines its initial temperature. Tributaries may alter the stream temperature as they mix with the mainstem. Velocity also influences temperature. A particle of water in a fast-moving stream is exposed to sunlight for a shorter time than that in a slow-moving stream.

The physical character of the stream and shoreline also are important. A well-shaded shoreline reduces the impact of warming by the sun. In a wide shallow stream, even a forested shoreline will permit lots of sunlight to fall upon the stream. A narrow, deep stream with a well-vegetated bank would remain cooler.

The character of the watershed also affects temperature. If the watershed is forested and steep-or hilly, runoff water will move quickly and the sun won't have much time to warm the runoff before it reaches the stream. Conversely, in a flat and sparsely vegetated watershed, the water moves more slowly, with more time to absorb heat from the ground surface and the sunlight.

Expected Impact of Pollution

We usually think of thermal pollution in terms of the discharge of heated municipal and industrial discharges. However, the process of watershed development also can affect temperatures in nearby streams. Streambank vegetation often is lost when land is cleared, thereby exposing the stream to increased warming by sunlight. A less obvious impact is that runoff water may be warmer, especially during the summer months when it flows over hot asphalt or concrete. Although temperature-induced impacts from development are important, they are difficult to measure as part of a typical stream monitoring program. It usually is more informative to note the loss of the shade trees and shoreline vegetation or the increase in paved areas in the watershed as indicators of likely temperature effects.

Temperature is reported in degrees on the Celsius temperature scale (^{o}C). The State water quality standard for temperature varies according to the stream classification. Temperature can not exceed 16^{o}C in Class AA streams, 18^{o}C in Class A streams, 21^{o}C in Class B streams, and 22^{o}C in Class C streams. In addition to the maximum allowed temperatures, the total amount of change in temperature as caused by human activities also is regulated. In other words, even if the temperature in a Class AA stream remains below 16^{o}C, if human disturbance causes too much change (as determined by a series of equations described in the regulation) then the standard will have been violated.

The following table summarizes temperature data for three Puget Sound area streams. The streams were selected to represent a range in land use and water quality conditions. The Cedar River watershed is almost 90% forested and has 44 "very good" water quality. The Newaukum Creek watershed is primarily forest, and agricultural land – mostly dairy farming – and is considered to have "fair" water quality. Land use in the Springbrook Creek watershed is

Temperature (^{o}C) Summary Data from 1988-89 From Three Western Washington Streams with Different Land Use and Water Quality.

	Yearly Average	Summer Range (May-Oct)	Winter Range (Nov-Apr)
Cedar River	9.5	10.0-16.0	4.9- 8.2
Newaukum Creek	9.9	9.9-13.0	5.0-10.1
Springbrook Creek	11.4	12.5-19.0	4.0-11.0

Revised From: Metro 1990. *Quality of Local Lakes and Streams 1988-89 Status Report.* Municipality of Metropolitan Seattle, Water Resources Section.

commercial and industrial with some agriculture; the water quality is considered to be "poor." These same streams will be used throughout this section on water quality parameters to provide an example of the normal range that can be expected in each type of data.

Dissolved Oxygen

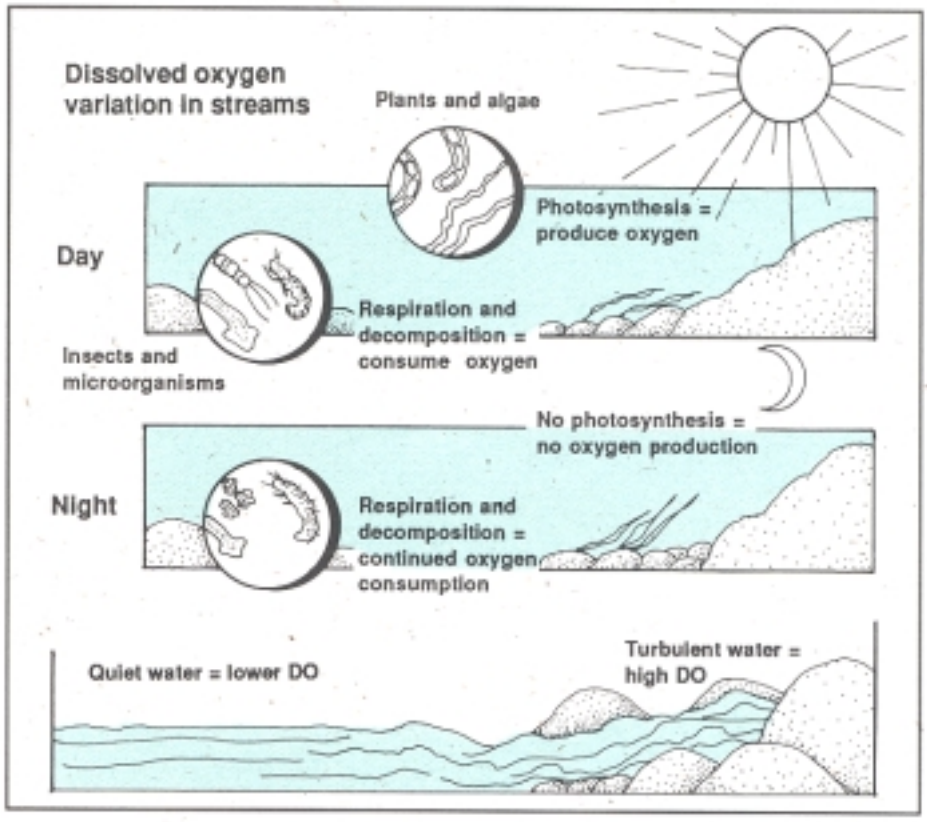
Why Is It Important?

Like terrestrial animals, fish and other aquatic organisms need oxygen to live. As water moves past their gills (or other breathing apparatus), microscopic bubbles of oxygen gas in the water, called dissolved oxygen (DO), are transferred from the water to their blood. Like any other gas diffusion process, the transfer is efficient only above certain concentrations. So, a certain minimum amount of oxygen must be present in water for aquatic life to survive. In other words, oxygen can be present in the water, but at too low a concentration to sustain aquatic life. In addition to being required by aquatic organisms for respiration, oxygen also is used for decomposition of organic matter and other biological and chemical processes.

Reasons for Natural Variation

Oxygen is produced during photosynthesis and consumed during respiration and decomposition. Because it requires light, photosynthesis occurs only during daylight hours. Respiration and decomposition, on the other hand, occur 24 hours a day. This difference alone can account for large daily variations in DO concentrations. During the night, when photosynthesis cannot counterbalance the loss of oxygen through respiration and decomposition, DO concentrations steadily decline. They are lowest just before dawn, when photosynthesis resumes.

Dissolved oxygen concentrations increase wherever the water flow becomes turbulent, such as in A riffle area, waterfall, or a dam. Oxygen concentrations are much higher in air, which is about 21 percent oxygen, than in water, which is a tiny fraction of 1 percent oxygen. Where the air and water meet, this tremendous difference in concentration causes oxygen molecules in the air to dissolve into the water until saturation is reached. More oxygen dissolves into water when turbulence caused by rocky bottoms or steep gradients brings more water into contact with the surface. A similar process happens when you add sugar to a cup of coffee. The sugar dissolves, but it will dissolve more quickly if you stir the coffee.



Another, physical process that impacts DO concentrations has to do with the temperature of the water and gas saturation. Cold water can hold, more gas – that is DO – than warm water. So, during the summer months when stream water is warmer, oxygen can be limited by the ability of the water to "soak up" more oxygen gas. A table comparing oxygen saturation at different water temperatures can be found on page 11 in the Lakes chapter.

There are other reasons for seasonal variation. During late summer, streamflows can get very low in the Puget Sound area. Many of the tributaries that provide oxygenated water to the main stream dry up, and as water moves slowly over what may previously have been riffles or rapids, there is less opportunity for aeration and oxygenation. Warmer summer temperatures also cause increased biological activity (growth, productivity, respiration, and decomposition), and therefore greater daily variability in DO.

Expected Impact of Pollution

Pollution tends to cause a decrease in stream oxygen concentrations. This change can be caused by addition of effluent or runoff water with a low concentration of DO or chemical or biological constituents that have a high oxygen demand – that is they require large amounts of oxygen before they can be thoroughly decomposed. The latter is often the more typical and more serious case.

The demand for oxygen doesn't occur directly where the effluent or runoff water is discharged but instead

Dissolved Oxygen Concentrations (mg/L)
Measured in Three Western Washington Streams during 1988-89.

	Yearly Average	Summer Range (May-Oct)	Winter Range (Nov-Apr)
Cedar River	11.4	9.4-11.9	11.0 - 12.4
Newaukum Creek	11.0	9.9-11.1	10.9 - 12.2
Springbrook Creek	5.8	2.1- 6.2	4.3 - 8.8

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somewhere downstream where decomposition finally occurs. This can make it difficult to show a direct relationship between addition of an oxygen demanding pollution source and decrease in oxygen concentrations. There is a way to determine the amount of oxygen required for decomposition of a pollutant source by measuring what is called the biochemical oxygen demand (BOD). Since this measurement is not typically included in citizen monitoring efforts it is not covered in this text. *Standard Methods for the Examination of Water and Wastewater* is a commonly used reference manual for water quality studies and provides information on BOD analysis. The full reference is included in the reference section at the back of this book.

Stormwater runoff also delivers oxygen-demanding substances to streams. When a watershed becomes developed, greater quantities of pollutants are released and the total volume of runoff increases. Most conventional pollutants (sediments, nutrients, organic matter) require oxygen for decomposition or for chemical reactions. Consequently, DO concentrations often decrease in streams located in a developed or developing watershed.

Dissolved oxygen concentrations are reported in units of milligrams of gas per liter of water (mg/L). (The unit mg/L is equivalent to parts per million [ppm].) The state water quality standard for oxygen in streams is based on the stream classification. DO concentrations must exceed 9.5 mg/L for Class AA streams, 8.0 mg/L for Class A streams, 6.5 for Class B, and 4.0 for Class C. The table above contains summary data for DO concentrations measured in three Western Washington area streams.

pH

Why Is It Important?

The pH of a sample of water is a measure of the concentration of hydrogen ions. The term pH was derived from the manner in which the hydrogen ion concentration is calculated – it is the negative logarithm of the hydrogen ion (H+) concentration. What this means to those of us who are not mathematicians, is that at higher pH there are fewer free hydrogen ions, and that a change of one pH unit means there is a tenfold change in the concentration of the hydrogen ion. For example, there are ten times more hydrogen ions available at a pH of 7 than at a pH of 8. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH less than 7 are acidic, while substances with pH greater than 1 are basic. The pH of most natural waters ranges between 6.5 and 8.5.

The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (e.g., phosphorus, nitrogen, and carbon) and heavy metals (e.g., lead, cadmium, copper). For example, in addition to determining how much and what form of phosphorus is most abundant in the water, pH also determines whether aquatic life can use it. Heavy metals tend to be more toxic at lower pH because they are more soluble and more bioavailable.

Reasons for Natural Variation

Geology of the watershed and the original source of the water determine the initial pH of the water. The greatest natural cause for change in pH in a stream is the seasonal and daily variation in photosynthesis, Photosynthesis uses up hydrogen molecules, which causes the concentration of hydrogen ions to decrease and therefore the pH to increase. Respiration and decomposition processes lower pH. For this reason, pH is higher during daylight hours and during the growing season, when photosynthesis is at its peak.

Although pH may be constantly changing, the amount of change remains fairly small. Natural waters are complex, containing many chemical “shock absorbers” that prevent major changes in pH. Small or localized changes in pH are quickly modified by various chemical reactions so little or no change may be measured. This ability to resist change in pH is called *buffering capacity*. Not only does the buffering capacity control would-be localized changes in pH, it controls the overall range of pH change under natural conditions. The pH scale may go from 0 to 14, but the pH of natural waters hovers between 6.5 and 8.5.

Expected Impact of Pollution

Because polluted conditions typically correspond with increased photosynthesis in a stream, pollution may cause a long-term increase in pH. The more common concern is changes in pH caused by discharge of municipal or industrial effluents. However, most effluent pH is fairly easy to control, and all discharges in Washington State are required to have a pH between 6.0 and 9.0 standard pH units, a range that protects most aquatic life. So, although these discharges-may have a measurable

impact on pH, it would be unusual (except in the case of treatment plant malfunction) for pH to extend beyond the range for safety of aquatic life. However, since pH greatly influences the availability and solubility of all chemical forms in the stream, small changes in pH can have many indirect impacts on a stream.

pH is expressed in terms of pH units. The State water quality standard for pH in Class AA, A, and B streams states that pH must fall within a range of 6.5 to 8.5. For Class C streams, pH must fall within a range of 6.5 to 9.0. Because pH represents the antilog of a number it is not mathematically correct to calculate simple averages or other summary statistics. pH should be reported as a median or range of values. The table at the right summarizes pH data to provide a comparison for three Western Washington streams.

Summary of pH Data (pH units) Collected from Three Western Washington Streams During 1988-89.

	Yearly Median	Summer Range (May-Oct)	Winter Range (Nov-Apr)
Cedar River	7.6	7.4 – 7.9	7.2 - 7.5
Newaukum Creek	7.7	7.9 – 8.0	7.4 - 7.6
Springbrook Creek	7.0	6.9 – 7.2	6.7 - 7.0

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Nutrients

Why Are They Important?

Nutrients in streams serve the same basic function as nutrients in a garden. They are essential for growth. In a garden growth and productivity are considered beneficial, but this is not necessarily so in a stream. The additional algae and other plant growth allowed by the nutrients may be beneficial up to a point, but may easily become a nuisance.

The main nutrients of concern are phosphorus and nitrogen. Both elements are measured in several forms. Phosphorus can be measured as total phosphorus (TP), or soluble reactive phosphate (SRP) (also sometimes called phosphate (PO_4) or orthophosphate (ortho-P). The last three represent different terms used to describe the fraction of TP that is *soluble* or available to organisms for growth. Nitrogen can be measured as total nitrogen (TN), total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3), nitrite-nitrogen (NO_2) [these are usually measured as nitrate-nitrite-nitrogen (NO_3-NO_2)], or ammonia-nitrogen (NH_4). TN is similar to TP and is used to represent the total amount of nitrogen in a sample. TKN represents the fraction of TN that is unavailable for growth or bound up in organic form; it also includes NH_4. The remaining fractions (NO_3-NO_2, and NH_4) represent bioavailable forms of nitrogen. If they are summed they can be compared to the SRP fraction of phosphorus.

One chemical form of an element can be converted into another. The conditions under which the conversion occurs are influenced by many factors, such as pH, temperature, oxygen concentration, and biological activity.

The total concentration of a nutrient (e.g., TP or TN) is not necessarily the most useful measurement. For example, if a sample is analyzed for TP, all forms of the element are measured, including the phosphorus "locked up" in biological tissue and insoluble mineral particles. It may be more useful to know the concentration of phosphorus that is actually available for growth. SRP better reflects bioavailability.

Although there are many different forms of nutrients that can be measured there are only three commonly used combinations. These are: (1) measure all forms of both elements – TP, SRP, TN, NO_3-NO_2, NH_4; (2) measure only total nutrients – TP and TN; or (3) measure only available nutrients – SRP and NO_3-NO_2 and NH_4. (In the first example TKN could be exchanged for TN. In either case, the remaining fraction can be estimated by difference.)

Reasons for Natural Variation

The concentration of nutrients and the form they are found in changes continually. How and why they change is a very complex field of study. First, the total input of nutrients varies depending upon land use and other factors. During the summer, nutrient input may increase due to fertilization of cropland or lawns and gardens. During the winter, high rainfall causes increased wash-off of organic matter such as leaves, twigs, grass, and other debris. Because decomposition of this organic matter releases nutrients, it constitutes an important source of nutrient loading.

If the stream is fed by a lake or other water source with naturally high variations in nutrient concentrations, the stream will reflect the same variations. In the Puget Sound region, salmon carcasses from annual spawning migration represent a large seasonal source of organic matter and nutrients.

Whether the increase in total nutrient concentrations results in higher available nutrient concentrations, and therefore an immediate increase in growth or productivity, depends upon the original form of the nutrient and physical conditions. If nutrients enter as organic matter that first needs to be decomposed before it can be utilized for growth, temperature becomes important due to its effect on the rate of decomposition. (During warmer months, nutrients entering the system as intact organic matter would be decomposed relatively quickly as compared to cold, wet-weather months when decomposition is slow.)

These dynamics are further complicated by the fact that increased growth leads to greater numbers of organisms that need even more nutrients. So, as nutrients become available they are immediately utilized. In this case, an increase in total nutrients would not be reflected by any measurable increase in available nutrient fractions. In short, clear, simple relationships between increases in organic matter or other sources of nutrients, and resultant increases in either total nutrient concentrations or available nutrient concentrations, become obscure.

Expected Impact of Pollution

Increased nutrient concentrations are almost always an impact of pollution. Municipal and industrial discharges usually contain nutrients, and overland flow from developed watersheds contains nutrients from lawn and garden fertilizers as well as the additional organic debris so easily washed from urban surfaces. Agricultural areas also contribute to nutrient increases through poor manure and fertilizing practices and increased erosion from plowed surfaces.

Nutrient loading can result in increased algae growth. In stream segments where conditions are right, algae take the form of an attached growth – called *periphyton* – on rocks, logs, and other substrate. You may have noticed long green filaments or masses of algae in streams or even stepped on rocks made slippery by these growths. Excessive growths of attached algae can cause low DO, unsightly conditions, odors, and poor habitat conditions for aquatic organisms.

Nutrient concentrations are reported in units of micrograms or milligrams of nutrient per liter of water (µg/L or mg/L). There are no State water quality standards for nutrient concentrations. The table above summarizes nutrient data from three Western Washington streams.

Nutrient Concentration (µg/L) Measured in Three Western Washington Streams during 1988-89 (No TN data are available.)

		TP	SRP	NH_4	NO_3-NO_2
Cedar River	A	14	9	18	290
	S	7-30	5-16	1-111	126-195
	W	10-25	3-11	1-29	315-585
Newaukum	A	100	83	100	1987
	S	43-65	37-59	1-28	1440-2350
	W	74-213	55-180	72-380	1560-3020
Springbrook	A	194	147	451	608
	S	180-254	52-230	175-725	320-740
	W	105-293	80-234	74-1240	405-963

A = yearly average; S = summer range (May-Oct); W = winter range (Nov-Apr)

Revised From: Metro 1990. *Quality of Local Lakes and Streams, 1988-89 Status Report.* Municipality of Metropolitan Seattle, Water Resources Section.

Total Suspended Solids and Turbidity

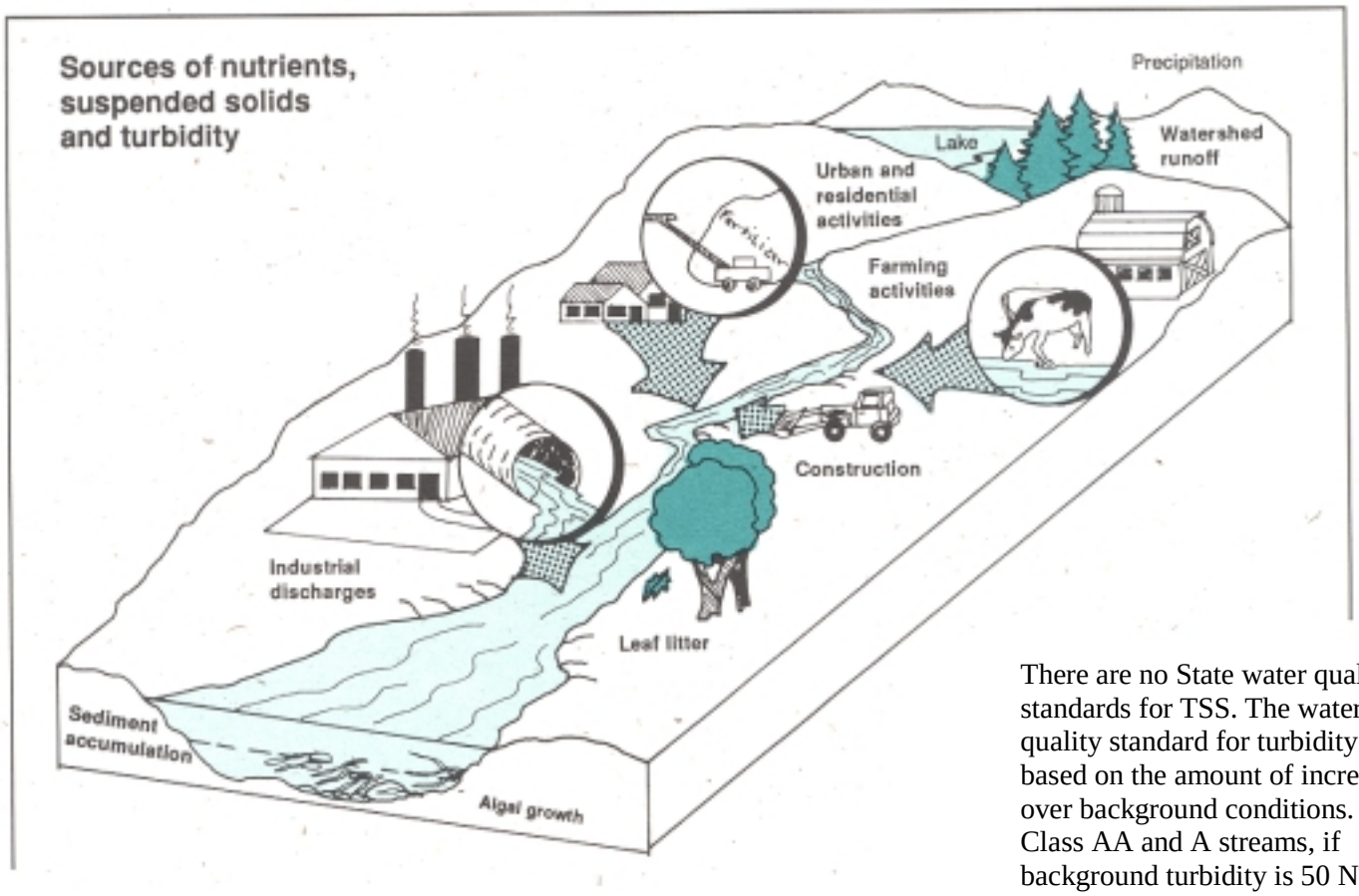
Why Is It Important?

Total suspended solids (TSS) concentrations and turbidity both indicate the amount of solids suspended in the water, whether mineral (e.g., soil particles) or organic (e.g., algae). However, the TSS test measures an actual weight of material per volume of water, while turbidity measures the amount of light scattered from a sample (more suspended particles cause greater scattering). This difference becomes important when trying to calculate total quantities of material within or entering a stream. Such calculations are possible with TSS values but not with turbidity readings.

High concentrations of particulate matter can cause increased sedimentation and siltation in a stream, which in turn can ruin important habitat areas for fish and other aquatic life. Suspended particles also provide attachment places for other pollutants, such as metals and bacteria. High suspended solids or turbidity readings thus can be used as "indicators" of other potential pollutants.

Reasons for Natural Variation

TSS and turbidity values vary naturally for two main reasons – one physical, the other biological. Heavy rains and fast-moving water are erosive. They can pick up and carry enough dirt and debris to make any stream look dirty. So, heavy rainfall may cause higher TSS concentrations or turbidity, unless the additional, particles are dispersed throughout large volumes of flood water. The native soils and geology of the watershed of course determine how easily erosion occurs.



A small part of the natural increase may be explained by seasonal changes in algae populations. It is the suspended forms of algae (i.e., those floating in the water column) that are measured by TSS and turbidity. If the original water source is a lake, or wetland where algae populations can vary drastically with season, this may show up as changes in stream TSS or turbidity. However, in streams themselves, attached forms of algae (i.e., those attached to rocks, logs, or other substrate) are far more common. The change in these populations aren't measured by TSS or turbidity until they wash off the substrate. Wash-off may not occur until the algal mass dies, is scoured off by large flows, or the mass becomes too large to remain on the substrate.

Expected Impact of Pollution

Land use is probably the greatest factor influencing changes in TSS or turbidity in streams. As watersheds develop, there is an increase in disturbed areas (e.g., cropland or construction sites), a decrease in vegetation, and increases in the rate of runoff. These all cause increases in erosion, particulate matter, and nutrients, which in turn promote increased algal growth. For example, loss of vegetation due to urbanization exposes more soil to erosion, allows more runoff to form, and simultaneously reduces the watershed's ability to filter runoff before in reaches the stream.

TSS concentrations are reported in units of milligrams of suspended solids per liter of water (mg/L). Turbidity is reported as nephelometric or Jackson turbidity units (NTU or JTUs), depending on the instrument used to perform the measurement.

There are no State water quality standards for TSS. The water quality standard for turbidity is based on the amount of increase over background conditions. For Class AA and A streams, if background turbidity is 50 NTU or less, then the total amount of increase can not be more than 5 NTU. If the background is greater than 50 NTU, then the increase can not be above 10 percent of the back- ground level. For Class B and C streams, if background turbidity is 50 NTU or less, then the total amount of increase can not be more than 10 NTU. If the background is greater than 50 NTU, then the increase can not be above 20 percent of the back- ground level. The following tables provide summary information for both TSS and turbidity for three Western Washington streams.

Turbidity (NTUs) Measured in Three Western Washington Streams During 1988-89.

	Yearly Average	Summer Range (May-Oct)	Winter Range (Nov-Apr)
Cedar River	1.1	0.4- 1.2	1.0 - 2.0
Newaukum Creek	2.4	0.7- 1.5	3.1 - 4.0
Springbrook Creek	22.0	13.0- 44.0	13.0 - 35.0

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TSS (mg/L) Measured in Three Western Washington Streams During 1988-89.

	Yearly Average	Summer Range (May-Oct)	Winter Range (Nov-Apr)
Cedar River	3.6	0.6- 5.0	3.5 - 6.2
Newaukum Creek	5.7	1.6- 5.1	7.5 - 8.8
Springbrook Creek	19.8	8.0- 26.0	6.7 - 44.0

Revised From: Metro 1990. *Quality of Local Lakes and Streams 1988-89 Status Report.* Municipality of Metropolitan Seattle, Water Resources Section.

Fecal Coliform Bacteria

Why Is It Important?

Fecal coliform bacteria are microscopic animals that live in the intestines of warm-blooded animals. They also live in the waste material, or feces, excreted from the intestinal tract. When fecal coliform bacteria are present in high numbers in a water sample, it means that the water has received fecal matter from one source or another. Although not necessarily agents of disease, fecal coliform bacteria indicate the presence of disease-carrying organisms, which live in the same environment as the fecal coliform bacteria.

Reasons for Natural Variation

Unlike the other conventional water quality parameters, fecal coliform bacteria are living organisms. They do not simply mix with the water and float straight downstream. Instead they multiply quickly when conditions are favorable for growth, or die in large numbers when conditions are not. Because bacterial concentrations are dependent on specific conditions for growth, and these conditions change quickly, fecal coliform bacteria counts are not easy to predict. For example, although winter rains may wash more fecal matter from urban areas into a stream, cool water temperatures may cause a major dieoff. Exposure to sunlight (with its ultraviolet disinfection properties) may have the same effect, even in the warmer water of summertime.

Expected Impact of Pollution

The primary sources of fecal coliform bacteria to fresh water are wastewater treatment plant discharges, failing septic systems, and animal waste. Bacteria levels do not necessarily decrease as a watershed develops from rural to urban. Instead, urbanization usually generates new sources of bacteria. Farm animal manure and septic systems are replaced by domestic pets and leaking sanitary sewers. In fact, stormwater runoff in urbanized areas has been found to be surprisingly high in fecal coliform, bacteria concentrations. The presence of old, disintegrating storm and sanitary sewers, misplaced sewer pipes, and good breeding conditions are common explanations for the high levels measured.

Fecal coliform concentrations are reported in units of the number of bacteria colonies per 100 mL of sample water (#/100 mL). The Washington State standards for fecal coliform bacteria vary according to stream classification. For Class AA streams, the geometric mean can not exceed a value of 50 organisms per 100 mL, and fewer than 10 percent of the samples can be greater than 100/100 mL. For Class A streams, the geometric mean can not exceed a value of 100/100 mL, and fewer than-10 percent can be greater than 200/100 mL. For Class B and C streams the geometric mean can not exceed 200/100 mL, and fewer than 10 percent of the samples can be greater than 400/100 mL. The equation used to calculate a geometric mean is described below.

Geometric Mean = $\sqrt[n]{X_1 X_2 X_3 .... X_\pi}$

The table below provides comparison values from three Western Washington streams.

Fecal Coliform Bacteria Concentrations (A#/100mL) Measured in Three Western Washington Streams

	Yearly Geometric Average	Summer Range (May-Oct)	Winter Range (Nov-Apr)
Cedar River	19	20-60	1-60
Newaukum Creek	439	47-1000	340-1800
Springbrook Creek	399	170-5800	57-900

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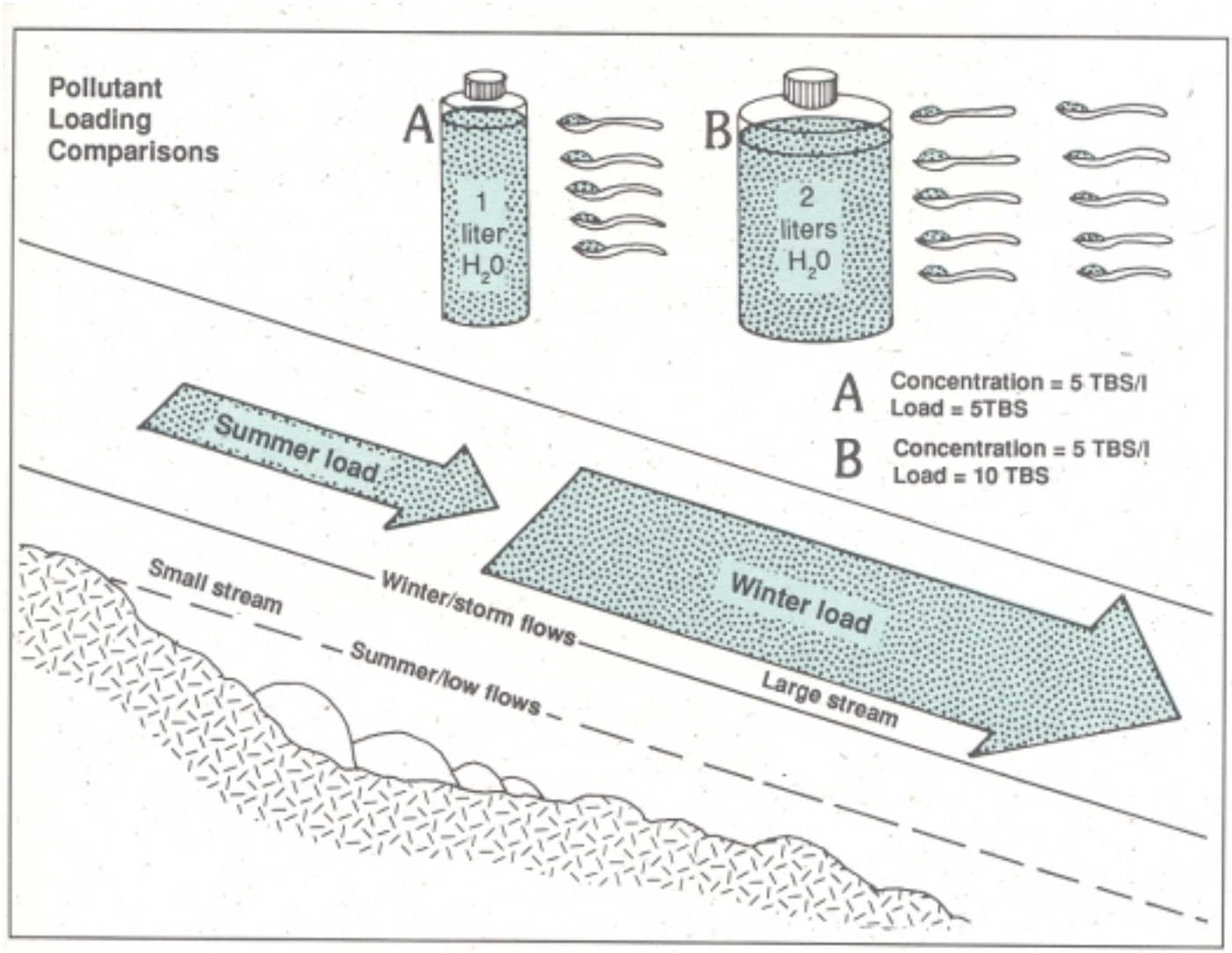


Pollutant Concentrations Versus Pollutant Loading

Before discussing data interpretation it may help to understand the difference between measuring the concentration of a pollutant and knowing what the load of the pollutant is. Imagine you have a liter of water and put five tablespoons of salt in it, the resulting concentration would be five tablespoons per liter (5 Tbsp/L). Now imagine you have a two-liter jug of water and add ten tablespoons of salt, the resulting concentrations would still be five tablespoons per liter (5 Tbsp/L). Although in the second case, the concentration of the pollutant, in this case salt, is the same as it was in the first case, the total amount of the pollutant – the load – is twice as high. Sometimes this pollutant load is more important information than the pollutant concentration.

Consider now a stream in the Puget Sound area where flow is low during summer and high during winter. For example, let's say winter flows are ten times higher than summer flows and the phosphorus concentration is the same in the stream during both winter and summer sampling periods. If you only considered the pollutant concentration you might be tempted to conclude that there was no difference in pollutant levels through the year. BUT, there is ten times more water in the stream during the winter, so there is ten times more phosphorus being transported by the stream in the winter. During the winter the stream contributes ten times the phosphorus load it contributes in the summer, even though pollutant concentrations are the same.

Likewise, think about a lake that has two inflowing streams. Stream A has ten times the flow of stream B, but both have similar concentrations of nutrients. Stream A is contributing ten times more nutrients to the lake than Stream B – it constitutes ten times greater load.

Although State standards and pollution indices are by necessity based on pollutant concentrations, in the case of streams, pollutant loads provide much more comparative information for assessing the level of impact. Pollutant loads are a function of pollutant concentrations and streamflow. Pollutant loads can be calculated for nutrients, TSS, and fecal coliform bacteria. Chapter Five provides a detailed example of how to calculate a pollutant load.

Developing a Stream Monitoring Program

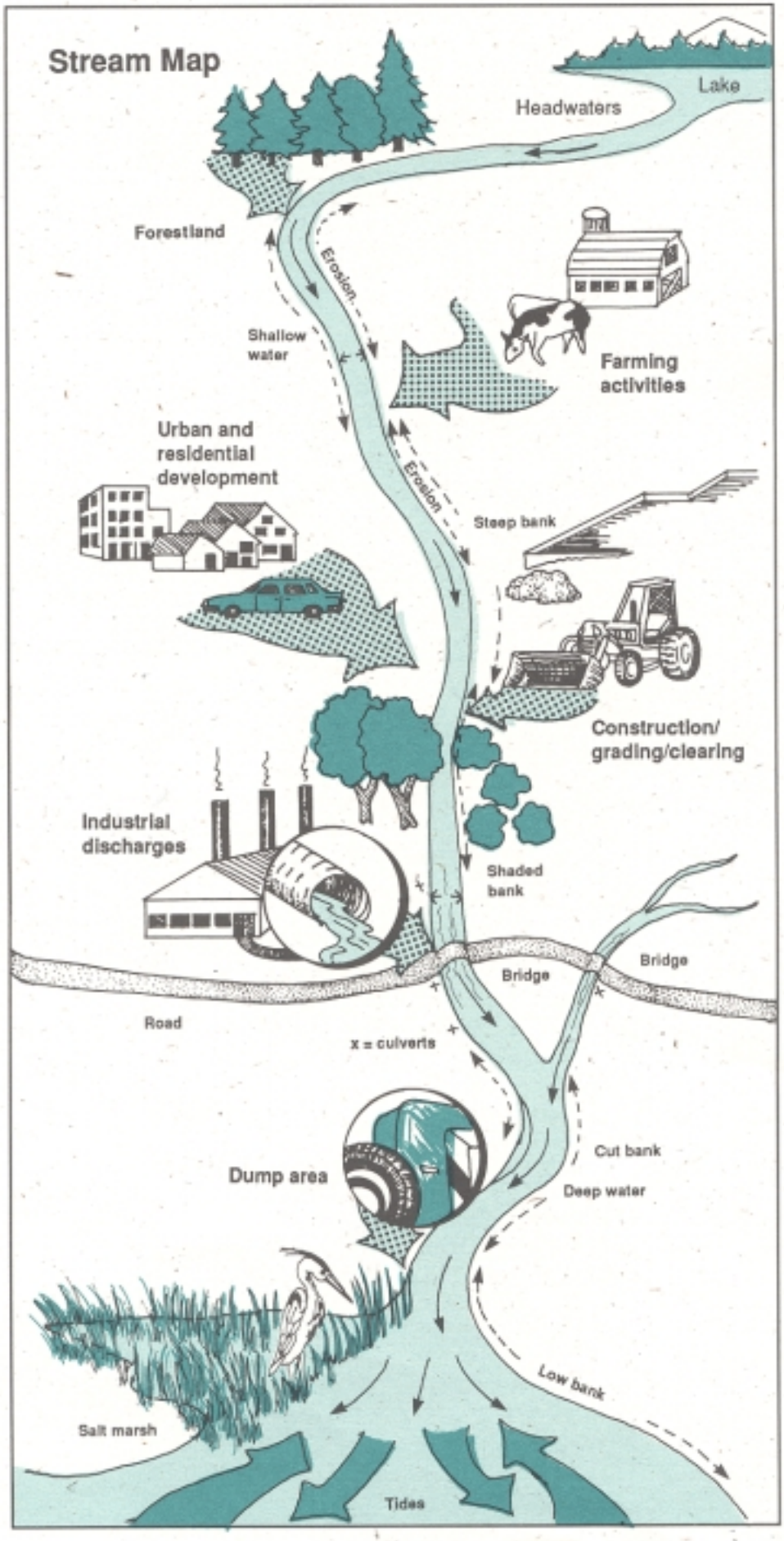
Consider this – streams are moving targets. When you collect a sample of stream water, it reflects a mixture of unknown upstream conditions and characteristics. Say you sampled a shady, fast-moving portion of stream, where you'd expect cooler temperatures. If the segment just upstream (beyond your vision) had been a long stretch of shallow, sunlit, sluggish water, the temperature of your sample might be relatively high – not what you had expected. The water sample reflects upstream characteristics and not just those of the sampling site.

This problem becomes more complex when you consider the addition of nutrients or organic matter. When nutrients are added to a stream, they may not result in a measurable increase in algae growth until a few miles downstream, where temperature, sunlight, or other growing conditions are just right. The resultant mass of algae will eventually require oxygen for decomposition. However, even as the algae die, they are carried farther downstream so that the decrease in oxygen does not occur at the same point as the increase in organic matter. This is an important concept to understand when you are developing your monitoring plan. Data you collect may not reflect conditions at the site in the way you might expect.

Getting Started

Before beginning a stream water quality sampling program, it is helpful to do some map work. Begin with a U.S. Geological Survey (USGS) topographic map. These maps can be found in any map store and many local sporting goods stores. Depending on the length of the stream, you might need more than one map.

First, trace the boundary of the watershed. Start at the mouth of the stream, and moving laterally away



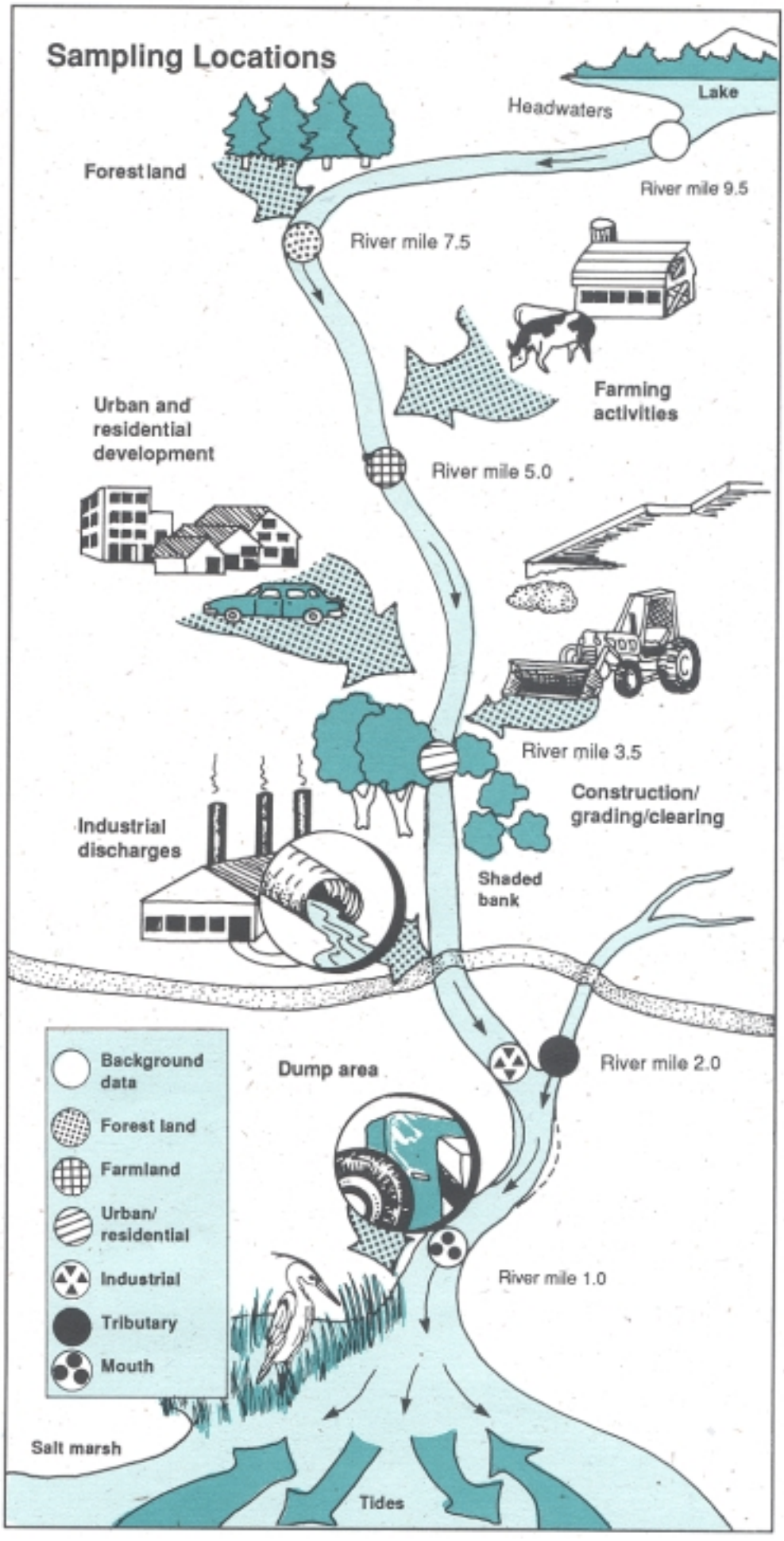
from the stream, follow the rising topography lines until you reach a spot where the land elevation begins to decrease. This is the edge of the watershed – mark the point on the map. Make a number of these points on both sides of the stream and near the headwaters. Then try connecting the dots by following between the topography lines. This is the boundary of the watershed. If you have trouble drawing in the line, imagine dropping a ball in the area and think again about which direction it would roll. If it would roll toward the stream, then the area should be included in the stream's watershed.

Use your knowledge of the area to add detail to the map, which is likely to be at least several years old. Many changes can occur in a watershed over several years, especially if it is in a developing area. Start by roughly outlining areas of the major land uses in the watershed. Show agricultural, rural, residential, urban, industrial, and any other category you find appropriate for your stream. If you know of a new mall or housing development, mark its location, too.

Next, think about the stream corridor itself. -Do you know of places where the bank is very steep, eroding, or trodden down by farm animals? Do you know where stormwater pipes or culverts enter the stream? Have people discarded washing machines, tires, cars, and other junk along the bank? Mark these features on the map. Look at where toads cross over the stream and try to remember what the area near the road looks like. This might help refresh your memory about other features to note on the map.

Keep this stream map current. Place it in your glove compartment and make additional notes whenever you see something worth noting, big or small. You may be able to better understand the reasons for water quality changes by continually updating your map.

A more advanced form of surveying stream features is to take a "stream walk" or "stream survey."



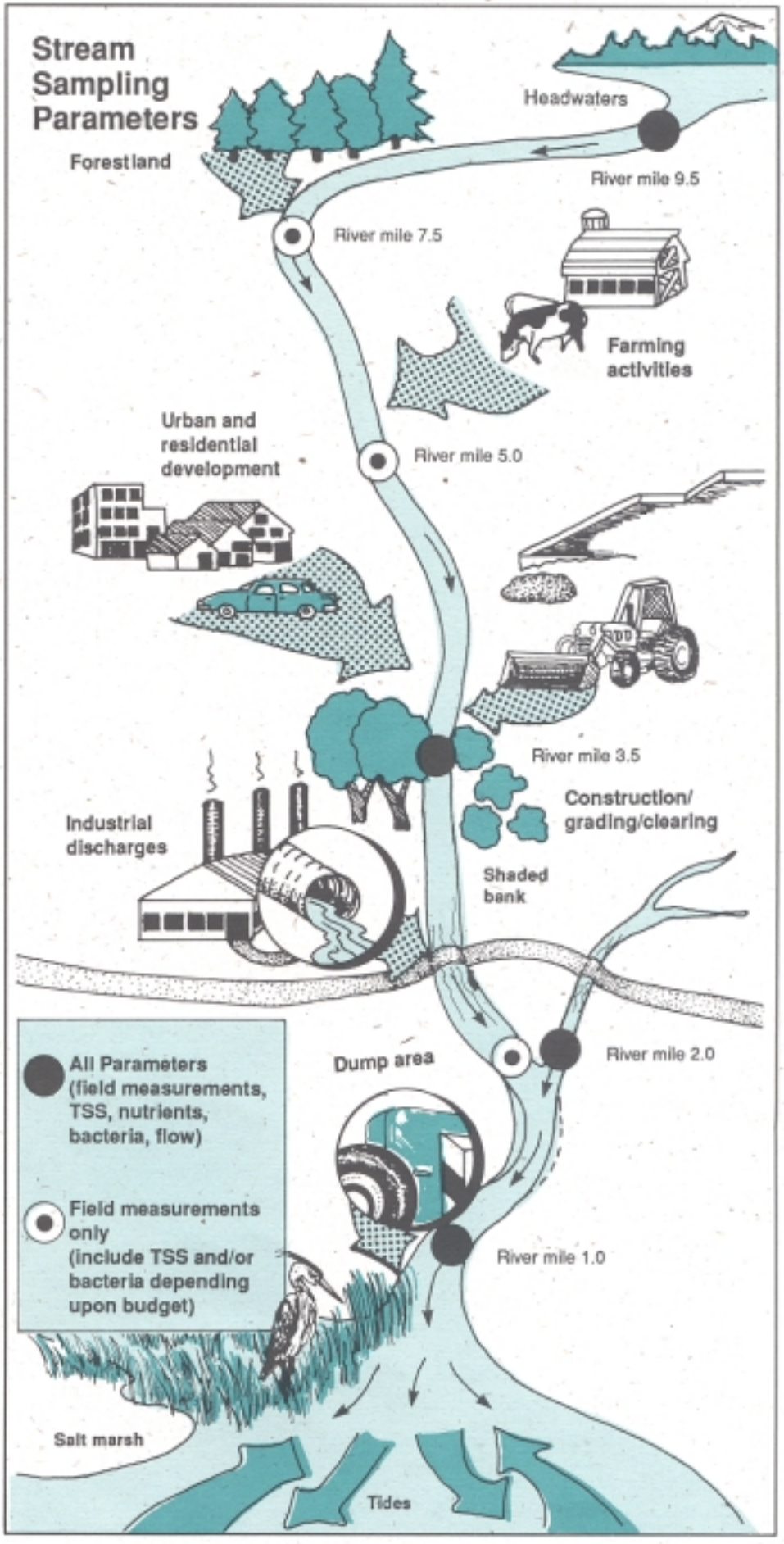
This entails selecting a stream segment and walking its length to make detailed notes on your observations. (Be sure to get landowners permission before starting out!) These notes should include the type and amount of streamside vegetation, the presence of logs or other large debris in the stream, the composition of the stream bottom, the presence of - oil/film or algae scums, and other, easy-to-recognize details. Standard checklists and field note forms are available to help you make good records. The U.S. Environmental Protection Agency (EPA) has a standardized streamwalk form and has developed a computerized database for inclusion of citizens' streamwalk results. The reference section at the end of this guide provides information on EPA's program.

Selecting Station Locations

The number of sampling stations and their locations will depend on your objectives, the number of volunteers involved, your budget, and safety and access considerations. If only one station can be sampled, a logical place for it would be at or near the mouth of the stream. (If you are monitoring strictly for fun or for a class project, convenience may be the overriding factor in sampling location.) If more than one station can be monitored, the headwaters of the stream or a location well above the area of human impact would be a good choice if you want "background" water quality data for comparison.

If you are interested in the effect of a tributary, locate one station above the tributary and one just below the mouth of that tributary. Pick a spot far enough below to ensure it has completely mixed with the main stream. To compare land use impacts, position stations upstream and downstream of the land use of interest, say a city or farmland. The idea is to isolate the source of interest.

NOTE: Because all stations in the watershed should be sampled on the same day, don't establish more stations than you can comfortably sample on a short winter's day.



Selecting Parameters

It often is possible to save money and time by not sampling for every parameter at every station. Like locations, parameters should be selected to meet project objectives, number of volunteers, and available money. Field measurements such as pH, temperature, dissolved oxygen, and stream gage height (see Chapter Five: Hydrology) are quick and inexpensive to measure once the initial equipment or chemical reagents are purchased.

TSS measurements can be made with equipment available at local high schools and so can sometimes be made with little or no lab cost. Turbidity measurements require special equipment and therefore have an associated, though low, lab cost. Usually people choose to measure either turbidity or TSS, not both since in some respects they measure the same thing. Available equipment and money may be determining factors in selecting between them.) These measurements (pH, temperature, DO, and TSS or turbidity) alone can comprise an adequate monitoring program again, depending upon your objectives. Consequently, these measurements often are made at all stations selected.

Including additional parameters such as nutrient or bacteria analyses provides more in-depth information. Since these parameters can be more expensive to analyze – depending upon the measurement method used – a decision on whether to measure them and at how many stations may be money dependent. If only a few of these samples can be collected, pick the stations that best meet your monitoring objectives. If flow measurements are being made, nutrient concentrations should be measured at the same stations to allow calculation of loadings.

Stream flow, although an important parameter, can be time consuming and difficult. Typically, flow is only measured at the most important stations, such as the mouth of the stream and just below tributaries where major changes in flow are expected. Instructions on taking stream flow measurements are included in Chapter Five.

When to Sample

A maximum sampling program would entail sampling every two weeks throughout the year. However, depending upon your objectives, a seasonal approach may be just as effective and will save time and money. This approach would entail biweekly or monthly sampling from May through September and then another spurt of sampling from December or January through March. In this way sampling will be concentrated on the most critical time periods in a stream – the low flow period when temperature and DO levels may be at their extreme, and the high flow period when pollutant loading may be at its peak. You may, of course, choose to sample during just one of these seasons; again, it will depend upon your monitoring objectives. For example, if salmon migration is a concern you might choose to sample only during late summer when high temperatures coupled with low DO could deter migration. Likewise, you might choose to sample only during storm events to estimate peak pollutant loads.

Example Stream Monitoring Strategies

Educational Monitoring

If the purpose of your monitoring program is to learn how streams work, then the sampling strategy should include locations, parameters, and time that would best depict the differences that have been described throughout this chapter. Diverse stations, such as a pool and a riffle, or shaded and unshaded segments, should be selected. Temperature, DO, and pH should change some through the day and should provide interesting comparison data if monitored through the summer season. They will likely not change much through the winter season, but will provide interesting information if compared to summer data. TSS or turbidity is interesting to compare between seasons, or before and after storms. In this case, comparison of TSS concentrations to loadings would be even better. If one or two nutrients could be sampled, SRP and TP would likely provide the best comparison data.

Baseline Study

The purpose of a baseline study would be to provide fairly general information on the stream. The information might be used to develop a more intensive monitoring plan or to provide information against which some future sampling results might be compared. Generally, a baseline study will include selecting a number of stations throughout the stream that represent stream segments of different character or land use. The same parameters might be analyzed at each station; DO, temperature, pH, TSS, and nutrients – either TP and TN only – or TP, TN, SRP, NO_3-NO_2, and NH_4. Bacteria also might be included if it was thought to be an existing or potential problem in the watershed. A baseline study would last over one or two years, but probably no longer.

Water Quality Assessment or Trend Monitoring

In this case the objective is to determine whether the water quality is good, bad, or otherwise, and to monitor whether the quality appears to be changing over time. One station located at the mouth of the stream can be used to assess the water quality and monitor trends. However, typically stations are also located at other points in the stream, similar to stations selected for baseline monitoring. Since the main idea is to monitor over a long period, it becomes even more important to select fewer stations and cut back on the parameters monitored at each. Again, the field measurements – pH, temperature, and DO – can be inexpensive and easy, and therefore measured in many places. TSS or turbidity also are fairly inexpensive and quite informative for assessment purposes. Nutrients (again, either TP and TN; or TP, TN, SRP, NO_3-NO_2, and NH_4) and bacteria would be measured at the most important stations (e.g., those below important tributaries or stream segments).

How to Report and Analyze Stream Water Quality Data

There is a great deal of variation in just how you may want to go about interpreting the information you collect. The level of interpretation will be partially dependent upon the type and quality of the data collected. The following are examples of different approaches to looking at your stream water quality data.

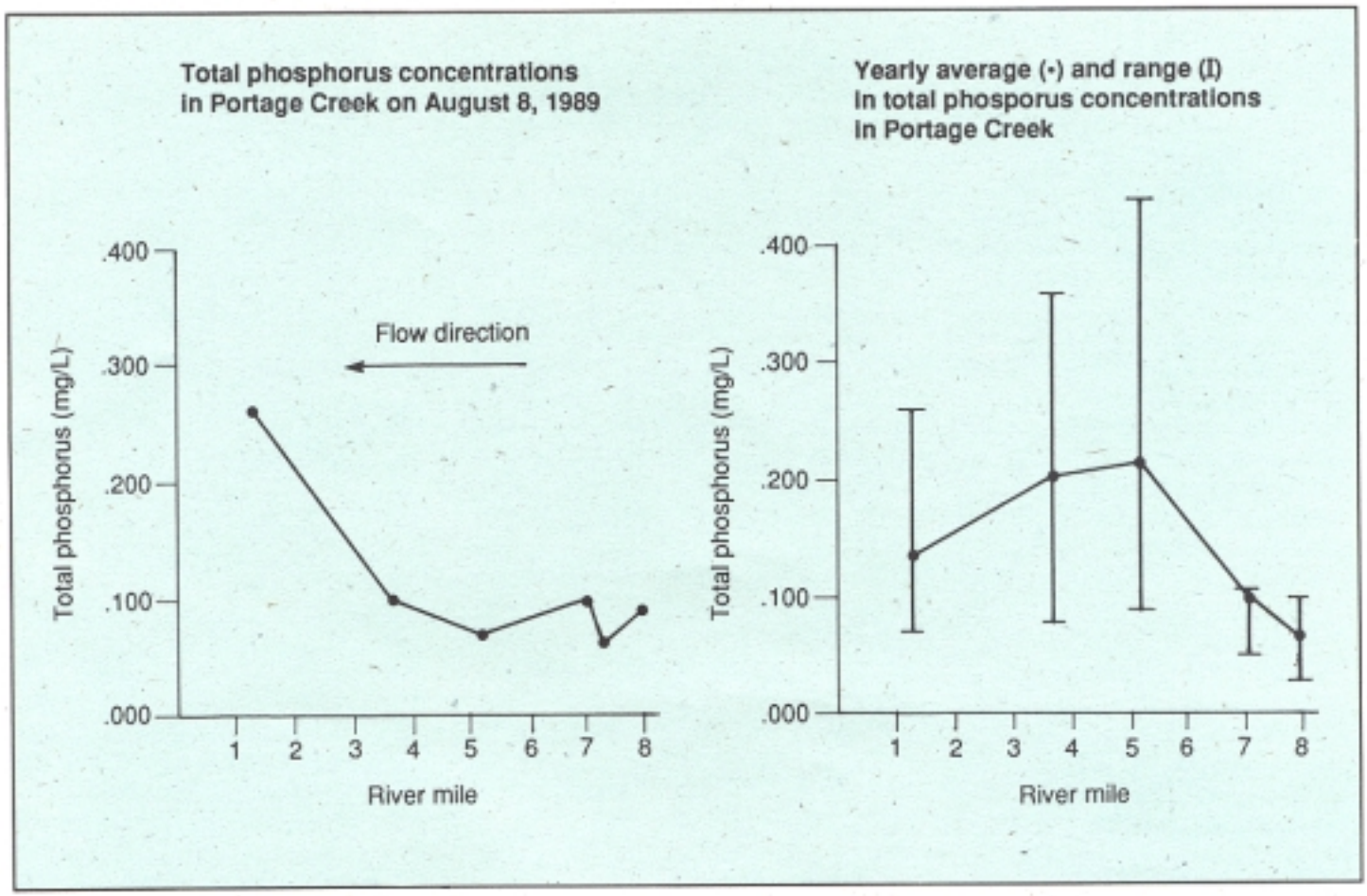
The most straightforward approach is to create a summary table of your data showing the average and range for each of the parameters measured. This will make it easier to compare them to applicable water quality standards. That would be as far as your interpretation would go. Does the stream meet water quality standards? Does it meet them at all stations at all times? You may want to calculate and compare seasonal averages as well. For example, the year-round average may indicate there is no DO problem, but perhaps by calculating the summertime average you will find there is a seasonal problem with meeting this water quality standard.

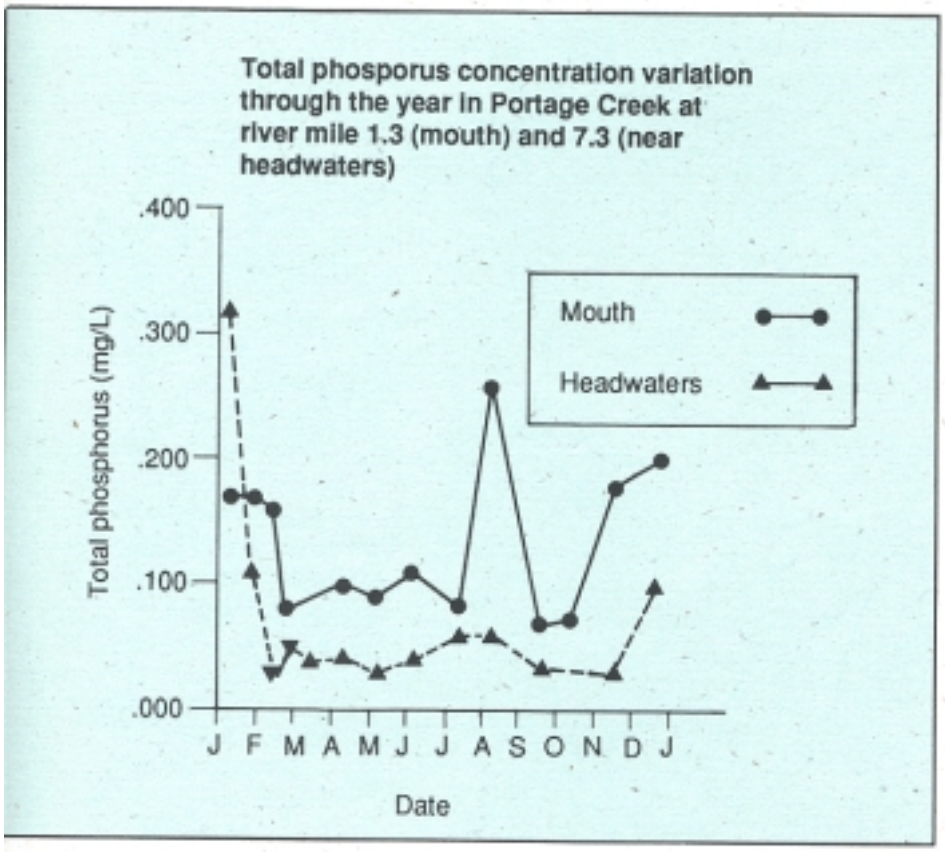
In streams it is often more interesting to consider how the quality of the water changes as it moves downstream and either picks up additional pollutants or picks up cleaner water that acts to dilute pollutants already present. The easiest way to make this comparison is to plot the parameter of interest against the river mile to provide a nice visual comparison. You can create a plot for any one sampling date or you can create it using the average concentrations for many dates and showing the range in the data by adding range bars.

To plot data the horizontal axis (x-axis) is used for the *independent* variable. It is called independent because it is not affected by the variable shown on the vertical axis (y-axis). Typical x-axis variables include time, date, and distance. The y-axis is used for the *dependent* variable; this variable changes over time or date or distance. Typical y-axis variables include the parameters measured in your sampling program such as dissolved oxygen, total phosphorus, and temperature. Choose the scale of each axis to match the range of numbers measured.

The graphs below were created from data collected in Portage Creek, a tributary to the Stillaguamish River, during 1988 and 1989. The graphs compare the change in total phosphorus concentration with river mile. The first plot contains data from one sampling date (August 8, 1989), while the second summarizes the average total phosphorus concentration for the year at each of the sampling points and also depicts the range in concentrations measured.

The first graph shows TP concentration rising substantially between river miles three and one.



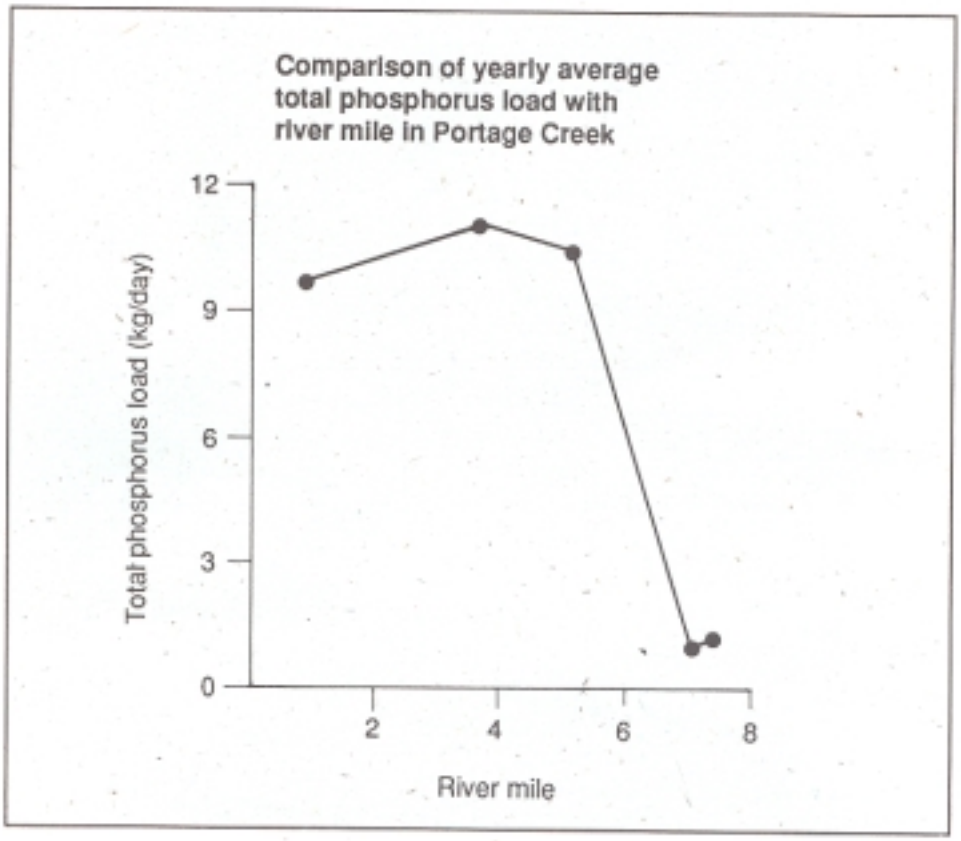


However, this situation does not appear to be a common trend in the stream when compared to the second graph. The second graph depicts the major increase in concentration occurring between stations seven and five. The variation in the data (range) also becomes most pronounced below station seven. Concentrations decrease at the station nearest the mouth, but it is unclear from this comparison of concentrations whether the decrease represents less phosphorus or whether additional stream flow is masking an increase in the pollutant. In this case, land use activities between stations five and one appear to be those most affecting stream water quality.

Because the discharge of pollutants to streams may change with weather and flow conditions, it also is informative to consider how the quality of the water changes over the course of the year. Again, a graph provides the best means of visual comparison. This time the horizontal axis is used to show the date. Two stations, for example the mouth and the headwater station, can be plotted on the same graph to provide additional comparisons.

The graph above depicts the change in TP concentrations through the year at the station nearest the mouth and one near the headwaters. At both stations the concentrations are highest during the December through January period, which corresponds to the time of year when the most runoff enters the stream. Except for the one January date, the TP concentrations near the headwaters are consistently below those measured near the mouth. At both stations TP concentrations increase during the summer and then again during the winter.

The next level of complexity takes into account the change in the volume of the river water to assess changes in pollutant loading. This is getting into pretty detailed analysis and is limited to those stations where flow has been measured. Again the x-axis is used to represent the river mile and the y-axis is used to represent calculated pollutant loads. The graph below illustrates the change in the load of phosphorus with distance downstream. Here it is clearly shown that the major increase in pollutant loading occurs between stations seven and five. The load decreases slightly below river mile three.



You may even want to compare different parameters to each other by including them on the same plot. If the reporting units and expected range of values are the same, you can use the regular y-axis for both parameters. If the reporting units and expected range of values are different, use a y-axis on the left for one of the parameters and draw another y-axis on the right for the other parameter. For streams, common comparisons of this type are: comparing different nutrients or nutrient fractions to each other (e.g., total phosphorus to total nitrogen, or total phosphorus to available phosphorus), or comparing nutrients to dissolved oxygen or pH or TSS. After you have made the graphs return to the beginning of this chapter and review each and the parameters and their reasons for variation. Try to explain the variations in your graphs by what you now know about how each of the parameters functions.

Additional Analysis and Interpretation Hints

- ❑ As stated previously, DO can reach critical levels during late summer when streamflows are low and temperatures are high. Plotting the DO concentration in late August against river mile will provide information on where levels become critical and allow you to guess what may have caused it. NOTE: If DO appears to be a problem in a reach of the river, try a pre-dawn monitoring event in late summer to assess what is termed the worst case condition.
- ❑ For fecal coliform bacteria the use of seasonal averages is probably the best way to compare between stations. Calculating and comparing the "load" of bacteria is most informative and may be the best way to assess the data.
- ❑ There are a number of additional parameters not described in this guide that can provide interesting, informative data. Two that would be worthwhile to investigate include BOD, and conductivity. *Standard Methods for the Examination of Water and Wastewater* would be a good starting point for further research. A complete reference is included at the end of this guide.

CHAPTER FOUR

From the Field to the Lab

Now that you've read about the different parameters and why we monitor them, it's time for the "hands-on" information needed to collect and analyze the samples. Proper sample collection and analysis are absolutely vital to the success of your monitoring program, whether it's simple or sophisticated. You just can't get reliable data with-poor technique. This chapter begins by describing what makes good data and explains the language of quality assurance and quality control (QA/QC). Next, it presents basic ground rules for sampling and step-by-step instructions for collection and measurement for each parameter.

What Makes Good Data?

Good data are data you can feel confident about - confident that the measurements made really do reflect the true conditions in the lake or stream, and confident that you have collected enough data over a long enough period to adequately characterize your environment.

Period of Record

The period of record is the length of time over which you collect data. If the data had been collected every 2 weeks for 10 years, you would have a good period of record. Sudden or gradual increases in pollutant levels could be reasonably attributed to some event or change within the system. Conversely, if data had been collected sporadically for 1 year, it would be difficult to say whether changes in pollutant levels signified an unusual occurrence or just normal seasonal change. In fact, an unusually large change measured on one sampling date would likely cause as much in the way of suspicions about equipment or laboratory problems as concerns about water quality. (Of course, if you had a good QA/QC plan those suspicions would be hard to justify.)

A long period of record can sometimes compensate for lower level sampling and analysis techniques. Even if there is a lot of "noise" in your data, water quality trends may be identifiable when you have a long period of record.

Quality of Each Piece of Data

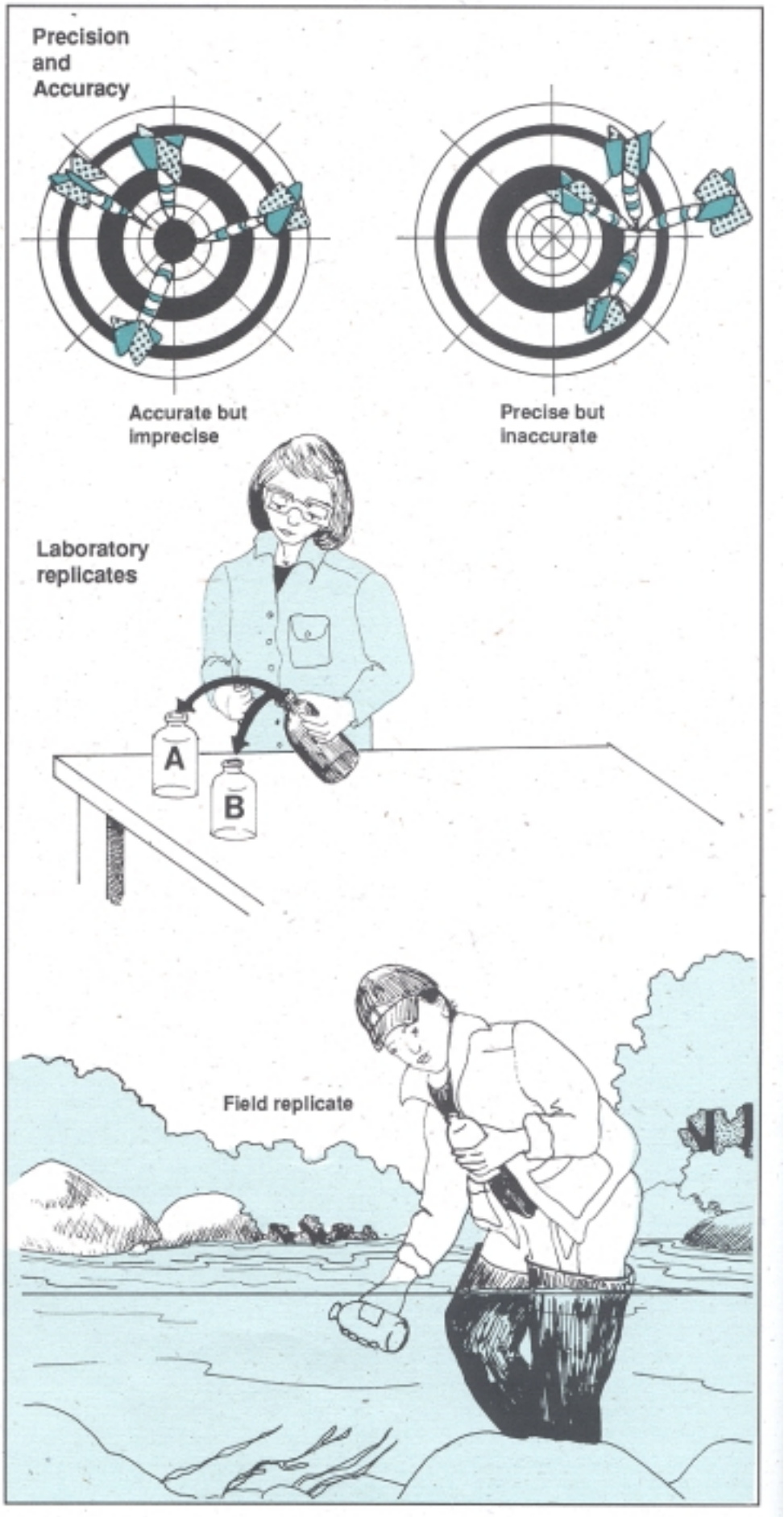
It is not enough to know you used state-of-the-art equipment and analysis techniques. Equipment breaks down and people make mistakes. Checks are needed within your monitoring program to catch potential problems. These checks are referred to as a quality assurance and quality control (QA/QC) plan.

QA/QC is the practice of making sure that collection and analysis techniques provide precise (i.e., repeatable) and accurate (i.e.. correct) information. Some QA/QC procedures apply to field operations and many apply to laboratory procedures.

Before you read on, it is important that you understand what QA/QC is all about. Imagine you have used the best possible field collection techniques and then sent your samples to a lab for phosphorus testing. What you don't know is whether the machine the lab uses to measure phosphorus will be working properly at the time your samples are measured. You also don't know how well the sample you collected represents average conditions in the lake or stream at the time of collection. By collecting a few extra samples, namely lab replicates and field replicates, you can answer these questions.

A field replicate is used to measure natural or *field* variability. The water you collect in one spot in a lake may be slightly different from the water a few feet away. If you collect two samples of stream water from the exact same spot by dipping the first bottle and capping it, and then dipping the second bottle, a good deal of water will have flowed past in the short time between dipping the samples. The second sample actually represents an entirely different "slug" of water. The two samples, called field replicates, will often be similar, but not always. Field replicates help you estimate the magnitude of this natural variation.

A lab replicate is used to assess analytical precision – the ability of the equipment, technique, and technician to come up with the exact same value in subsequent measurements on the same sample. For this reason, it is essential that the lab replicates are true replicates of the same sample. For example, if you fill a bucket with stream water, collect two phosphorus samples from the water in the bucket, and have them both analyzed at the same time, the samples are lab replicates. If instead you fill two buckets with water, collect one phosphorus sample out of each bucket, and have them analyzed at the same time, the samples are field replicates. Laboratory replicates are usually submitted in such a way that the lab technician running the analysis does not know that the sample is a



replicate. "Blind" replicates eliminate the possibility for bias from the laboratory in reporting their results.

The lab and field replicates are ways of determining how precise your results are. It also is important to know how accurate the measurements are. Accuracy is measured in the lab through the calibration standards. These are samples prepared from distilled-deionized "pure" water that contain a known concentration of a specific substance or will, produce a known instrument response.

Other QA/QC terms you may hear are field blanks, lab blanks, and spiked samples, all of which are additional checks on the accuracy and precision of results. Unless you become involved in data analysis, the main QA elements in which you will be interested concern field sampling procedures and field equipment checks and calibrations.

The complexity of the QA/QC plan determines how much confidence you and others will have in your results. Certain objectives require greater accuracy and precision than others. If you were cutting down a dead snag in the middle of the forest, you would decide approximately where the snag should fall and then cut away. If the same snag were in your front lawn, with the house, high-voltage electric lines, and the family car nearby, you would make sure that the tree fell exactly where you wanted it to. You might even hire a professional to cut it down. The same holds for water quality monitoring – there are times when a rough estimate will do and times when you need to be exact.

QA/QC guidelines need to be set for each project regardless of the intended use of the data. If you do not include any QA/QC checks, make a statement to that effect in the monitoring plan. This will ensure that people reviewing the data will know how to categorize the information when comparing it with other data.

Perhaps one of the most notable differences between a "seasoned" water quality specialist and a beginner is the willingness of the former to throw out questionable samples and data. If there is a reason to suspect a sample wasn't collected or analyzed properly, it is best to discard the data and not let it "pollute" the high-quality data you may already have collected.

Ground Rules

The following ground rules refer to general sampling guidelines that are applicable to all water quality samples collected. (For each of the parameters described, special precautions may be needed to ensure collection of a good quality sample. These are described later for each parameter under the section titled "Field Sampling Considerations.")

- ❑ The single most important ground rule for the monitoring program is this: *Document everything you do.* A permanent record lets others who may want to use your results know how the data were obtained so they can use the same procedures or at least know how to compare them. Documentation becomes even more important in a volunteer monitoring program since it provides a ready-made training aid for new volunteers.
- ❑ Safety first! Never enter a stream or lake if the current is too strong or conditions too rough – use a safety line in swift waters. Always have a buddy along who can help if you get in trouble. Wear a life vest whenever you are in a boat.
- ❑ All sample containers need to be washed with a dilute acid (sulfuric or hydrochloric) and thoroughly rinsed with deionized-distilled water. It is very important to keep these bottles clean between collecting the samples. Keep their caps on tight, and don't remove them until the sample water is collected. The Puget Sound Estuary Program protocols and standard methods referenced at the back of this guide give detailed washing guidelines.

- ❑ Rinse each container with sample water three times before placing the sample in the container permanently. (Some samples require addition of a preservative that may be added ahead of time. If this is the case, then the bottles should not be rinsed first.)
- ❑ When sampling in a stream, extra precautions are needed to ensure a sample is not collected from a disturbed area. Always begin sampling at the station nearest the mouth of the stream and work your way upstream.
- ❑ When it is necessary to enter a stream to collect a sample, always take a few steps upstream from where you entered the water, face into the current, lean forward, and reach upstream to collect the sample.
- ❑ Always collect samples from a few inches below the surface of a stream, or from the depth of about an arm's length in a lake.
- ❑ When sampling in a lake or over a bridge where equipment can be sunk and lost, tie off the equipment to a solid, stable object first.
- ❑ Label all sample bottles with station name, date, time, and parameters to be analyzed. Use indelible ink!

- ❑ Take lots of field notes. Include weather observations, visual appearance of the sampling station or water quality, equipment problems, and descriptions of techniques used.
- ❑ Be consistent. Don't change sampling method, equipment use, or station locations between sampling stations or sampling days without noting why the change was made and permanently identifying which data belongs to which set of sampling techniques or equipment used.

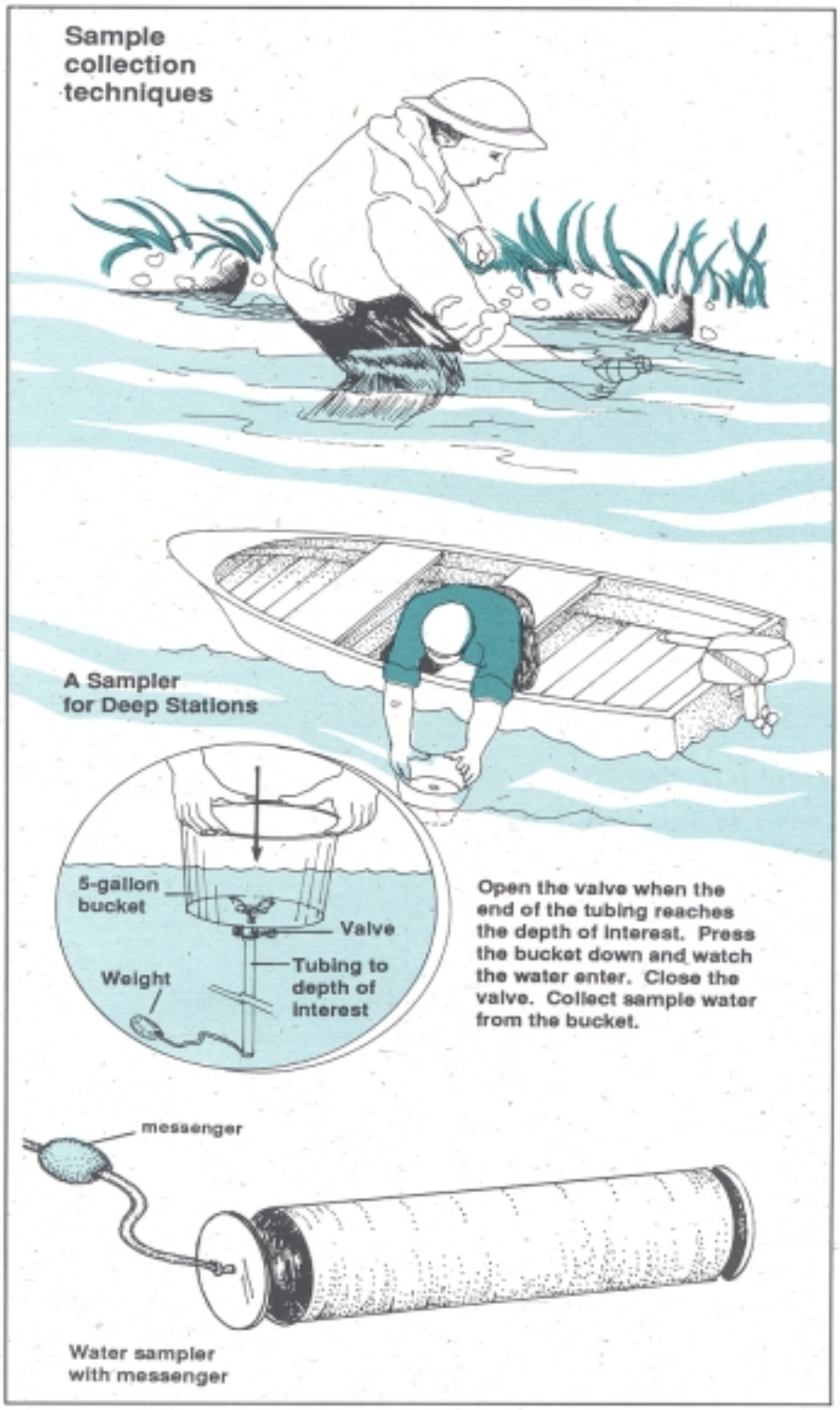
Collecting the Sample

There are quite a number of techniques for getting water from the lake or stream into a sample bottle. The one selected depends upon the sampling site.

The most common method is to hand dip the sample. It also is the easiest. Hand dipping is ideal if you're sampling from a boat and only need a surface sample, or if you can wade far enough from shore to collect your samples. To avoid capturing the tiny organisms and debris that float on the surface film of water, the sample should be collected from below the water surface. Hand dipping lets you collect water from the right location and depth.

To collect samples as far from the shoreline as possible (lakes) or well out into the main moving channel (stream), use a long or extendable pole. Rig the pole so that it can hold a sample bottle, either temporarily or permanently. Such a device is easy to make and works well. It also allows you to control the depth at which the sample is collected.

Samples also have been collected by using a weighted bucket attached to a rope. This method is handy when sampling from a tall bridge where a long pole won't work. If the water is shallow, make sure the bucket doesn't disturb the stream bottom.



More sophisticated equipment is usually needed to collect samples from more than one depth in a lake. Several samplers have been designed for this purpose. The most common are tube-shaped samplers with openings on both ends. The ends are propped open – like a mouse trap – while the sampler is lowered to the desired depth. The line used to lower the sampler is marked in 1-foot or 1-meter sections and is equipped with a weight called a messenger. When the sampler reaches the desired depth, the messenger is released. When the messenger hits the sampler, the trap is sprung, the ends close, and the sampler then can, be lifted to the surface.

Sampling and Measurement Methods

For each parameter described in Chapters Two and Three, field sampling considerations, common measurement methods, and QA/QC considerations are discussed here.

Dissolved Oxygen

Field Sampling Considerations

Dissolved oxygen concentrations may change drastically in lakes depending upon depth and distance from shore. Sampling stations and depths should be selected according to whether or not you are trying to measure these differences or not. If just one surface station is being measured, pick a station near the middle of the lake and collect the sample at arm's length below the water surface.

When collecting stream DO samples at several stations for comparison, it is important to select stations with similar flow conditions. Do not select one station in a slow-moving pool and another in a riffle area (unless of course one of your objectives is to measure these differences). The best sites are smooth-flowing – like the "glide" area between riffles and pools.

DO samples should represent average conditions in the stream reach being measured. A sample collected in the middle of the stream at least a few inches below the water surface is a safe bet. If the sample must be collected from the shore, be sure to pick a site where there is enough current to ensure adequate mixing – don't sample from stagnant, slow-moving water if it is not representative of the stream segment.

Assuming your objective is to compare measurements between stations or between seasons, DO samples should be collected at nearly the same time of day each time you sample. Otherwise, the daily variations in DO concentration that were described in Chapters Two and Three may mask changes due to other factors. The time of sampling and water temperature should be recorded. This problem with daily variations in DO (and other parameters) also comes into play if you sample more than one station. For example, if it takes a full day to accomplish the entire monitoring effort, then by default some stations will be sampled in mid-morning, while others will be sampled in mid-afternoon. To retain as much consistency as possible in the data collected, always sample your stations in the same order.

The Use of Field Kits for Water Quality Monitoring

Many of the measurements described in this guide can be made with the use of water quality monitoring "field kits." Forget about test tubes, glass beakers, expensive electronic equipment, or a technician in a white lab coat. These kits are convenient, easy to use, and come with clear, simple directions. The measurements can be quickly made while you are still in the field. This certainly beats the alternative of taking samples into a lab and spending hours doing complex analyses.

However, the difference between a kit and traditional lab techniques is like the difference between opening a can of soup and making your own from scratch. The instant version just does not meet the standards of the traditional method. Likewise, kit measurements do not meet the requirements for precision and accuracy needed for professional quality data. At the same time, kits can play an important role in monitoring programs. Their usefulness is highly dependent upon the monitoring objectives. They are a great educational tool and can provide good broad-based data for general use.

Specific instructions on how to use kits have not been included in this guide because they are provided with the kits and will vary according to the kit manufacturer.

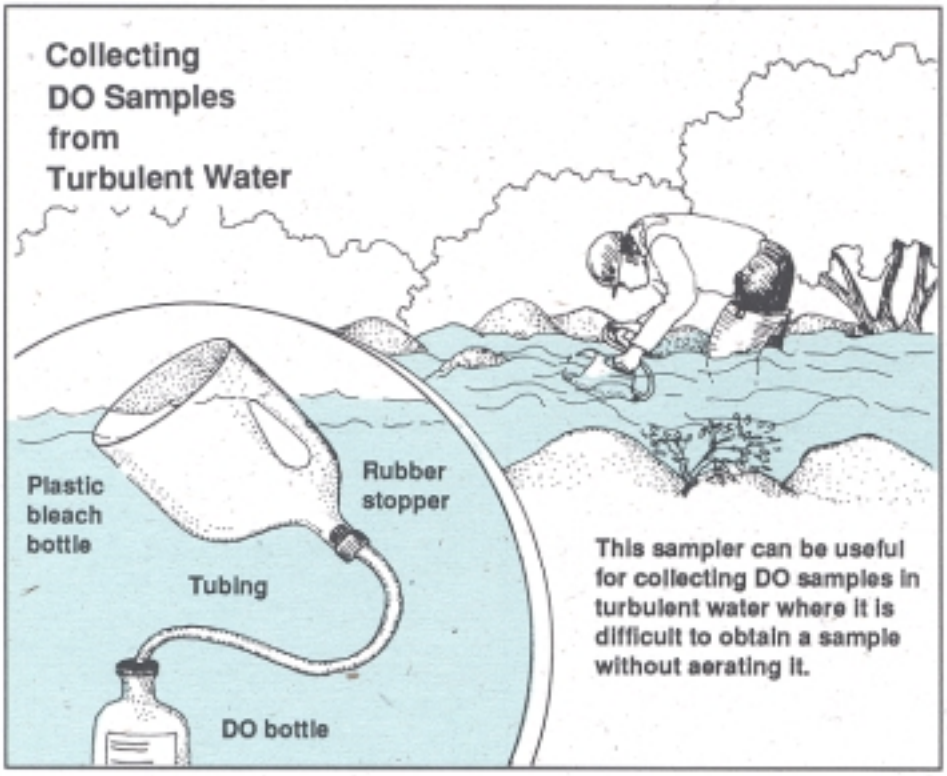
Measurement Methods

There are three common methods for measuring DO. The first and most reliable is the Azide-Winkler titration method, against which the others are compared to test for accuracy. However, this method also requires the most training and the use of some strong chemicals. For these reasons, it is not often used in citizen monitoring programs. The second and probably most common method is the use of a DO probe, and meter. DO also can be measured with field kits.

For all three methods, the most important step may be the collection of the sample. Precautions must be taken to ensure the sample isn't aerated during collection and that no bubbles are trapped in the container. Both the Winkler method and kits require that samples be collected into a special type of bottle called a BOD bottle.

If you are hand dipping the BOD bottle, lower the bottle about halfway into the water and let it fill slowly. If you are, sampling in a stream, allow the water to overflow for at least 2 minutes or until the water in the bottle has replaced itself two or three times. Check to be sure no air bubbles are present before you lift the bottle – look closely just below the neck of the bottle, where bubbles often get caught. If you see bubbles, gently tip the bottle to either side to allow bubbles to escape. Carefully stopper the bottle so no air pockets form below the cap. Do this by tilting the BOD bottle slightly and slowly lowering the cap. You may want to turn the bottle upside down and watch for bubble movement. If you see bubbles, dump the sample and start over.

If the sample was obtained by a sampling device of some kind, the water can not be simply poured into a BOD bottle since this would cause aeration of the sample. Instead, the sample must be drawn off from a tube located near the bottom of the sampling device. Place the rubber tube into the bottom of the BOD bottle and fill the bottle, again



allowing the bottle to overflow until the water has been replaced two or three times. While still letting sample water flow down the tube, slowly pull the tube from the bottom of the bottle and fill the bottle to its brim. Check for bubbles. Carefully stopper the BOD bottle as described above.

Azide-Winkler Method

1. Fill a 300-mL glass stoppered BOD bottle with sample water. Remember – no bubbles!

2. Immediately add 2 ml of manganese sulfate to the collection bottle by inserting the calibrated pipette just below the surface of the liquid. (If the reagent is added above the sample surface, you will introduce oxygen into the sample.) Squeeze the pipette slowly so no bubbles are introduced via the pipette.

3. Add 2 mL of alkali-iodide-azide reagent in the same manner.

4. Stopper the bottle with care to be sure no air is introduced. Mix the sample by inverting several times. Check for air bubbles; discard the sample and start over if any are seen. If oxygen is present, a brownish-orange cloud of *precipitate* or *floc* will appear. When this floc has settled to the bottom, mix the sample by turning it upside down several times and let it settle again.

5. Add 2 mL of concentrated sulfuric acid via a pipette held just above the surface of the sample. Carefully stopper and invert several times to dissolve the floc. At this point, the sample is "fixed" and can be stored for up to 8 hours if kept in a cool, dark place. As an added precaution, squirt distilled water along the- stopper, and cap the bottle with aluminum foil and a rubber band during the storage period.

6. In a glass flask, titrate 201 mL of the sample with sodium thiosulfate to a pale straw color. Titrate by slowly dropping titrant solution from a calibrated pipette into the flask and continually stirring or swirling the sample water.

7. Add 2 mL of starch solution so a blue -color forms.

8. Continue slowly titrating until the sample turns clear. As this experiment reaches the endpoint, it will take only one drop of the titrant to eliminate the blue color. Be especially careful that each drop is fully mixed into the sample before adding the next. It is sometimes helpful to hold the flask up to a white sheet of paper to check for absence of the blue color.

9. The concentration of dissolved oxygen in the sample is equivalent to the number of milliliters of titrant used. Each milliliter of sodium thiosulfate added in steps 6 and 8 equals 1 mg/L dissolved oxygen.

NOTE: Be very careful when doing DO analyses. The reagents are corrosive, so keep them away from your skin and clothes. Wear safety goggles and wash your hands when you are done.

Probe and Meter Method

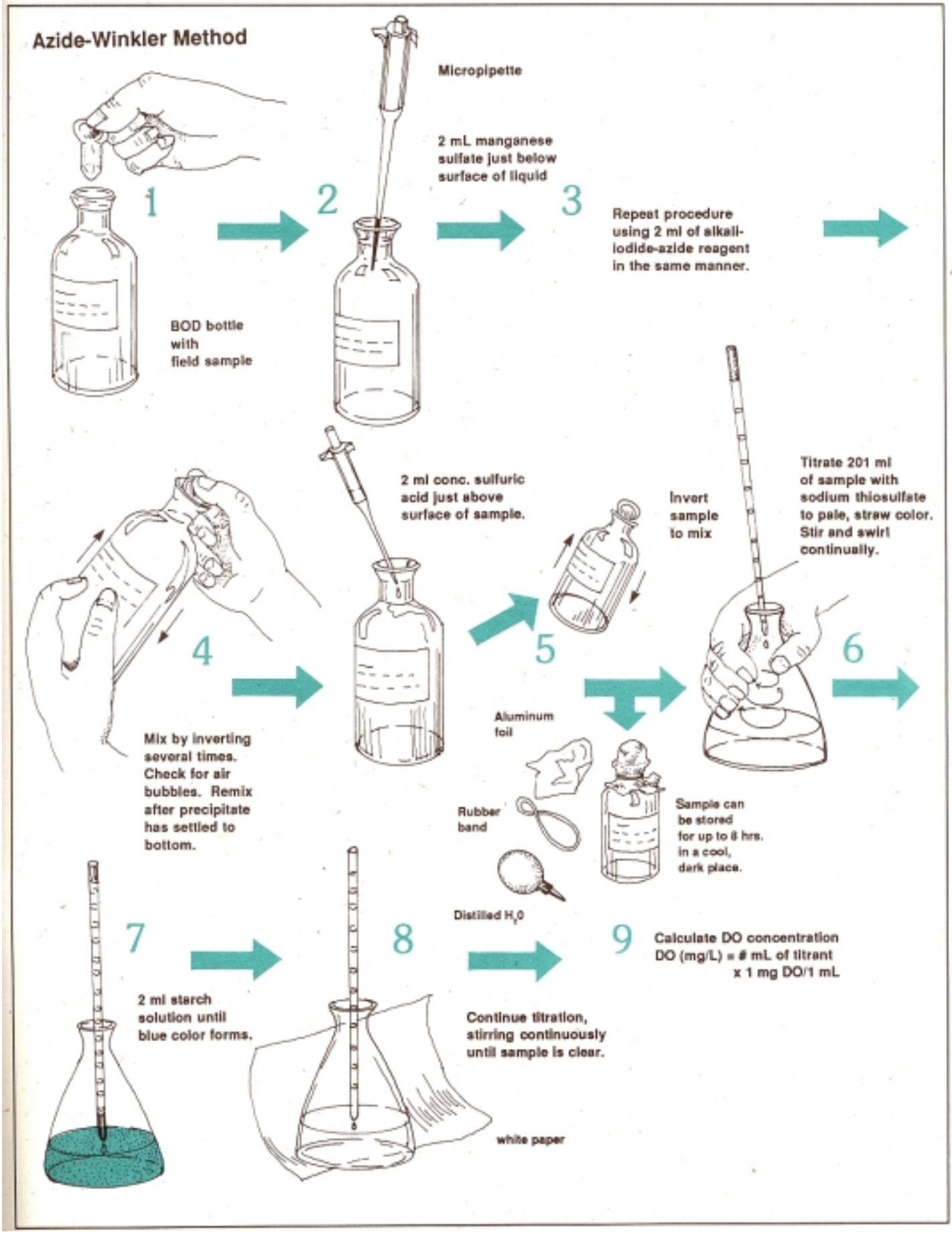
1. Calibrate the probe according to the manufacturer's suggestions.

2. Collect the water sample into any appropriate sample container, being careful to avoid aerating the sample as described above.

3. Place the probe in the sample, allow the meter to equilibrate, and read the DO concentration directly off the scale. NOTE: The probe may need to be *gently* stirred to aid water movement across the membrane.

Field DO probes are easily ruined through deterioration of the membrane, trapping of air bubbles under the membrane, and contamination of the sensing element. It often is difficult to assess whether or not a probe is functioning properly. Because of this, the meter must be calibrated before and after each series of measurements. When you calibrate the instrument, you compare DO concentrations measured by the probe to those measured using the Azide-Winkler method described above and then correct all samples for any measurement error. The meter manufacturer's calibration procedure should be followed exactly. If the error is high or erratic, all sample results should be discarded.

Azide-Winkler Method



QA/QC Considerations

Even though the Winkler DOs are the method against which the others are calibrated, there are still tests that can be made to ensure the Winklers themselves are accurate. To test the method, you need to have samples with a *known* oxygen concentration so you can compare your results to what you know is the real answer. These are called *calibration samples or standards*. A 100 percent saturation solution can be prepared by bubbling air into distilled water. If low DOs are expected, a zero DO solution can be made by adding excess sodium sulfite and a trace of cobalt chloride to a sample. In a professional lab, a calibration standard would be analyzed with each batch of samples run.

Randomly select 5 to 10 percent of the samples for duplicate laboratory analysis. If you are interested in field variability, select 5 to 10 percent of the samples for field duplication (e.g., collect two samples from the same station).

If you are using a probe and meter or field kit for measurement, 5 to 10 percent of your samples should be checked against the Winkler DO method.

pH

Field Sampling Considerations

Because pH values can change rapidly, this parameter must be measured in the field immediately after collecting the sample.

Measurement Methods

There are three methods for measuring pH; a probe and meter, litmus paper, and a field kit. The most accurate and reliable method is the probe and meter. This method is no less convenient than the other methods, but requires a more expensive piece of equipment.

Probe and Meter

1. Calibrate the probe and meter according to the manufacturer's directions. Use of two buffers (pH 7 and 10) for calibration is recommended.

2. Sample water can be collected in any glass or plastic container. Collect enough sample water so that you can submerge the tip of the probe. Rinse the probe with sample water before placing it in the sample.

3. Place the probe in the sample and wait for the meter to equilibrate. If the meter needs to be manually adjusted to correct for temperature – you'll know it does if it has an extra temperature knob – adjust it to the temperature of the sample before allowing it to equilibrate. The meter will have come to equilibrium when the signal becomes steady. If it is taking a long time to equilibrate, you may try gently stirring the probe. However do not agitate the sample since this may cause changes in the pH.

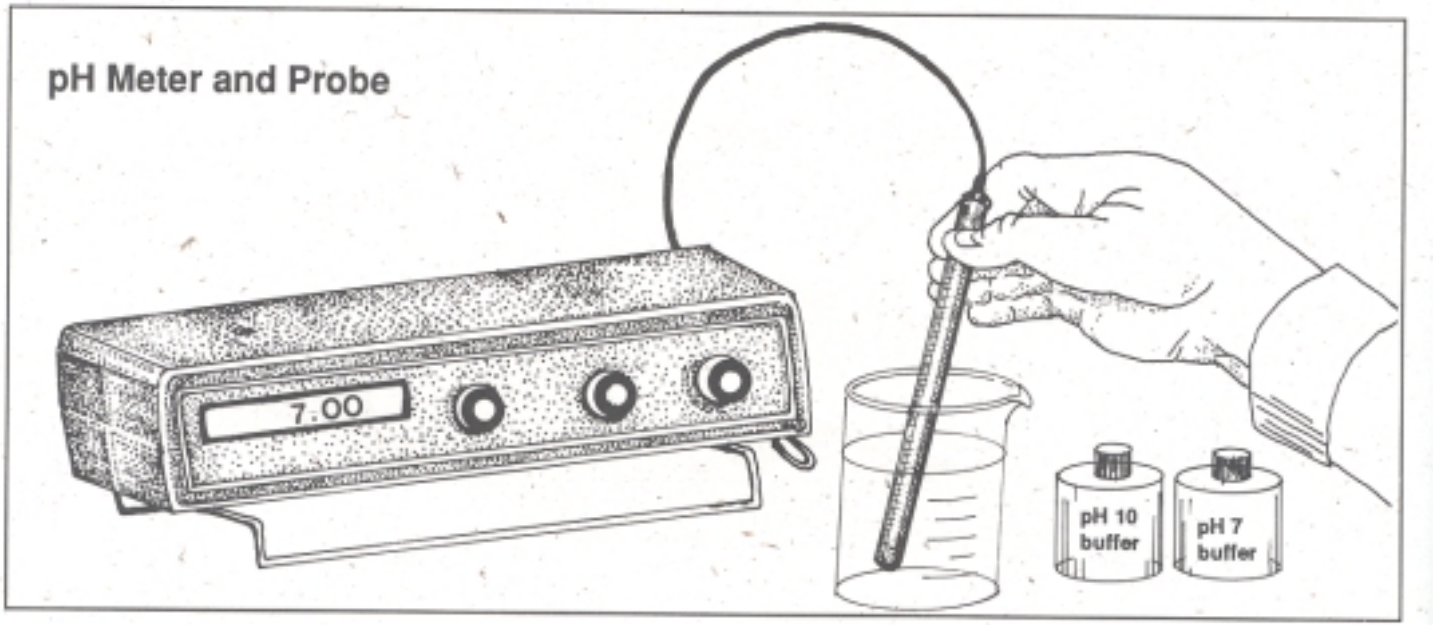
4. Read the pH directly from the meter according to the manufacturer's directions.

Litmus Paper

Litmus paper is simply a strip of colored paper that is soaked in sample water. The paper turns a different color depending upon the pH of the solution. It provides a very coarse measurement of pH – it is fine for making simple determinations, but it is too coarse a measurement for allowing comparisons between sampling, dates or stations.

QA/QC Considerations

Follow the manufacturer's instructions for storage and preparation of the probe. Most probes need to be kept moist during storage – this is important! Rinse the probe with distilled water and blot dry



between all samples.

The probe must be standardized with known buffer solutions every 3 hours and whenever a major change in the pH of the sample water is expected. (In natural waters where there is no large influence from an effluent discharge or other potential source for pH change, major pH change is not likely to be a problem.) Follow the manufacturer's instructions for calibrating. Use two standards for calibration, a neutral standard and either an acidic or basic (alkaline) standard, depending upon the expected pH range of the samples. In natural fresh waters, standards with pH 7.0 (neutral). and pH 10.0 (base) usually are appropriate.

To assess field variation, collect duplicates at 5 to 10 percent of the stations and measure pH.

The accuracy of field kits or litmus paper can be checked by collecting a few samples to be read back at the lab with a pH probe. However, due to the time lapse and possibly rapid changes in pH, this lab check would be used only as a rough verification of results.

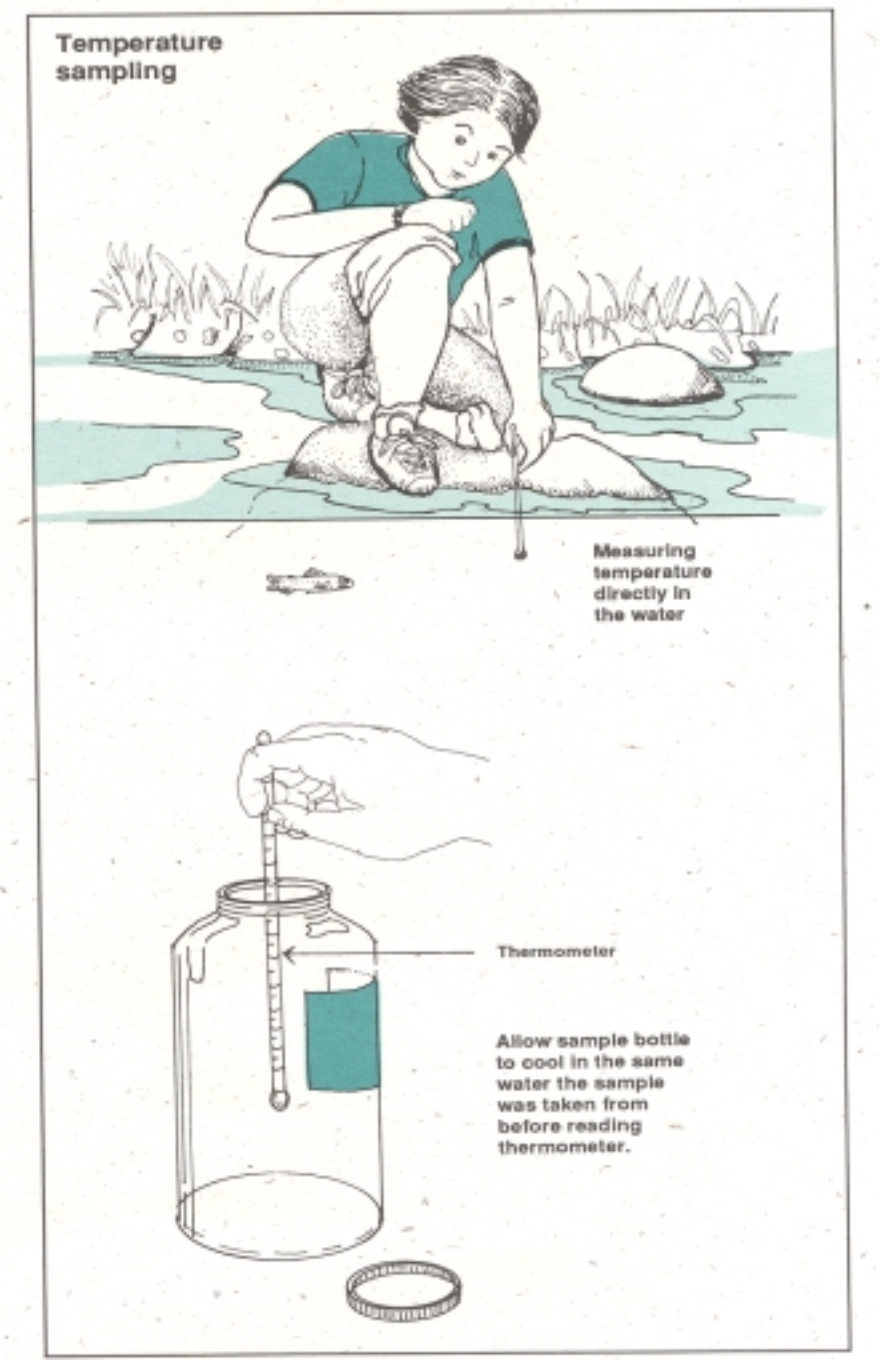
Temperature

Field Sampling Considerations

Whenever possible, measure temperature by placing the thermometer directly into the lake or stream. For stations where this is not possible, allow the sampling container to cool in the sample water before the sample is collected. Measure temperature immediately upon sample collection. Remember to select sampling sites and locations that are representative of the stream reach or lake.

Measurement Methods

Water temperatures are measured with a common thermometer, or by heat-sensing elements located at the tips of DO probes, pH probes, and the like.



1. Measure temperature by lowering the thermometer so the tip is a few inches below the water surface, or place the thermometer in the sampling container. Allow the thermometer time to come to equilibrium and read immediately.

2. Record the time of day.

QA/QC Considerations

All thermometers should be checked against a thermometer certified by the American Society for Testing and Materials or the National Bureau of Standards. If this has not been done, be sure to use the same thermometer for the entire study so that thermometer error is at least consistent throughout the study. If more than one thermometer is used, calibrate them against each other.

Secchi Disk Depth

Field Sampling Considerations

Excessive waves, wind, or sunlight may jeopardize Secchi disk readings. To minimize these effects, take readings during calm days that are partly cloudy to sunny. Anchor the boat at the sampling station to avoid boat drift, and lower the Secchi disk off the shady side of the boat. If the Secchi disk drifts too fast for an accurate reading – that is, the line is not vertical in the water – try weighting the bottom of the disk to make it sink faster or taking the measurement on the downwind side of the boat. If none of these techniques work, and you do not think you can obtain an accurate reading, DO NOT make the measurement because it will not be a good representation of lake conditions on that day.

Be sure to note weather condiions along with the Secchi disk reading.

NOTE: Secchi depth readings are rarely taken in streams because of the inaccuracies associated with flowing water, disk movement, and shallow depths.

Measurement Methods

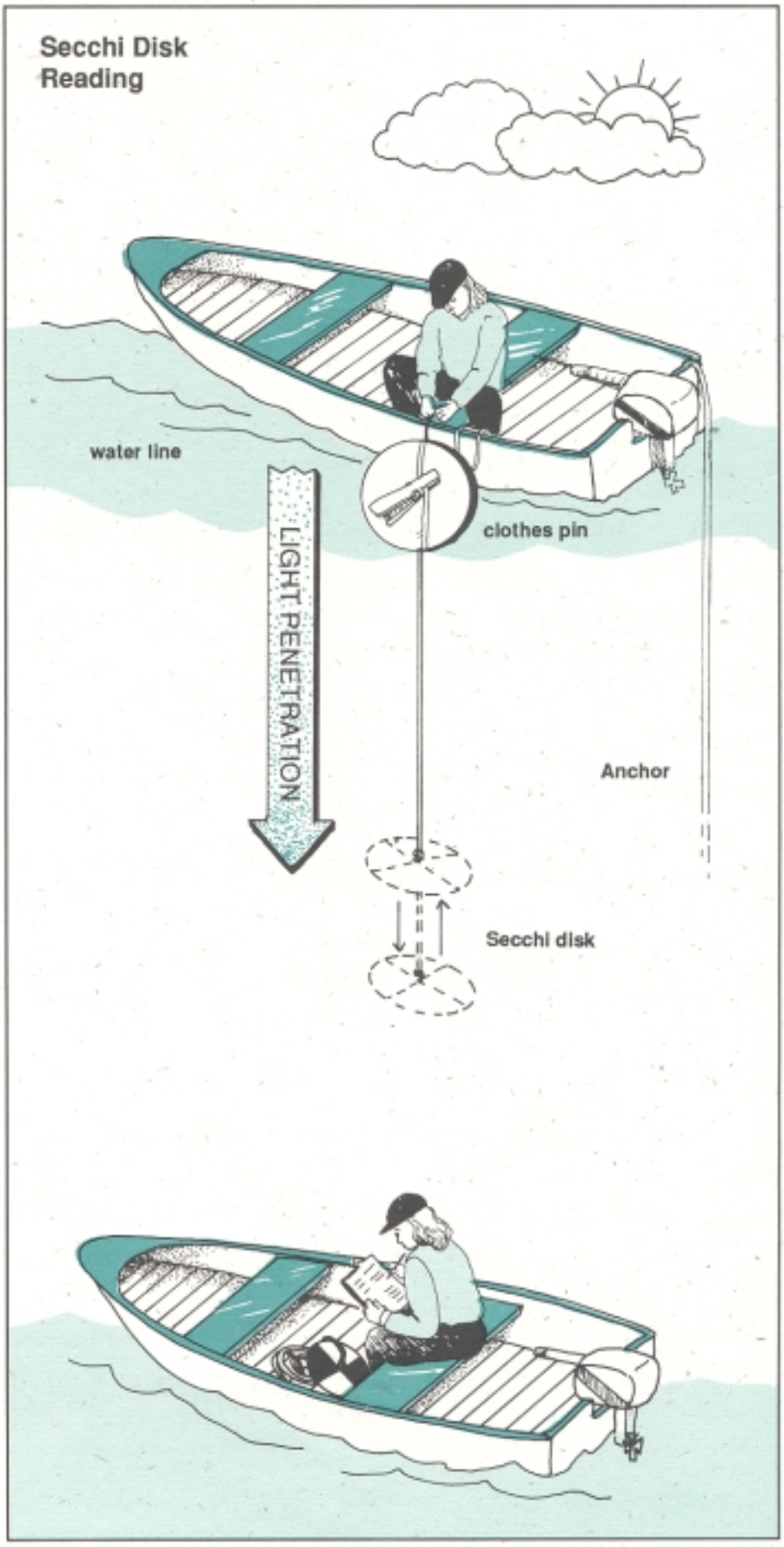
1. Slowly lower the disk into the water to the point where it just disappears.

2. Place a clothespin on the line where it meets the water surface, or mark the point on the line in some other way.

3. Continue lowering the disk a few more inches, and then slowly raise it until it just becomes visible again. Mark this spot with another clothespin or hold the rope here between your fingers.

4. The spot halfway between the two marks represents the average Secchi disk reading. Mark the spot by moving the clothespin or other marker to the spot.

5. Carefully measure or count the distance from the disk to the marked spot. Record the distance to the nearest tenth of a foot or meter.



QA/QC Considerations

The Secchi disk reading is subjective because of differences in people's vision and weather conditions. There is no QA/QC check that can be used to "calibrate" the different readings. The slight differences in vision generally are considered insignificant. Some of the error caused by the subjectivity of this measurement can be reduced by having the same person make the measurement each time.

Nutrients

Field Sampling Considerations

There are no special field sampling concerns associated with nutrient samples other than those described in the section on basic sample collection techniques. It is especially important that sample containers be clean when collecting nutrient samples. Containers used for nutrient analyses should be acid-washed (soaked in dilute hydrochloric acid) and rinsed thoroughly with distilled water. If you are collecting samples for later laboratory analysis, you must properly preserve and store them. Professional labs usually provide properly cleaned bottles, often with preservative already in them. Clarify these procedures with the lab before sampling.

Measurement Methods

Although there may be numerous laboratory techniques for analyzing any one nutrient, this should not be a concern for a volunteer monitoring program. For the purpose of this guide, there are only two methods: analysis by a certified lab, or analysis by the use of field kits. In the first case, volunteers only need be concerned with proper collection and preservation techniques. In the second case, detailed directions will be provided with the kits.

If nutrient samples are collected for later analysis, proper handling and preservation are important. The following table details handling, preservation, and holding times for each of the nutrients. All require the same initial treatment – preservation with sulfuric acid (*except* for SRP) and storing in the dark at 4°C. (This means storing them on ice in a cooler until you can get them to a refrigerator.) The amount of time they can be held in this condition before analysis varies. It is the lab's responsibility to analyze the samples before the time limit expires. They need to report the time and day of analysis. One of the QA/QC checks you should make when data are returned is that samples were run within an acceptable time limit.

Preserve nutrient samples by inserting a few drops of sulfuric acid into the sample bottle. Enough sulfuric acid needs to be added to reach a pH<2. The amount needed will vary depending upon the volume of water being preserved; however, it doesn't need to be an exact amount. Typically about a half a milliliter or half an eye dropper full is enough to preserve a 250-mL sample. Test the number of drops needed on one sample and use that amount for the rest of the study. Do not test pH on a sample you intend to have analyzed unless you ensure that the sample isn't inadvertently contaminated.

Because the preservation and handling methods are the same for all but the SPR, one sample bottle can be used for most of the nutrient analyses from one station. This will save time, energy, and space because fewer bottles will need to be washed, fewer samples will need to be collected, and less space will be needed in the ice chest, refrigerator, and whatever other storage containers are used. Usually one 500-mL container plus an additional 125 mL container, if SRP is .being analyzed, will suffice for all the nutrients. Have this OK'd with the lab ahead of time.

The Special Case of SRP

SRP (aka orthophosphorus or phosphate) samples must be filtered within 8 hours of collection and then analyzed within 2 days. Because of the delay between collecting samples and getting them to a lab for analysis, the filtering usually must be done by the persons doing the monitoring. Filtering requires the use of a small pump, filtering apparatus, and 0.45 µm membrane filters that have been soaked in distilled water before use. A minimum of 50 mL of water must be filtered for each sample, and then poured into a fresh, properly cleaned sample bottle (acid washed and distilled water rinsed). The entire filtering apparatus needs to be acid rinsed and thoroughly rinsed with distilled water between each sample.

Proper Storage and Handling Procedures for Nutrient Samples

Parameter	Preservation with Sulfuric Acid	Holding in the dark at 4°C	Preferred Time Limit for Analysis	Maximum Time Limit for Analysis
Ammonia	Yes	Yes	7 days	28 days
Nitrate-Nitrite	Yes	Yes	24 hours	28 days
Total Nitrogen	Yes	Yes	--	28 days
SRP	No*	Yes	48 hours	48 hours
Total Phosphorus	Yes	Yes	48 hours	28 days

*SRP samples must be filtered within 8 hours and then preserved.

QA/QC Considerations

In addition to standard lab QA/QC, lab replicates should be collected for 5 to 10 percent of the samples, based on a random selection process. If kits are used for analysis, you may want to check your results against laboratory methods. In this case, 5 to 10 percent of the samples should be replicated by the laboratory method to check kit precision against more sophisticated lab methods.

TSS and Turbidity

Field Sampling Considerations

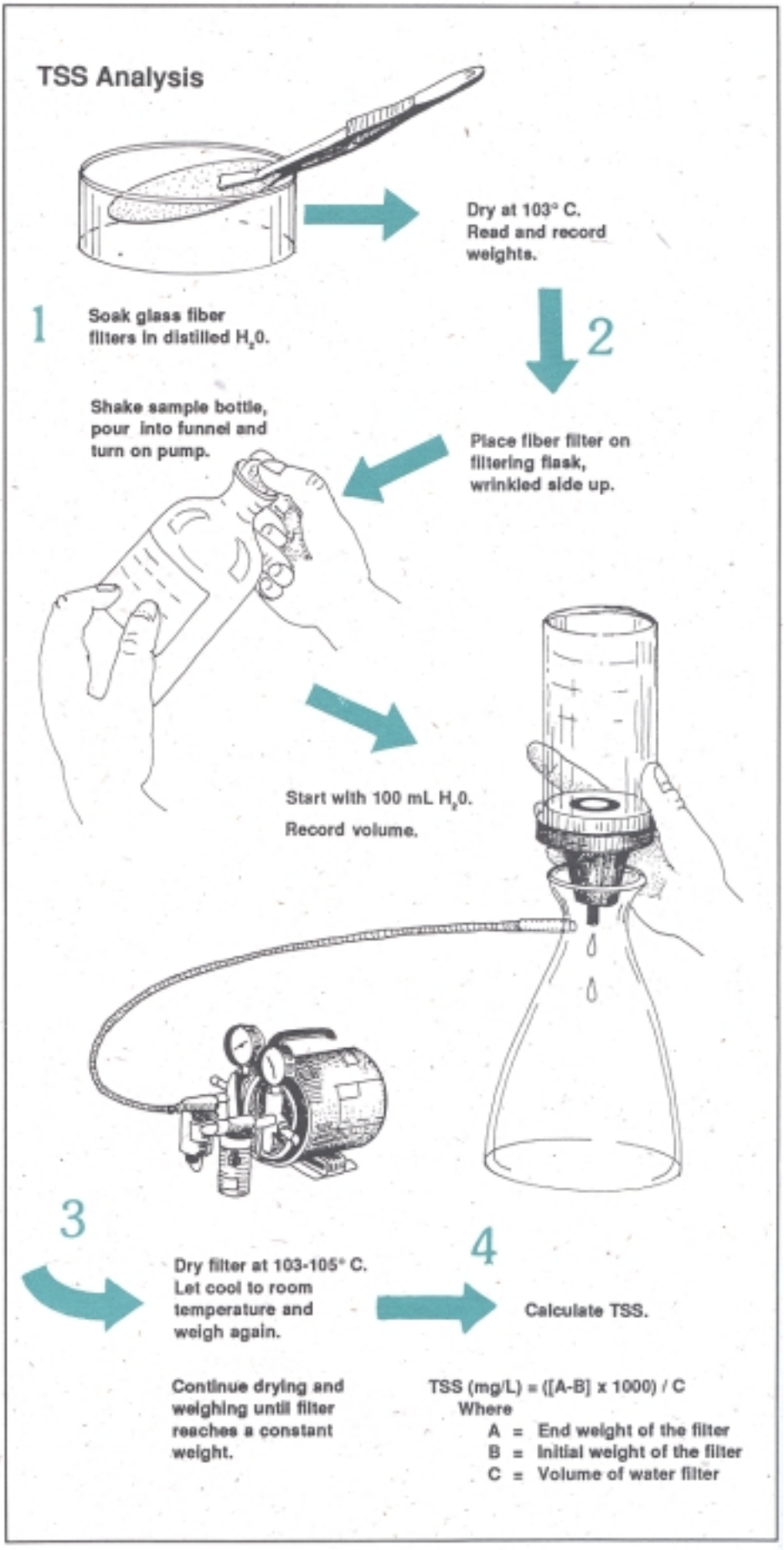
There are no special field sampling concerns associated with these parameters other than those described in the section on basic sample collection techniques. It is especially important for these parameters that the sample is collected from undisturbed water. Once you step into a stream, you stir up the stream bottom – that's why you step upstream, lean, and reach into the current for the sample. In lakes, boat propeller action also may disrupt sediments in shallow areas. Again, do not sample from disrupted water.

Measurement Methods

TSS

1. Before sampling, prepare glass fiber filters by first soaking them in distilled water, drying them at 103°C, and weighing and recording their weights.

2. Place the dried, weighed glass fiber filter onto a filtering flask – wrinkled side up. Shake the sample bottle first, then pour in the water and turn on the pump. (The amount of water you need to filter may change according to water conditions. Start with 100 mL. Use less volume if the filter gets clogged too quickly and more if the water filters through very fast.) Record the volume of water filtered.



3. Dry the filter at 103 to 105°C, let it cool to room temperature, and weigh it. Dry it, cool it, and weigh it again. Continue until the fiber reaches a constant weight. Record the end weight.

4. The increase in weight represents TSS. Calculate TSS by using the equation below.

TSS (mg/L) = ([A-B]*1000)/C
Where A = End weight of the filter
B = Initial weight of the filter
C = Volume of water filtered

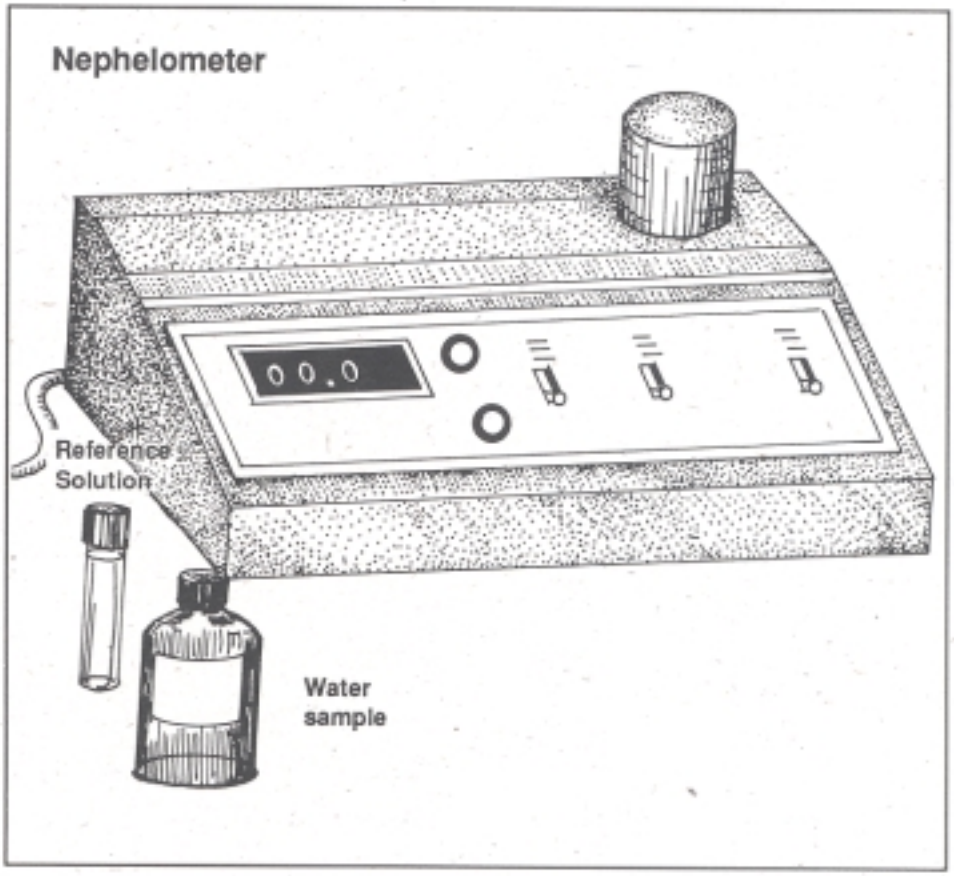
Turbidity

Turbidity is a measurement of the optical property of water – a measure of the amount of light that is scattered and absorbed by particles in the sample. It is a simple measurement that requires the use of either a nephelometer or Jackson turbidimeter to compare a reference solution to the sample. Turbidity measurement does not require any sample preparation, other than shaking the sample bottle well before analysis. The sample is simply poured into a glass tube, placed inside the instrument with a reference solution and the result is read directly from the instrument. (The nephelometer has recently become recognized as the more accurate and recommended piece of equipment for this analysis. However, if a Jackson turbidimeter is what you have available, it will work fine.)

TSS and turbidity samples should be held in the dark on ice or at 40°C. In this condition, TSS samples can be held for up to 7 days and turbidity samples for up to 2 days.

QA/QC Considerations

Randomly select 5 to 10 percent of the samples and collect lab replicates for them. Lab QA/QC will involve selecting 5 to 10 percent of the samples for duplicate analysis, and calibration of all equipment used.



Fecal Coliform Bacteria

Field Sampling Considerations

Bacteria samples, more than any of the other water quality parameters, are the easiest to contaminate. The sample bottles and their caps must be thoroughly cleaned and sterilized in an autoclave before each use. The caps must remain tightly on the bottles until just before the sample is collected. Care must be taken when unscrewing the cap and collecting the sample to ensure nothing touches the inside of the cap or bottle - including your hands or fingers.

Because bacteria attach themselves to small particulate matter, there are two sampling precautions that bear emphasis. First, *always* collect the sample upstream of any area that may have been disrupted by entering the stream – take a few steps forward, lean into the current, and collect the sample at arm's reach. Second, the top film of water will have an excess accumulation of bacteria, so it is not representative of stream or lake conditions. For the sample to be a good representation of water conditions, only a small portion of this surface film should be sampled.

A standard technique has been developed for collecting bacteria samples to account for these differences. To avoid the surface layer, the bottle is "plunged" through the surface film by holding the bottle directly upside down and quickly submerging it. An inch or two below the surface, tilt the bottle toward the current and slide it in an arc toward the surface, removing the bottle in a vertical position. Leave about one-half inch, of air space at the top. Immediately cap the bottle and put the sample on ice in a dark place (an ice chest).

The official procedure for analyzing bacteria requires analysis within 6 hours of collection. This is rarely possible. However, they *must* be run within 30 hours or the results should be discarded.

Measurement Methods

There are two common laboratory procedures for analyzing fecal coliform bacteria: membrane filtration (MF) and most probable number (MPN). The two are not directly comparable, so pick one method and stay with it. MF is the recommended procedure for freshwater monitoring and is more commonly used at this time. However, it is not as reliable a method as MPN in very turbid samples.

Field kits also are available for measuring bacteria. They still require access to some special equipment – such as petri dishes and a small oven or incubator – but if your group has access to a small lab and some equipment, field kits can be used successfully for educational purposes.

QA/QC Considerations

Bacteria often exhibit a large amount of field variability, so collection of field replicates (5 to 10 percent of the samples) can be important for this parameter. Lab replicates for 5 to l0 percent of the samples can be collected, but some error is introduced when pouring from one sample container to the other. Lab replicates also should be analyzed as part of the lab's standard QA/QC policy.

Chlofophyll a

Field Sampling Considerations

Due to the fact that algae live primarily near the surface of a lake, chlorophyll a samples are typically collected just below the surface. Collecting a sample at one station near the midpoint of the lake is often adequate for a simple characterization of seasonal changes or possible trends in chlorophyll. If the monitoring objective is to compare portions of the lake, their chlorophyll samples should be collected accordingly. Because algae can be blown by the wind, samples collected near shore or at the downwind end of the lake may not be representative of average lake conditions.

Since algae can quickly reproduce or die, which will change the relationship between live cells and dead cells in your sample, samples need to be preserved in the field. A few drops of magnesium carbonate solution will adequately preserve a 200-mL sample. (NOTE: Be sure the lab doing the analysis is aware that you are interested in the chlorophyll a concentration, not just chlorophyll)

The density of the algae population will determine how much sample is needed for the analysis. During the winter when populations are low, 1,000 mL (1 liter) may need to be filtered to get an accurate reading. On the other hand, in summer months during an algae bloom, the filter may clog before 50 mL have been filtered through it. To ensure the lab has ample water, a 1,000-mL sample should be collected.

Measurement Methods

Chlorophyll a is measured by filtering a known amount of sample water through a glass fiber filter. The filter paper itself is used for the analysis. The filter is ground up in an acetone solution and either a fluorometer or spectrophotometer is used to read the light transmission at a given wavelength, which in turn is used to calculate the concentration of chlorophyll a. Because of the equipment requirements for this test, it is assumed that the filtering and analysis will be done by a professional lab.

QA/QC Considerations

Randomly select 10 percent of the samples for lab replicates. Field variability can be assessed by collecting field replicates for 5 to 10 percent of the samples.

CHAPTER FIVE

Getting a Handle on Hydrology

As described in Chapter Three, stream flow greatly influences the character of a stream. By its own merits, it is an important parameter for understanding stream water quality. Stream flow also is necessary for calculating *pollutant loadings* – an important tool for interpreting stream water quality data. The following chapter describes how to measure flow and how to set up a staff gage for measuring stream height. It also explains how to use staff gage measurements to predict stream flows and how to calculate pollutant loads using stream flow data.

Measuring Stream Flow

Stream flow measurements can provide important information for both streams and lakes. In addition to allowing a comparison between pollutant loading and concentration, the changing relationship between precipitation and stream flow can be an important indicator of impacts from developing watersheds.

As watersheds develop, an ever-increasing portion of the land is covered by buildings, concrete, and asphalt. These *impermeable* surfaces prevent rainwater from seeping into the ground, and instead tend to channel and speed water on its way to the nearest stream. In a developed watershed, a small amount of rain may cause a rapid rise in flow in nearby streams, whereas the same amount of rain may have caused an imperceptible change in stream flow previous to development.

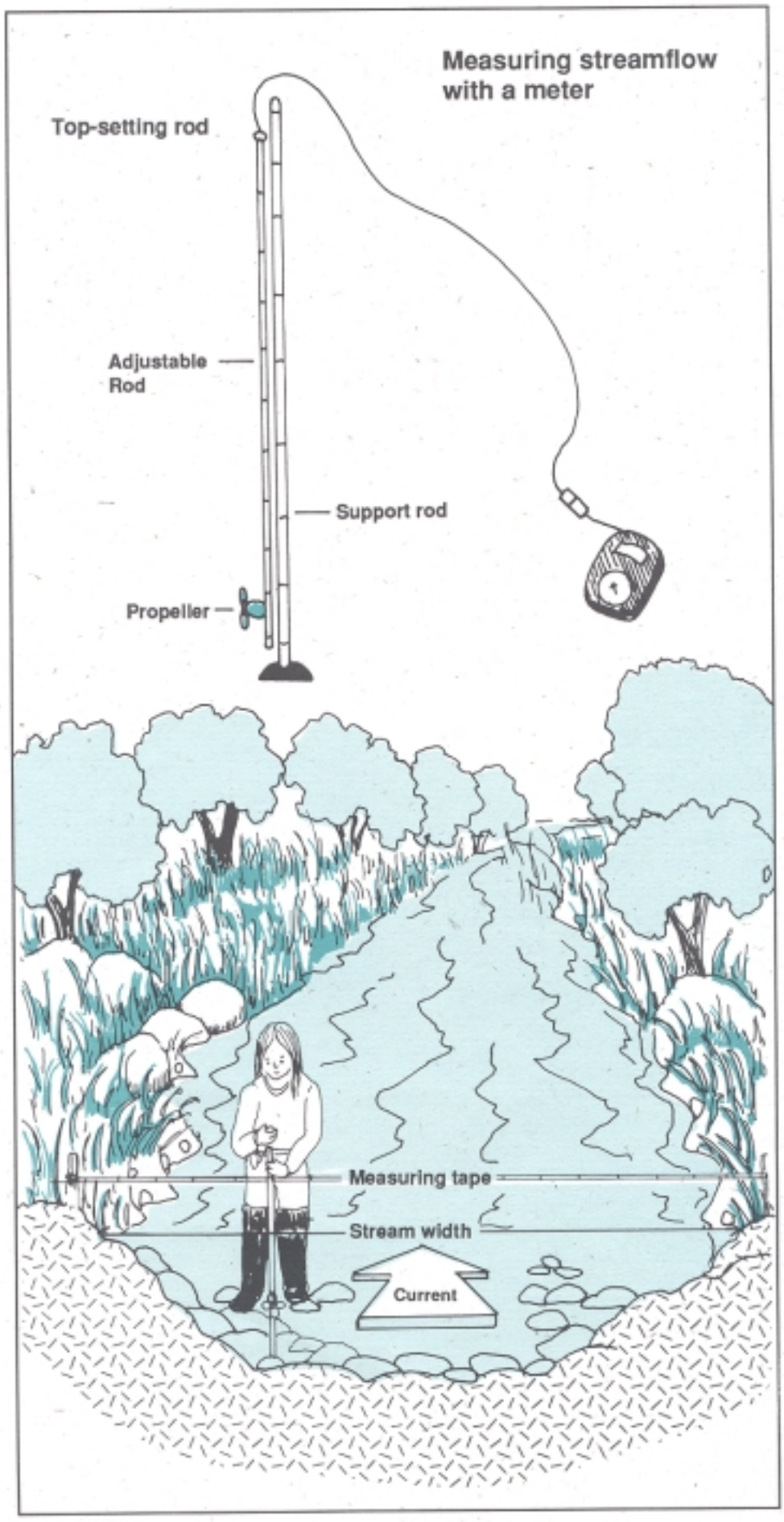
Taking streamflow measurements can be a fairly involved process if done right, but there also are simple methods that can be used to provide rough estimates for comparison. Two methods are described here. The first is a slightly modified version of the official U.S. Geological Survey (USGS) method. It is the method that most professionals use. The second is a simple method for obtaining a rough estimate that doesn't require any expensive equipment. For both methods, the first step is to choose a good spot for making the measurements.

Selecting a Station for Streamflow Measurement

Selecting the proper location for measuring stream flow can be as important to collecting accurate information as the method used to take the measurements. Ideally, all of the following criteria should be met. In reality, they rarely are. However, it is important to understand the limitations of the site you select and the potential effects on streamflow. measurements.

- ❑ The site should be readily and *safely* accessible. Never, enter a stream if the water is too high or moving too fast for you to feel comfortable. Remember that a segment that was safely crossed in summer may be inaccessible in winter. Expect a difference and make a conscious decision each time you enter a stream.

- ❑ The site should lie in a section of stream that is freeflowing:
  - The stream should be straight for enough distance to have relatively uniform flow. (The USGS recommends 300 feet. In most smaller streams, you will be lucky to find a 100-foot straight section.)
  - The station should be located a sufficient distance upstream of tributaries and tidal action to ensure flow is not affected by either.
  - The stream should be confined to one channel. (Check to be sure there are no side channels or evidence that these may form during high flow conditions.)
  - Streambanks should be high and stable enough to contain maximum flows.
  - The streambank and channel should be relatively free of thick brush or vegetation that may slow the water and make measurements difficult.
  - Flow should be uniform and free of eddies, slack water, and excessive turbulence.
  - The streambed should be uniform. (Check for large boulders or logs, and consistency in depth and velocity.)



Measuring Stream Flow with a Meter

The Equipment

The three most common types of flow meters in use are cup, propeller, and magnetic meters. Cup and propeller meters determine flow velocity according to the number of revolutions of the cups or propeller over a given time interval. Magnetic meters measure the difference in water pressure as water flows around a sensor.

Whichever meter you use, it needs to be mounted on a rod or strung at the end of a cable to allow the propeller or other mechanism to be held in one place while the measurement is taken. Usually the meters are mounted on what is called a top-setting rod. A top-setting rod actually consists of two rods: a support rod and a smaller rod that can slide up and down the support rod. This second rod holds the business end of the meter (let's call it the propeller) and allows it to be raised or lowered to the desired depth.

You may be surprised to learn that the velocity of water changes with depth. Hydrologists have determined that average velocity in a stream occurs just below mid-depth – at 0.6 times the total depth to be exact. That is where you want to place your propeller. Top-setting rods are designed so that you can slide the propeller up or down the support rod – which rests on the stream bottom – and measure velocity at the desired depth.

Making the Measurement: The USGS Method

1. String a measuring tape across the stream at right angles to the flow. Tie the tape off at both sides of the stream. Make it taut enough so that it doesn't sag near the middle. easure the stream width. Leave the tape in place.

2. First determine the width intervals you will measure. The official method requires that at least 20 points of measurement be made across the width of the stream. To do this, divide the total stream width by 20 to calculate the distance between points. If you have been lucky enough to find a station that has a relatively uniform depth and velocity, or if it is a narrow stream, 20 points may be more than you need. In many cases, especially in very small streams (and depending upon the accuracy you desire), it is adequate to measure velocity at 1-foot, or one-half-foot intervals even if that means you may only have five or ten measurements. Measuring points should be closer together or more frequent wherever there is a lot of variation in the depth or velocity of the cross section.

3. Start at the very edge of one bank and work your way across the stream, measuring velocity with the meter at each of the 20 points and noting your distance from the bank edge where you started. For example, if your stream was 20 feet wide, you would make measurements at one-foot intervals. The first measurement would be taken at zero feet from the edge (the velocity will likely be zero), the second at 1 foot and so on to 20.

NOTE: Stand at least 1 foot away on the downstream side of the tape and hold the meter and rod next to the tape. Be sure you are standing far enough from the meter to ensure that the eddies around your boots are not interfering with the flow measurement.

4. At each measuring point, read and record the total depth, multiply the total depth by 0.6 to determine the depth of average velocity, set the propeller at the new depth, read and record the velocity. Also, remember to record your distance from the bank for each measurement.

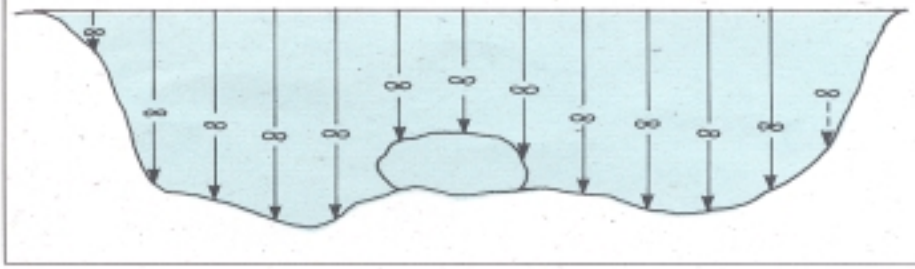
5. The total amount of water moving through your section is a function of the size of the stream (cross-sectional area) and the velocity. Use the velocity measurements and the depth and distance measurements you recorded to calculate the total volume of water flowing through the section (total discharge).

Finding the Average Velocity

Stream velocity varies vertically (from surface to the bottom) at each point in a stream. Stream hydrologists have developed a standard technique to ensure consistency in determining the "average" velocity at a given point. The USGS method assumes that at points where the depth is less than 2.5 feet, the aver- age velocity occurs at six-tenths of the total depth. Where the stream is deeper than 2.5 feet, the velocity is mea- sured at two-tenths and eight-tenths of the total depth, and the average of the two readings is used as the average velocity -at that point.

How to Measure and Calculate Total Discharge in a Stream Segment

Distance from Left Bank	Total Depth (ft)	Depth of Av. Velocity (ft)	Velocity (fps)	Discharge (cfs)
0	0	0	0	0
0.5	0.4	0.24	0.20	0.04
1.0	1.9	1.14	0.35	0.33
1.5	2.1	1.26	0.42	0.47
2.0	2.3	1.38	0.63	0.73
2.5	2.3	1.38	0.65	0.75
3.0	1.4	0.84	1.12	0.78
3.5	1.3	0.78	1.15	0.75
4.0	1.5	0.90	1.20	0.90
4.5	2.0	1.20	.93	0.93
5.0	2.1	1.26	.95	1.00
5.5	2.1	1.26	.95	1.00
6.0	2.0	1.20	.88	0.88
6.5	1.5	0.90	.92	0.69
7.0	0	0	0	0
			Total	9.27



How to Calculate Flow

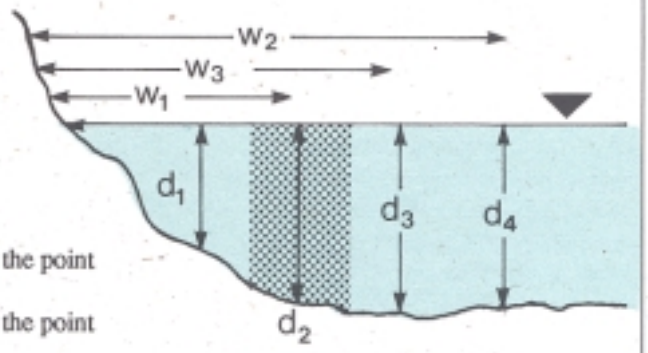
Calculating discharge from each of the width intervals:

$$q_2 = v_2 d_2 (w_3 - w_1)/2$$

where: q_2 = discharge at width interval 2 (cfs)
v_2 = velocity measure at width interval 2 (ft/sec)
d_2 = depth at interval 2 (feet)
w_3 = distance from the bank or initial measuring point to the point following interval 2 (feet)
w_1 = distance from the bank or initial measuring point to the point preceding interval 2 (feet)

Calculate the total discharge (flow) as the sum of each of the partial discharges.

$$Q = q_1 + q_2 + q_3 + q_4 \cdots q_n$$



6. Total discharge is calculated as the summation of the discharge from each of the intervals measured, as described and illustrated above and on page 61.

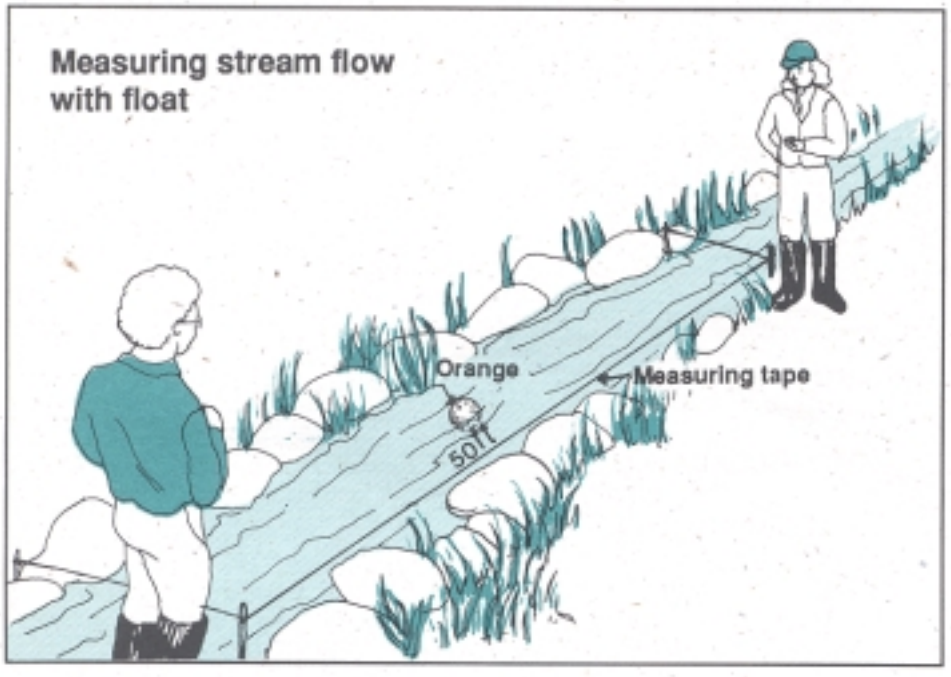
Measuring Stream Flow with a Simple Float

If a flow meter is not available or a rough estimate is adequate, you can measure flow by using a float. The float can be any buoyant object, such as an orange or a partially filled plastic water bottle. It needs to be heavy enough so that about an inch of it is below the water line. (Don't use glass or any material that may cause problems if you are can't retrieve the float after the measurement.)

1. Measure off at least 50 feet along the bank of a straight section of stream. If possible, string a rope across each end of the 50-foot length.

2. Estimate the cross-sectional area of the stream at one of these ends by using the total stream width and the, average depth. (Calculate the average depth from depths measured at 1- to 2-foot intervals.)

Total width (ft) x Average depth (ft) area



3. Release the float at the upstream site. Using a stopwatch, record the time it takes to reach the downstream tape. (If the float moves too fast for an accurate measurement, measure off 75 or 100 feet instead of 50.) Repeat the measurement two more times for a total of three measurements.

4. Calculate the velocity as distance traveled divided by the average amount of time it took the float to travel the distance. If the distance roped off is 50 feet and the orange took an average of 100 seconds to get there, the velocity is 0.5 ft/sec.

$$\frac{50 \text{ ft}}{100 \text{ sec}} = 0.5 \text{ ft/sec}$$

5. Correct for the surface versus mid-depth velocity by multiplying the surface, velocity by 0.85.

$$0.5 \times 0.85 = 0.43 \text{ ft/sec}$$

6. Calculate the discharge in cubic feet per second (cfs) by multiplying velocity (ft/sec) by the cross-sectional area (ft^2) of the stream.

$$0.43 \text{ ft/sec} \times 10.73 \text{ ft}^2 = 4.62 \text{ cfs}$$

Using a Staff Gage

A staff gage is nothing more than a long ruler placed semi-permanently in a stream or lake and used to read water depth. Stream gages are the most common and useful measure and are therefore emphasized here. However, you also can put a staff gage in a lake to monitor changes in lake water level.

Why Use a Staff Gage?

Staff gage information can be used in an indirect way to estimate stream flow. If you place a staff gage near a section of stream for which you are collecting flow data, you can identify the relationship between stream depth and stream flow. Once you know this relationship, you can estimate flow from the stream depth without having to take the time and trouble to make a detailed flow measurement. Periodically, the staff gage will need to be recalibrated against measured flows since the streambed, and thus the relationship between stream height and flow, can be expected to change over time.

Setting Up a Staff Gage

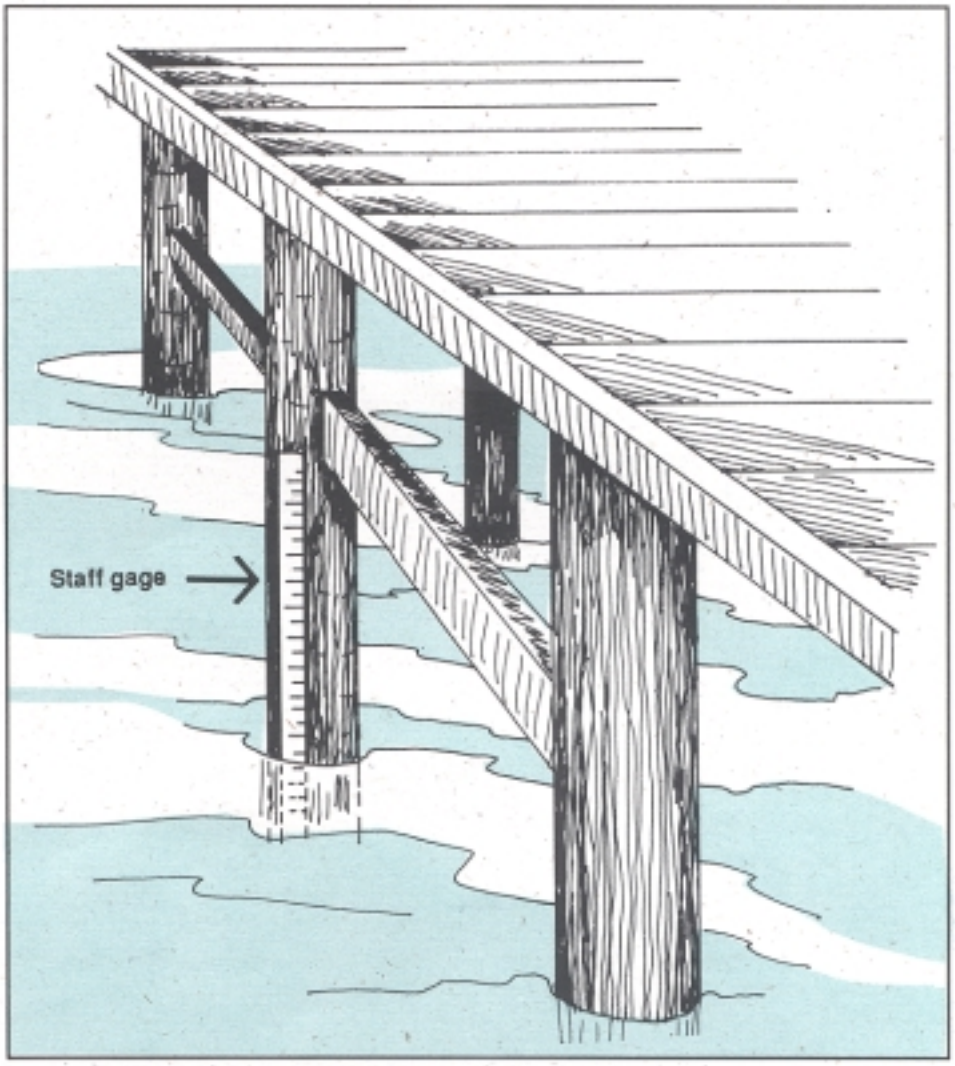
As was the case with stream flow, site selection is very important. The criteria used to select a flow measuring site are also important to the selection of a gage site. In fact, most of the time you will want to place a staff gage wherever you monitor flow.

Once you have selected a good flow monitoring site, it still may be hard to find a proper place for the staff. If placed too near the side of the stream, the staff may be dry during summer months. If placed near mid-stream, it may be washed away by high winter flows. The staff should not be placed in very slow-moving water or in a pool because sediments will accumulate around its base. The resulting localized changes in water flow patterns could affect your readings. On the other hand, turbulent water can make it difficult to read the gage. If your station is located near a bridge that has pilings in mid-stream, the downstream side of the piling often provides a good location for a gage.

The simplest way to install a staff gage is to attach it to a permanent structure, such as the bridge piling mentioned above. Life is rarely so convenient. You may have to provide your own "permanent" structure, for example, by pounding a strong metal pipe into the stream bed. Be sure the pipe is strong and tall enough to last through high water conditions. A PVC pipe also works. However, since these pipes are light and hollow, numerous holes should be drilled through them to allow the water to flow freely through the pipe. This will alleviate much of the extra strain on the pipe caused by high, fast-moving water. (NOTE: Lakes are easy. Just attach the gage to the end of a dock or pier where you can easily lean over and read it. Be sure the dock is permanently anchored to the lake bottom. A floating dock or one that is removed every year won't work.)

You can also "gage" a stream without using a staff gage by measuring the distance between the water surface and a known fixed height. If a bridge crosses your stream near where you want to establish a staff gage, you're in luck. The distance between the bridge and the surface of the water changes in response to changes in the stream depth. Measuring the distance from the bridge to the water surface lets you determine stream height.

To use this method, make a permanent mark on the side of the bridge to be sure your measurement is always taken at the exact same spot. Drop a weighted tape measure until the weight touches the water and record the distance from the bridge to the water. This is a wonderfully simple method of obtaining stream



height data, but it may not be highly precise. Even very small changes in stream depth or height may reflect large changes in stream discharge, particularly in a wide stream. When measuring the distance to the water surface from a bridge, you may have difficulty telling just exactly when the weight has reached the water's surface. On a windy day, the tape may not hang straight down to the water surface, or waves may make the tape bounce. Furthermore, different people who take the reading will likely interpret the point of contact with water a bit differently. The farther above the water the bridge is, the more these factors are likely to affect accuracy.

To reduce the error from this method, be sure your mark on the bridge is clear and has a line showing exactly where the tape should be read. Write down exactly how you are defining the surface of the stream. For example, is it when the weight touches the water, or when the weight is fully submerged? Taking care of these small details will improve consistency in the measurement.

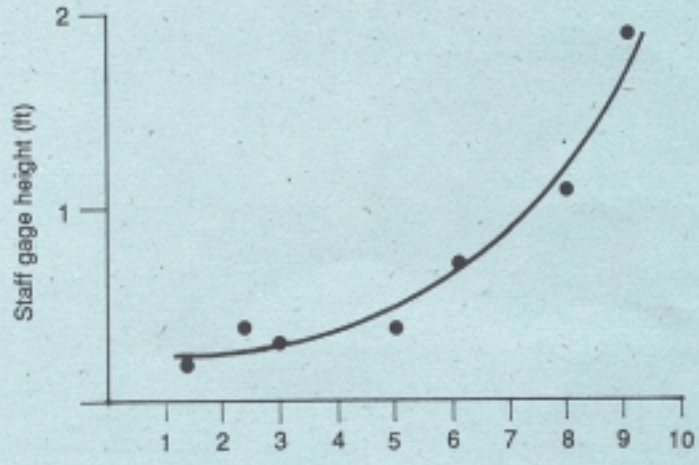
Forming a Stage-Discharge Relationship

Each time you take a flow measurement, you should take a gage reading, On a sheet of paper or in a computer file, keep a record of each flow measurement. You take and the corresponding staff gage reading. Once you have enough data, you simply plot these two variables on a graph and draw or compute the resulting curve.

Draw a graph with an x-axis and y-axis. The x-axis, the horizontal line, will be the streamflow measurement. The y-axis, the vertical line, will be the staff gage reading. Place a dot on the graph where each streamflow and corresponding staff gage measurement intersect. Draw a smooth, curved line between the points. Now you have a stage-discharge relationship. From now on, you can simply take the gage reading and estimate the stream flow from your prediction curve.

As convenient as a stage-discharge relationship is, it still needs to be supported by real data. The more data points you use to develop your graph, the better, The graph is accurate only for the stream flows that fall within the data range you used to create the graph. For example, if all your measurements were taken during June through September when stream flows were low, the graph could not be used to predict high flows in December. Be sure to collect data during a wide range of flow conditions. In general, if you have about four data sets from the low-flow period and four from the high-flow period, you can comfortably prepare the graph. Make periodic checks of the discharge curve, especially after periods of flooding. Recalibrate the curve if the periodic checks indicate the relationship has changed. Eventually, natural changes in the stream bottom will result in a change in the relationship between flow and gage height.

Forming a Stage-Discharge Curve



Staff Gage (ft)	Stream Flow (cfs)
.20	1.3
.40	2.3
.30	3.0
.40	5.0
.70	6.1
1.10	8.0
1.40	8.3
1.90	9.0

Calculating Pollutant Loads

The importance of pollutant loading calculations was described in Chapter Three. Loading is a simple function of concentration and flow. Loading can be reported in a number of different units and can be calculated as shown in the table.

Pollutant Load Calculations

$$L = f \times c \times d$$

where L = load
f = units conversion factor (see table)
c = concentration of pollutant
d = discharge

Units for Reporting Loading

Pollutant Concentration Unit	Flow Unit	Conversion Factor	Load Unit
mg/L	cfs	5.39	lb/day
µg/L	cfs	5390	lb/day
#/100 mL	cfs	284.7	#/sec

Resources and References

Volunteer Monitoring Information

The Volunteer Monitor –
The National Newsletter of Volunteer Water Quality Monitoring
c/o Adopt a Beach
710 Second Ave., Suite 730
Seattle, WA 98104
(206-296-6591)

National Directory of Citizen Volunteer Environmental Monitoring Programs
Rhode Island Sea Grant Information Office
University of Rhode Island Bay Campus
Narragansett, RI 02882-1197
(401-792-6842)

Save Our Streams Program
Izaak Walton League of America
1401 Wilson Blvd., Level B
Arlington, VA 22209
(703-528-1818)

Volunteer Resource Guide: A Citizen's Directory to Volunteer Opportunities in Caring for Washington's Outer Coast, Puget Sound, and Associated Watersheds
Volunteers for Outdoor Washington
Adopt a Beach
607 Third Ave., Room 210
Seattle, WA 98104
(206-467-0278)

Available Soon:

Field Guide to Watershed Inventory and Stream Monitoring Methods
Adopt-A-Stream Foundation
P.O. Box 55558
Everett, WA 98201
(206-388-3313; 1-800-424-4EPA)

Lake and Stream Associations

These groups promote the exchange of information and public awareness about lakes and streams, and offer technical support to private citizens and citizen groups.

Washington State Lake Protection Association (WALPA)
P.O. Box 1206
Seattle, WA 98111-1206

North American Lake Management Society (NALMS)
P.O. Box 217
Merrifield, VA 22116

Adopt-A-Stream Foundation
P.O. Box 55558
Everett, WA 98201

Information Manuals

Field Manual for Water Quality Monitoring
by Mark Mitchell and William Stapp
William B. Stapp
2050 Delaware
Ann Arbor, MI 48130

Adopt-A-Stream Teacher's Handbook
Delta Laboratories, Inc.
34 Elton St.
Rochester, NY 14607

Water Quality Indicators Guide: Surface Waters
(Ask for: Pub # SCS-TP-161)
P.O. Box 2890
Washington, DC 20013

Standard Methods for the Examination of Water and Wastewater, 17th ed.
American Public Health Association (APHA)
Washington, DC

Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound
USEPA - Office of Puget Sound
1200 Sixth Ave.
Seattle, WA 98101

Water Quality Sampling Kits

HACH Company
P.O. Box 389
Loveland, CO 80539
(1-800-227-4224)

LaMotte Chemical Products
P.O. Box 329
Chesterton, MA 21620
(1-800-344-3100)