WATER QUALITY & MONITORING

By Kitt Farrell-Poe

"A river is the report card for its watershed." - Alan Levere, Connecticut Department of Environmental Protection, 2000

INTRODUCTION

Think about the water you drink, as well as the water you bathe, cook or clean with. What kind of quality does it have before you use it? Do you know what's in it or what state it is in (such as temperature)? What happens to the waste water afterwards? These questions reflect upon one of the most important concepts of watershed stewardship—**water quality**.

Water quality is a term used to describe the chemical, physical, and biological characteristics of water, generally in terms of suitability for a particular—or designated--use. Like the quote above from Alan Levere, the quality of a water body—in most cases a river—is the best indicator of what's going on in the rest of the watershed, both uphill and upstream. Water quality is also a function of the geology of the watershed. For example, highly mineralized soils and rock may result in highly mineralized water.

Water-quality monitoring is the process of sampling and analyzing water conditions and characteristics. This chapter will discuss the various water characteristics that have an effect on the designated uses of water bodies and volunteer monitoring as a means to measure these characteristics.

Figure 1. Oak Creek. Photo courtesy Robert Emanuel.

In this chapter, you will learn:

- About the benefits of volunteer monitoring
- Common water-quality monitoring parameters and why each is important
- Considerations for developing a monitoring plan
- Components of a successful monitoring program

WATER QUALITY

Water characteristics, such as dissolved oxygen, pH, nutrients, and temperature, are known as **parameters**. Parameters can be physical, chemical or biological in nature.

Some of the physical characteristics of water quality include but are not limited to **temperature**, **dissolved oxygen** and **suspended solids**.

Chemical parameters are a measure of substances, such as **nutrients**, **heavy metals** and **pesticides**, which are dissolved in the water or are in particulate form.

Biological parameters refer to aspects of the living environment, from microscopic **algae** and **invertebrates** to **macrophytes** and fish.

River/Stream	Lake/Pond
Reservoir	Beach/shore
Wetland	Estuary
Ground water	Wash/Arroyo
Canal	Spring

Table 1. Types of environments.

Under guidance from the U.S. Environmental Protection Agency (USEPA), states develop water-quality standards that designate levels of each parameter that are acceptable for designated uses such as drinking water, irrigation, swimming, and aquatic life.

This section describes many common parameters monitored by volunteers and agencies. These parameters are monitored for one or more of the following reasons:

- They are important for human health.
- They are important for aquatic health.
- They are important for some industrial or agricultural uses; and
- They are part of state water-quality standards or federal water-quality criteria.

Information on recommended monitoring protocol is available from the Arizona Department of Environmental Quality (ADEQ). Information on Arizona's water-quality standards is also available from ADEQ (see list of websites at the back of this chapter). Federal water-quality criteria, which serve as guidance for the states, are available from the USEPA (see **Resources** at the end of this chapter).

Monitoring different aspects of water quality over time enables changes to the aquatic environment to be detected, and an understanding of ecosystem health to develop. Measuring a combination of these parameters allows a complete picture of the status of a water resource to emerge. If only physical or chemical parameters are measured, it is difficult to gauge the impact they have on the life in or using the water. Similarly, measuring biological parameters can tell you if the ecosystem is under stress, but not necessarily what is causing the stress. The combined data can be used to generate information essential for those managing and protecting natural resources, allowing them to determine if the conditions of the water resource are improving or worsening with time and human use.

The questions that you want to answer and the type of environment (Table 1) that you are concerned about determine the

Table 2. Water Quality Parameters (USDA-CSREES Volunteer Monitoring, 2003)

Physical/Chemical Parameters	
Temperature	Dissolved oxygen (DO)
Alkalinity	pH
Salinity	Phosphorus
Nitrogen	Hardness
Flow/Water level	Chloride
Turbidity or Secchi transparency	Metals
Suspended sediment or Total suspended solids	Organic chemicals
Dissolved Solids (TDS)	Biochemical oxygen demand (BOD)
Electrical Conductivity	Color
Total suspended solids (TSS)	Radiochemicals
Biological Indicators	
Macroinvertebrates	Aquatic Wildlife
Bacteria	Chlorophyll
Phytoplankton	Fish
Shellfish	Exotic/Invasive species
Aquatic or terrestrial vegetation	Algae

parameters that you should monitor. Table 2 lists some potential monitoring parameters. It is not enough to be simply "concerned about water quality," but rather you need to know what *in particular* you are interested in learning about the water.

According to USEPA, volunteers most commonly monitor for pH, dissolved oxygen, water temperature, stream flow, turbidity (or transparency), phosphorus, nitrogen, macroinvertebrates, bacteria, habitat, and land condition. Electrical conductivity and total dissolved solids are two other useful parameters that can be easily measured.

WATER-QUALITY PARAMETERS

The following is a discussion of the chemical, physical, biological parameters commonly monitored.

Chemical Parameters

pH is a measure of the level of activity of hydrogen ions in a solution, resulting in its acidic or basic quality (Figure 2). pH is measured on a **logarithmic scale** that commonly ranges from 0 (acidic) to 14 (basic), with 7 being neutral. Each stream organism is adapted to a specific pH range.

The pH in most rivers unaffected by humans ranges from 6.5 to 8. The pH range of survivability of most freshwater organisms ranges from about 4.5 to 9. Western soils, which are typically alkaline, are a natural contributor to elevated pH conditions (low acidity) in Arizona's lakes, rivers, and reservoirs.

Humans contribute to elevated pH primarily in the form of nutrient runoff (most commonly fertilizer), which leads to increased algae growth and higher pH. Low pH can be especially harmful to aquatic organisms. Low pH affects physiological (biological) functions of aquatic life through the reduction of enzyme activity and effectiveness. In Arizona, low pH conditions have been identified in approximately twenty stream miles. Low pH results when atmospheric oxygen and water comes in contact with sulfides such as pyrite, which

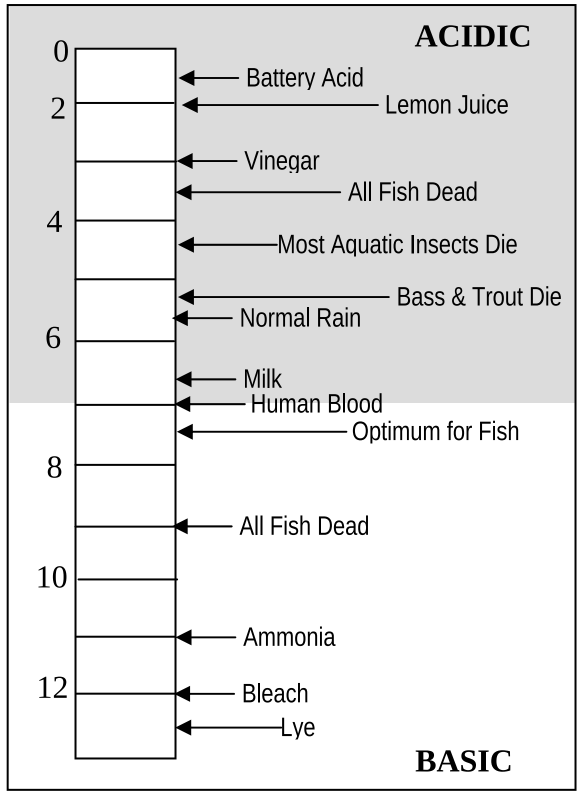

Figure 2. pH scale.

reacts and forms acid. The acid then dissolves naturally occurring metals, resulting in acid mine drainage and elevated concentrations of metals in water.

Total dissolved solids (TDS) is a measure, in milligrams per liter (mg/L), of the amount of dissolved materials in the water. Ions such as potassium, sodium, chloride, carbonate, sulfate, calcium, and magnesium all contribute to the dissolved solids in the water. In many instances resource agencies use the terms TDS and salinity interchangeably, since these ions are typically in the form of salts. Measuring total dissolved solids is a way to estimate the suitability of water for irrigation and drinking. This is an important parameter for drinking water because high TDS values may result in a 'salty' taste to the water.

Groundwater often has higher levels of dissolved solids than does surface water because of its contact with aquifer geologic material and more time to dissolve rock and mineral materials. When stream flow is at base flow conditions, most of the source water is from groundwater, and dissolved solids concentrations are high. When stream flows are high from rain or snowmelt, dissolved solids measurements typically are low.

In the Colorado River Basin (upper and lower), it is estimated that financial losses due to elevated salinity range between $300,000 and $500,000 dollars annually, but could go as high as $1.5 billion if salinity issues were left unchecked.

Electrical conductivity is the ability of a substance to conduct an electrical current, measured in **microsiemens** per centimeter (mS/cm). **Ions** such as sodium, potassium, and chloride give water its ability to conduct electricity. Conductivity is an indicator of the amount of dissolved salts in a stream. Conductivity often is used to estimate the amount of total dissolved solids (TDS) rather than measuring each dissolved constituent separately.

Nutrients are chemical elements that are essential to plant and animal life and growth. Nitrogen and phosphorus are two nutrients that are important to aquatic life. Some nutrients form a part of the water's TDS, others, such as ammonia, are found dissolved completely into the solution. At high levels, however, they are considered **contaminants**. High levels of nutrients can cause increased growth of algae beyond what is normal. Decaying algae mats can cause foul odors and tastes. And as algae produce energy or decay, they remove dissolved oxygen from the water.

Nutrients are measured in milligrams per liter (mg/L). Commonly measured nutrient parameters include nitrate, ammonia, orthophosphate, and total phosphorus. Both nitrogen and phosphorus are affected by chemical and biological processes that change their form and transfer them to or from water, soil, decaying organisms, and the atmosphere. In nature, both nitrogen and phosphorus come from the soil and decaying plants and animals. Fertilizers, untreated sewage, as well as domestic and wild animal waste are common sources of nutrients. In this way, nutrients are "cycled" or moved through the environment. Nutrient recycling in Arizona's lakes is a big problem.

ADEQ is developing standards for ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen. The ammonia standards are designed to protect fish, while the nitrite and nitrate criteria are set for drinking water. The federal government does not have formal standards for phosphorus, but it does have recommended levels. Because background levels of nutrients can vary from watershed to watershed, the USEPA is working to develop nutrient criteria based on regional characteristics. A detailed explanation of nutrient impact is available at the USEPA's Watershed Academy Website (see **Resources** at the end of this chapter).

Dissolved oxygen (DO) is needed by fish and other stream organisms. In unaltered streams, dissolved oxygen levels usually determine the ability for the stream to support aquatic oxygen-dependent life, as defined by temperature and elevation. As plant and animal material decays, it consumes dissolved oxygen. Turbulence, interaction with the air, and photosynthesis replenish oxygen in the water. Cold water can hold more dissolved oxygen than warmer water. Dissolved oxygen measurements can be expressed as a concentration, milligrams per liter (mg/L), or as percent saturation (the amount of oxygen the water holds compared to what it could absorb at that temperature).

Biochemcial oxygen demand (BOD) is a related concept. While there are many factors that influence dissolved oxygen, the most important is the amount of organic matter decomposing in the water. Oxygen in the surrounding water is consumed as microorganisms decompose this organic matter. In other words, BOD is a measure of the use of dissolved oxygen by life forms, particularly during decomposition.

Manufactured chemicals such as solvents, Polycholorinated bi-phenos (PCBs), and pesticides are expensive to monitor. The samples must be collected following strict protocols, and the water must be analyzed by a professional lab. ADEQ has established procedures for sampling these chemicals. Monitoring for some of the manufactured chemicals can be dangerous; therefore, it is recommended that volunteers avoid monitoring for these chemicals.

Metals are found in Arizona's surface water and groundwater both naturally and they are added to the water by acid mine drainage and by air deposition. As in manufactured chemicals, the samples must be collected following strict protocols, and the water must be analyzed by a professional lab. Additionally, some metals pose an inherent health hazard and monitoring requires specialized training such as a 40-hour OSHA-approved course as well as special safety equipment. Due to the strict protocols and hazards associated with analysis for metals, monitoring this parameter is normally accomplished by professionals. Because of these issues, volunteers should not monitor environmental sites where metals may be found.

Physical Parameters

Stream flow (discharge) is the volume of water discharged or moving through a stream at any given time. Stream flow often is expressed in cubic feet per second (cfs) or sometimes as gallons per minute (gpm). The discharge of a stream can vary on a daily, weekly, monthly, and seasonal basis in response to precipitation, snowmelt, dry periods, and water withdrawals. Stream flow affects water chemistry; thus, water-quality measurements should always be interpreted in relation to stream flow. Also, stream flow is particularly important in interpreting dissolved oxygen readings.

Water temperature is a crucial aspect of aquatic habitat for two reasons. First, water temperature affects nearly all other water quality parameters. Aquatic organisms are adapted to certain temperature ranges. As the upper and lower limits of the range are approached, the organism becomes more susceptible to disease. Also, fish that spend extra energy searching for cool areas might be at a disadvantage when competing for food. Stream temperature is regulated by solar energy, the surface area of the stream, shade, the volume of water moving through the stream, and several other factors. In Arizona, reservoir releases can be a factor in water temperature fluctuation.

Suspended solids are particles of sand, silt, clay, and organic material moving with the water or along the bed of the stream. Suspended solids usually are measured as a concentration, milligrams per liter (mg/L). High levels of suspended solids can cause problems for aquatic organisms, both as the solids travel through the water and after they are deposited on the streambed. Suspended solids can reduce visibility, making it hard for fish to find prey. Solids also can clog the gills of fish and suffocate macroinvertebrates such as insects.

Turbidity measures water clarity or the ability of light to pass through water. Turbidity is a measure of the amount of particulate matter and dissolved color that is suspended in water. Water that has high turbidity appears cloudy or opaque. High turbidity can cause increased water temperatures because suspended particles absorb more heat and can also reduce the amount of light penetrating the water. High levels of turbidity make it difficult for fish to find prey and indicate high levels of suspended solids. Turbidity often is measured as a way to estimate amounts of suspended solids. Turbidity is an optical property, however, and does not directly reflect the amount or types of solids; thus it must be used carefully. Turbidity is measured in Nephelometric Turbidity Units (NTUs) or with a **Secchi disk**.

Transparency or **Secchi depth** is the depth to which one can see into a lake and is an indication of water clarity. This measurement—an alternative to measuring turbidity—is obtained by lowering a black and white Secchi disk into the water and recording the depth at which it is no longer visible as well as the differences in color.

Biological Parameters

Bacteria such as *Escherichia coli* (*E. coli*) and fecal coliform are measured as indicators of more harmful bacteria. High numbers of these types might indicate the presence of other bacteria that cause illness. Most analytical methods involve growing bacteria in a water sample on a Petri dish and counting the colonies. The results are given as the number of colony-

Table 3. Common water quality impacts potentially associated with selected land uses.

Source	Common Pollutants or Impacts
Construction	Sediment, turbidity, total suspended and dissolved solids, thermal impacts, dissolved oxygen/biochemical oxygen demand
Cropland	Sediment, turbidity, total solids, nutrients, thermal impacts, pesticides
Grazing land	Sediment, fecal bacteria, turbidity, nutrients, thermal impacts
Forestry	Sediment, turbidity, total solids, thermal impacts
Lawns/Golf courses	Nutrients, turbidity, total solids, bacteria
Marinas/Boat usage	Nutrients, bacteria, petroleum hydrocarbons
Mining	Sediment, alkalinity, pH, total dissolved solids, leached metals
Recreation	Fecal bacteria, nutrients, turbidity, total solids
Septic systems	Fecal bacteria, nutrients, dissolved oxygen/biochemical oxygen demand, conductivity, thermal impacts
Sewage treatment plants	Dissolved oxygen/biochemical oxygen demand, turbidity, total solids, conductivity, nutrients, fecal bacteria, thermal impacts, pH, manufactured chemicals
Suburban/Urban runoff	Turbidity, nutrients, thermal impacts, conductivity, dissolved oxygen/biochemical oxygen demand, bacteria, metals, petroleum hydrocarbons

forming units (CFU) per 100 milliliters (ml) of water.

Bacteria populations fluctuate in response to stream flow, temperature, energy sources, disturbance of the streambed, time of year, and time of day. Bacteria can survive for long periods on land and in stream sediments.

Benthic macroinvertebrates are organisms that are large (macro) enough to be seen with the naked eye and lack a backbone (invertebrate). Benthic refers to the bottom of a waterway. Examples of benthic macroinvertebrates include insects in their larval or nymph form, crayfish, clams, snails, and worms. Most live part or most of their life cycle attached to submerged rocks, logs, and vegetation. The basic principle behind the study of macroinvertebrates is that some are more sensitive to pollution than others. If a stream site is inhabited by organisms that can tolerate pollution and the more pollution-sensitive organisms are missing, a pollution problem is likely.

Submerged aquatic vegetation (SAV) provides invaluable benefits to aquatic ecosystems. SAV refers to plants that float or grow below the water surface. It not only provides food and shelter to fish and invertebrates but also produces oxygen, traps sediment and absorbs nutrients such as nitrogen and phosphorus. Whereas SAV are dependent upon the transmission of sunlight through the water, the location of individual species depends upon a variety of factors such as salinity, depth and bottom sediment.

Other microorganisms include **protests** such as amoebas, ***Giardia*** and **cyanobacteria**. These and many other organisms can be toxic to humans, livestock and other mammals consuming water.

Field Conditions

Whenever any monitoring is done, specific information gathered about field conditions (weather, stream flow, livestock grazing, other activities) and documentation on sample handling and equipment is critical. Without this type of information, agencies such as ADEQ or the USEPA cannot accurately interpret the data.

LAND USE IMPACTS ON WATER QUALITY

If you have a concern that certain land uses or activities in your watershed may be impacting water quality, you may be able to focus your monitoring efforts. Many land uses have specific types of water quality impacts associated with them. For example, excess lawn fertilizers and pet waste often result in runoff from residential areas containing high levels of bacteria and phosphorus or nitrogen. Table 3, from USDA-CSREES Volunteer Water Quality Monitoring Project, contains a list of land uses and potential water quality impacts.

WATER-QUALITY MONITORING

For many years, agencies and citizens across the United States have been monitoring water quality as a way to track pollution and determine the condition of aquatic ecosystems. We monitor water quality to:

- Identify particular pollutants of concern
- Identify whether the quality of the water is sufficient for a particular use
- Target sources of pollution
- Detect trends
- Determine the effectiveness of watershed restoration and enhancement projects
- Census the water quality status of a particular water body

Recently, citizens have begun to monitor additional aspects of aquatic systems to gain a more complete picture of watershed health. These aspects include stream life, such as macroinvertebrates, the physical structure of the stream, and habitat conditions. By monitoring water quality, stream life, and habitat, we can better understand the health of stream ecosystems.

"We should do some monitoring" is a common response when concerns are expressed about local watershed conditions or resources. But you need to consider many issues before acting on this idea. There's a long list of potentially useful watershed characteristics that can be assessed, and an even longer list of ways to assess them. Without some careful planning, you may waste a lot of time, energy, and money.

You can use monitoring to identify both watershed enhancement opportunities and to evaluate results of enhancement activities. Monitoring can be very challenging, however, because regardless of location within a watershed (stream, riparian area, wetland, or upland), there are many conditions that can be measured. Furthermore, these conditions vary a lot depending on time, location, and management approaches.

Simply put, you may need to take many careful measurements in order to understand a situation. Usually, there are few shortcuts to a well-designed watershed evaluation or monitoring plan.

Many formal watershed assessments and resource monitoring programs have been or soon will be conducted under a variety of public and private initiatives. Detailed guidelines and technical assistance on these activities are available from many organizations (see the **Resources** section at the end of this chapter).

This section simply provides a general overview of some important considerations when undertaking nearly any type of watershed evaluation or monitoring effort. It will serve as a foundation for your work with specific projects as discussed in other chapters in this section.

VOLUNTEER MONITORING

Local residents can play a large role in water-quality monitoring. Volunteer monitors work in partnership with a variety of groups, from grassroots nonprofits to watershed councils, soil and water conservation districts, and agencies. Volunteers become involved in monitoring programs for many reasons. These reasons include:

- To promote stewardship;
- To take ownership and responsibility for local water resources;
- To identify problems in surface water and groundwater;
- To contribute to their community; and
- To learn about the environment.

Volunteer groups also partner with state agencies in the process of establishing **Total Maximum Daily Loads** (TMDLs) of pollutants, while others work with landowners to monitor the effects of best management practices. Working with federal or state agencies—in this case ADEQ—is an important step towards assisting in monitoring watershed health. Potential volunteers or groups are encouraged to work with ADEQ to develop a water quality monitoring program. Other helpful agencies include the U.S. Geological Survey (USGS), and the Natural Resources Conservation Service (NRCS). The Forest Service, National Park Service and Bureau of Land Management may also be of assistance.

Volunteer monitors come together to share data, program management techniques, and experiences through such forums as the quarterly newsletter *The Volunteer Monitor* and the National Volunteer Monitoring Conference. Organizations such as Global Learning and Observations to Benefit the Environment (GLOBE) and Global Rivers Environmental Education Network (GREEN) promote the involvement of youth in water-quality monitoring.

This section is aimed at individuals or groups interested in learning more about citizen-based monitoring. It also describes several monitoring strategies and presents 10 components of a successful monitoring project. Detailed information on parameters, monitoring strategies, and citizen-based monitoring can be found in the references at the end of this chapter.

MONITORING PROTOCOLS

Once you've determined exactly what you are going to monitor, you'll need to decide exactly how you will monitor. A variety of resources are available to draw from when developing your program's monitoring protocols. Many volunteer monitoring programs have successfully modified established monitoring methods or developed new methods that are supported by established scientific methodologies. When backed by strong quality assurance and quality control (QA/QC) procedures, these "volunteer" methods can be acceptable for many uses. Using widely accepted monitoring procedures such as those approved by the USEPA can be very important for data credibility.

If your plan for monitoring is to assist ADEQ, then ADEQ requires that all water quality monitoring have appropriate standard procedures (SAPs) and quality assurance procedures (QAPs). These documents help determine if ADEQ is going to be able to use your data. A Quality Assurance Project Plan (QAPP) is imperative if the data is intended to be used (see below for more information on QAPPs). Volunteers are encouraged to work with water monitoring professionals to develop these documents prior to implementing monitoring.

Another tremendous source for information regarding monitoring methods is the Volunteer Monitoring Methods series by USEPA (see **Resources**). This series includes methods for monitoring lakes, streams, and estuaries, as well as guidance for monitoring wetlands and QA/QC project plan development. Each manual describes in great detail methods appropriate for volunteers and provides numerous references to a variety of volunteer monitoring programs and other methods. The *Volunteer Monitor* newsletter sponsored by USEPA publishes descriptions of new or innovative monitoring methods, as well as program management ideas, and includes extensive contact information (see **Resources**).

MONITORING STRATEGIES

A monitoring strategy describes what, how, and where you will monitor in order to answer a particular water-quality question. In order to gain useful data from a water-quality monitoring project, it is essential to articulate the question you are trying to answer. From this question you develop the goals and objectives for the project. In turn, these goals and objectives will guide you in designing a monitoring strategy.

Your monitoring question will guide you in deciding which parameters, where, and when to sample. Examples of monitoring questions include:

- Have suspended sediment levels changed over time at a site?
- How do nutrient levels vary among streams that flow through areas with different land uses?
- Has water temperature changed as a result of planting willows along a small stream?

Each question will produce a different monitoring strategy. See Table 4 for examples of increasingly specific goals and objectives and ***Appendix A*** for a complete matrix of monitoring activities typically performed by volunteers.

Table 4. Examples of increasingly specific goals for watershed monitoring projects (Oregon State University, 2002).

Purpose	Goal	Method
Support ADEQ total maximum daily load (TMDL) development.	Collect data of appropriate quality for use in ADEQ temperature computer models.	Measure continuous temperature and flow (end of summer) at the mouth of major tributaries to the mainstem river. Compile temperature data and quality assurance information in ADEQ data forms. Submit data electronically in ADEQ forms at end of season.
Fill data gaps identified in watershed assessment.	Measure water quality and habitat inlow-gradient streams flowing through agricultural lands.	Measure pH, dissolved oxygen, and temperature frequently enough to detect diurnal fluctuations in summer. Collect macroinvertebrates in early fall and compare results from professional identification with those from ADEQ reference sites.
Educate community about links between water quality and land use.	Collect sufficient data to demonstrate differences in water quality in streams bordered by healthy and degraded riparian zones.	Assemble existing water quality information from two contrasting areas and summarize in a poster for library display. Measure shade, channel width, and substrate once a year and water quality quarterly at two contrasting sites. Interpret data by comparing existing standards and illustrating differences in seasonal fluctuations.
Monitor effectiveness of restoration projects.	Collect sufficient water quality data to detect trends *or* for at least 5 years.	Measure shade, flow, and channel characteristics at restoration sites once a year. Collect continuous data upstream and downstream of restoration sites during summer. Use appropriate step trend analysis to compare data collected before and after a restoration project.

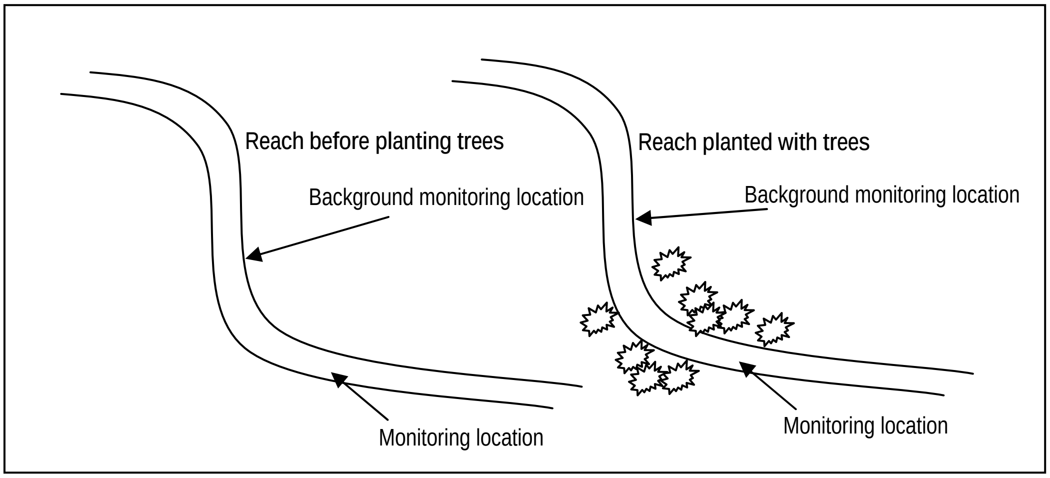

Figure 3. Before and after monitoring. Note that USEPA recommends monitoring background conditions at the same time as each monitoring sample is taken.

One of the challenges of designing a water-quality monitoring strategy and interpreting the resulting data is that stream conditions can change hourly, daily, seasonally, annually, and over the long term, even without human impacts. Dissolved oxygen concentrations, for example, can change throughout the day as water temperature changes and algae respire. Stream flow will vary from day to day, month to month, and between years; these changes affect the levels of many parameters. To yield useful information, a monitoring strategy must address this variability.

Trend, baseline, and effectiveness monitoring are three types of monitoring that address common monitoring questions. This section briefly introduces each type and applies it to monitoring stream temperature. These and other monitoring types are discussed further in many of the resources listed at the end of this chapter.

TREND MONITORING

Trend monitoring involves repeated measurements at a site over a period of time. These measurements are examined to see whether a pattern emerges such as an increase, decrease, or cycle.

A typical trend monitoring question about temperature might sound like "Has stream temperature increased over time at a particular site?" In order to determine whether stream temperature has increased at a site, it is important to measure other factors that affect stream temperature and to understand how temperature varies with background temperature. Stream flow, for example, is extremely important. The smaller the volume of water, the more easily it heats. Therefore, stream flow should be considered when developing a monitoring strategy. It is important to separate the effects of changes in stream flow from the effects of changes in land use.

It also is important to monitor at the same time in the summer each year. Monitoring should be done during the time that impacts are expected.

BASELINE MONITORING

Baseline monitoring establishes a reference point. This reference point then can be compared with future conditions or against a standard.

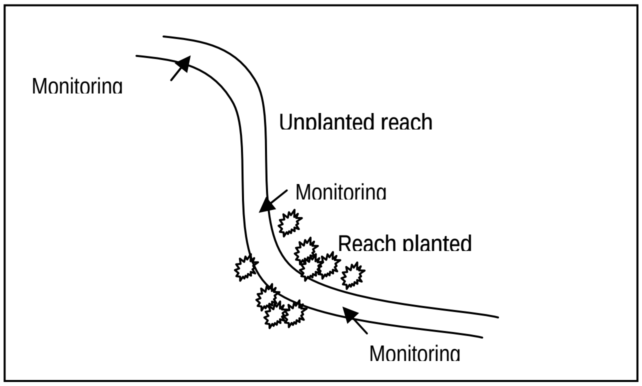

Figure 4. Pre- and post-treatment monitoring.

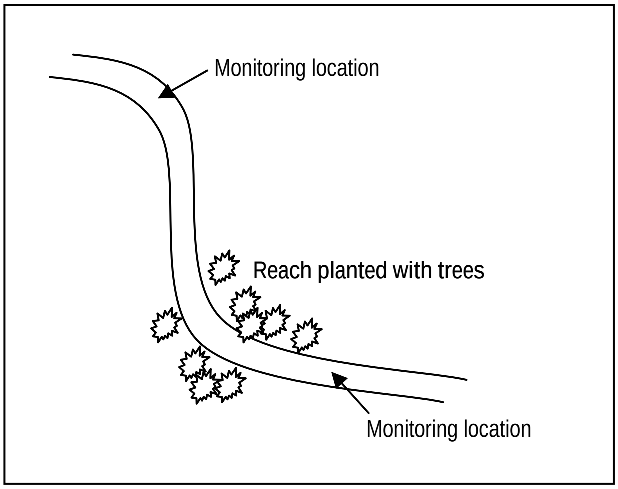

Figure 5. Upstream and downstream monitoring.

For example, a typical question for monitoring total dissolved solids (TDS) using baseline monitoring is "What is the TDS at a site, and how does that compare to Arizona's water-quality standard?"

For baseline monitoring of stream temperature, collect measurements from late spring throughout the summer and into early fall at a particular point.

EFFECTIVENESS MONITORING

Effectiveness monitoring is used to determine whether a management activity has produced the desired water-quality results or benefits and would address the stream temperature question: "Did planting cottonwoods along the stream improve water temperature?" Three common approaches to effectiveness monitoring are to monitor before and after the project, upstream and downstream of the project, or paired reaches.

Monitoring before and after riparian planting provides data that can be difficult to interpret. In this approach, monitoring takes place at a single point at the downstream end of the area to be planted (Figure 3). Stream temperature is monitored before the trees are planted and again as the shade develops.

This approach is challenging because changes in precipitation and discharge can affect water temperature. The year before the willows are planted, for example, might be a low water year, while two summers later the flows might be extremely high. Take these fluctuations into account when interpreting data. It might be hard to say with certainty whether changes in stream temperature were caused by the increased shade or by natural factors.

Another common approach is to monitor upstream and downstream of a project (Figure 4). This strategy provides more information than the before–after approach because both sites experience the same changes in stream discharge, climate, and other factors. The natural variations in stream conditions are accounted for. This method of monitoring is in fact required by the USEPA for monitoring effectiveness of environmental projects.

The most useful monitoring strategy is the paired reach strategy (Figure 5). In this strategy, water temperature is monitored at the upstream and downstream ends of two adjacent stream reaches. Then willows are planted along one of the reaches. Both reaches are monitored to see whether the planted reach responds differently over time than the unplanted reach. This strategy accounts for sources of variability before, during, and after the project. It also provides a control reach against which the planted reach can be compared.

MONITORING PLAN

Once you've determined how you will monitor, you will likely want to create monitoring procedures manual. Having a detailed written manual helps to ensure consistency between monitors and over time, and is an important quality assurance element for many programs. While you will want to prepare a monitoring manual specific to your program, there is no point in "reinventing the wheel." There are many number of good resources from which to adapt materials. A search of the Internet will uncover many hundreds. In the resources section, there is a list of selected Extension-associated monitoring manuals to get you started. Also, have ADEQ review your plan if they will eventually use the data.

TEN COMPONENTS OF A SUCCESSFUL WATER-QUALITY MONITORING PROGRAM

This section introduces considerations for anyone wishing to start a water-quality monitoring program. These considerations and others are discussed in more detail in publications such as Volunteer Stream Monitoring: A Methods Manual (USEPA, 1997), The Volunteer Monitor's Guide to Quality Assurance Project Plans (USEPA, 1996), Starting Out in Volunteer Water Monitoring (USEPA, 1998; www.USEPA.gov/owow/monitoring/volunteer/startmon.html) and the Designing Your Monitoring Strategy: Basic Questions and Resources to Help Guide You (USDA-CSREES Volunteer Water Quality Monitoring Project (see **Resources** at the end of this chapter).

1. A diverse Technical Advisory Committee.

A Technical Advisory Committee (TAC) is a group of people who can provide technical review of all stages of the monitoring project. A TAC might:

- Give advice on monitoring questions and the sampling strategy;
- Find resources such as monitoring equipment and money;
- Promote community buy-in of the project;
- Review the results and conclusions for credibility;
- Assist with data interpretation and presentation; and
- Vouch for the project's credibility to agencies.

A broad selection of technical expertise and diverse perspectives will make the project both scientifically sound and acceptable to the community. The TAC might be composed of university scientists, natural resource agency staff, watershed stakeholders, landowners, and interested citizens.

Include state and federal monitoring experts as much as possible. You might want to invite participation from the United States Geological Survey (USGS), the Arizona Department of Game and Fish, ADEQ, or other agencies that manage land in the watershed, major industries in the basin, and industries or cities that have permits to discharge into the river.

Different TACs have varying amounts of involvement in monitoring projects. Some meet annually to review the project and results. Other TACs never meet formally, but their individual members review draft plans and reports and are available for consultation as time allows.

2. Clear monitoring questions.

A clear monitoring question is essential for producing useful monitoring results. The Designing Your Monitoring Strategy: Basic Questions and Resources to Help Guide You, published by USDA-CSREES Volunteer Water Quality Monitoring Project, suggests that defining the problem, goals, and objectives at the beginning of a monitoring project will help structure the monitoring so that the data collected provide reliable answers to the questions (USDA-CSREES, 2004). Table 4, produced by the Oregon Department of Environmental Quality Volunteer Monitoring Coordinator, provides a matrix that can help you set goals and objectives for your project. The USDA-CSREES Volunteer Water Quality Monitoring Project has an extensive matrix (following this section) to assist you with this process. Don't forget that your TAC also can help with this process.

3. A quality assurance project plan (QAPP).

A quality assurance project plan outlines monitoring procedures in detail so that the samples, data, and reports are of high enough quality to meet project objectives. It describes the field, lab, and data management protocols; procedures for training and overseeing volunteers; and data interpretation and presentation methods.

Ideally, the plan is developed in collaboration with the TAC and is approved by funding agencies or those that will use the data, such as ADEQ. In Arizona, ADEQ's Volunteer Monitoring Coordinator provides input into these plans and approves them. USEPA's The Volunteer Monitor's Guide to Quality Assurance Project Plans provides step-by-step instructions on how to develop a quality assurance project plan.

4. A well-designed sampling strategy.

A sampling design or strategy is the "what, where, when, and how" of water-quality monitoring. Choose parameters, sampling schedules, sampling locations, and methods that will answer your monitoring questions.

5. Appropriate testing methods.

The method you choose to measure each parameter plays a large role in the overall quality of your data. In choosing methods, take the following factors into consideration.

Precision and accuracy describe the repeatability of the measurement and how close it is to the true value of the parameter, respectively. Most parameters can be measured at varying levels of precision and accuracy. A colorimetric pH kit, for example, might measure pH to a precision and accuracy of +/- 1 pH unit. A pH meter and probe, on the other hand, might measure pH with a precision and accuracy of 0.1 pH unit. Equipment such as a pH meter must be properly calibrated to be both precise and accurate in measurements.

Cost generally increases as precision and accuracy increase. It is not always necessary to use highly accurate methods, so you might want to prioritize where to put your money.

The level of expertise necessary to produce reliable data depends on the method. Depending on the time available for training and supervision of volunteers, you might want to choose a simple method with few steps and chemical reagents versus a more complex method.

6. Quality assurance (QA) and quality control (QC).

Quality assurance and quality control, often referred to as QA/QC, ensure the quality of the data. According to the Oregon Plan for Salmon and Watersheds' Water Quality Monitoring Guidebook, quality assurance is the overall project management, including organization, planning, data collection, documentation, and quality control. Quality control, on the other hand, is a series of technical activities conducted routinely to minimize errors (OPSW, 1999). Errors can occur in the field, lab, or office, so QC should be included in all aspects of the project.

Examples of QC activities include repeating field measurements, calibrating equipment properly, splitting samples with a professional lab, reviewing data sheets for errors, and checking an electronic database against data sheets. The Volunteer Monitor's Guide to Quality Assurance Project Plans provides more detailed guidance on QA/QC activities (USEPA, 1996).

7. Training.

Monitoring staff or volunteers must receive training and commit to collect data according to the monitoring plan and selected methods. Staff or volunteers must coordinate sample collection, equipment calibration and maintenance, and chemical management (if any). Training should be conducted periodically, even if participants have been monitoring for a long time. Include a description of the training procedures and schedule in the monitoring plan.

8. Safety.

Always follow safety precautions in the field and laboratory; no water sample is worth injury, exposure, or death. Encourage individuals collecting field data to work with a partner at all times. Cancel monitoring during hazardous weather. If monitors will be wading streams, provide training on estimating hazardous stream flows. In both the lab and the field, wear gloves and goggles when using chemicals. Dispose of chemicals properly.

9. Data management.

Collect and store data so that they are easily accessible in case your project experiences staff turnover or receives requests for data from outside organizations. Use a field data sheet when collecting water samples and testing them in the field. Data sheets will help you be consistent in your field procedures. They also provide space to record observations that might help you interpret the data.

Store data on a computer and back them up on disks. Whether you use a database program or spreadsheet program, the format should be easy for someone outside the project to understand. ADEQ does have a preferred data storage format for sharing data. Data that goes to ADEQ must have a quality assurance project plan.

10. Data interpretation and presentation.

Data interpretation and presentation are the final steps, and often the ultimate goal, of monitoring. When designing a monitoring plan, it is critical to include enough time and funding for data interpretation and presentation to the community, TAC, agencies, and other stakeholders. These steps allow the data to be used by water resource management agencies, landowners, and local decision makers.

When interpreting data, keep in mind the questions you asked when developing your monitoring plan. Use charts and graphs to attempt to answer the questions. Ask the TAC to review drafts of your reports and findings before you present them to the public.

When presenting your results and findings, keep your audience in mind. Different groups might want different products. An agency, for example, might be interested in tables, or might prefer to receive the data electronically. Local residents, on the other hand, might be more interested in seeing the information in newspaper articles, a poster at the local library, or an easy-to-read publication. For a lay audience, it is important to:

- Use charts, graphs, maps, and pictures;
- Reduce tables of numbers to summary statistics; and
- Write clearly and eliminate technical terms.

The Massachusetts Water Watch Partnership has produced a manual, *Ready, Set, Present!*, that focuses on presenting water-quality data to a range of audiences using many different methods. The manual covers oral presentations, written presentations, effective graphics, media relations, and exhibits (Massachusetts Water Watch Partnership, 2000).

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SUMMARY

Water quality describes the chemical, physical, and biological aspects of water, generally in terms of suitability for a particular use. Water-quality monitoring is the process of sampling and analyzing water conditions and characteristics (USEPA, 1997). These characteristics, such as dissolved oxygen, pH, and temperature, are known as parameters.

Local residents and agencies monitor water quality to:

- Identify particular pollutants of concern;
- Identify whether the quality of the water is sufficient for a particular use;
- Target problem areas;
- Detect trends; and
- Determine the effectiveness of restoration or enhancement projects.

Commonly monitored parameters are:

- pH;
- conductivity;
- phosphorus;
- stream flow;
- nitrogen;
- bacteria;
- total dissolved solids;
- turbidity;
- dissolved oxygen;
- temperature; and
- suspended solids.

Asking a monitoring question and developing a monitoring strategy are two important parts of water-quality monitoring. Three common types of monitoring are trend monitoring, baseline monitoring, and effectiveness monitoring. To monitor the effectiveness of a best management practice, before and after monitorirng provides the most useful information.

Ten important considerations to keep in mind when developing a monitoring program are:

1. Include a diverse Technical Advisory Committee;
2. Develop a quality-assurance project plan;
3. Establish clear monitoring questions;
4. Design well-designed sampling strategy;
5. Use appropriate testing methods;
6. Develop quality assurance and quality control;
7. Conduct regular training and re-training;
8. Train for field and laboratory safety; and
9. Develop a strategy for data management as well as data interpretation and presentation.

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WORDS TO KNOW

Algae – Simple, single-celled, colonia, or multi-celled, mostly aquatic plants.

Bacteria – Microscopic unicellular organisms, typically round, rod-like, spiral or thread-like. Bacteria are an important part of aquatic and terrestrial food webs. Bacteria may be a source of disease.

Biochemical oxygen demand (BOD) – A measure of the amount of oxygen removed by aquatic life. Measuring BOD is used to determine the level of organic pollution in a water body—the greater the BOD, the greater the water pollution.

Chlorophyll – The green pigments of plants. *Chlorophyll a* and *Chlorophyll b* are the two most common forms. Cholorphyll reactions generate sugars, oxygen and carbon dioxide.

Electrical Conductivity – A measure of the ability of a solution to carry an electrical current.

Contaminant – A substance in water of public health or welfare concern, usually undesirable and found in concentrations higher than normal.

Dissolved oxygen (DO) – Concentration of oxygen dissolved in water. DO is important for most aquatic life. A lack of adequate dissolved oxygen is an indicator of poor water quality.

Heavy metal – Metallic elements with high atomic weights that are generally toxic in relatively low concentrations to plant and animal life. Heavy metals tend to accumulate in the food chain. Examples include lead, mercury, cadmium, chromium, and arsenic.

Invertebrate – An animal without a spinal cord, usually replaced by a hard exoskeleton or shell. Examples include insects, spiders, crayfish, snails, or clams.

Ions – An atom or molecule that carries an electrical charge (either positive or negative).

Logarithmic scale – a mathematical scale in which each unit represents a power of ten greater than the previous unit. Used in a **pH** scale.

Macrophyte – Organisms large enough to be visible without the aid of magnification or otherwise greater in size than bacteria or other single-celled organisms.

Microsiemen – A unit of measurement for electrical conductivity.

Nutrient – An element or compound essential to life, nitrogen, phosphorus, and many others.

Parameter – A variable, measurable property whose value determines the characteristics of a system—in this case a water body.

Pesticides – Any chemical agent used to control particular organisms. Examples include insecticides, herbicides, and fungicides.

pH – Is generally referred to as the negative logarithm of the hydrogen ion concentration dissolved in water and found as hydroxide ions. pH is a standard method by which to measure the acidity of a solution.

Phytoplankton – Microscopic floating plants, mainly algae, that live suspended in water bodies and drift about.

Pollutant – Something that pollutes—especially waste material that contaminates water, air or soil.

Protocol – A method or set of methods to be followed in a particular order.

Radiochemical – A molecule that emits radioactivity; examples include uranium oxide or radon gas.

Secchi disk – a circular plate, generally about 10-12 inches in diameter and on which is a black and white pattern. Used to measure the clarity or transparency of water.

Stream flow – The discharge measured in cubic feet per second (cfs) that occurs in a natural channel.

Submerged aquatic vegetation (SAV) – Plants growing or floating beneath the surface of a water body.

Suspended solids – Solids which are not in true solution and which can be removed by filtration or settling. These solids are generally carried within the water as separate particles.

Temperature – The degree of hotness or coldness.

Total dissolved solids (TDS) – A measure of the amount of material dissolved in water (mostly inorganic salts).

Total Maximum Daily Load (TMDL) – The maximum quantity of a particular pollutant that can be discharged into a body of water without violating a water quality standard.

Transparency – The portion of light that passes through water without distortion or absorption. A measure of the turbidity of water (see below).

Turbidity – A measure of the reduced transparency of water due to suspended material, dissolved solids and colloidal materials. Turbid water does not transmit light as well as clear water because of suspended materials.

Water quality - A term used to describe the chemical, physical, and biological characteristics of water, generally in terms of suitability for a particular use.

Water quality monitoring – The process of sampling and analyzing water conditions and characteristics.

RESOURCES

Monitoring Guidelines & Protocols

Field Manual for Water Quality Monitoring: An Environmental Education Program for Schools. (1997) Mark K. Mitchell and William B. Stapp. Manual prepared to assist citizens in the development of attitudes, knowledge, and skills essential in helping to maintain and improve water quality of rivers. Kendall/Hunt Publishing Company: Dubuque, Iowa.

Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, USEPA 910/9-91-001. (1991) L. MacDonald and R. Wissmar. U.S. Environmental Protection Agency.

Monitoring Rangelands: Interpreting What You See, NR 503. (1998) G. Allen Rasmussen. Utah State University Extension. Logan, UT. This handbook deals with simple monitoring techniques to provide a minimum starting point to help learn to read the land.

Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams. (1997) S. Bauer and T. Burton. Idaho Water Resources Research Institute, University of Idaho, Moscow.

Oregon Watershed Assessment Manual. (1998) Oregon Watershed Enhancement Board, Salem.
Ready, Set, Present! (2000) Massachusetts Waterwatch Partnership, Amherst.

USDA-CSREES Volunteer Water Quality Monitoring Project,
http://www.usawaterquality.org/volunteer

The Volunteer Monitor's Guide to Quality Assurance Project Plans, USEPA 841-B-96-003. (1996) U.S. Environmental Protection Agency. Discusses USEPA's guidance for documenting quality assurance methods, project organization, goals and objectives, with examples and references.

Volunteer Estuary Monitoring: A Methods Manual, USEPA 842-B-93-004. (1993) U.S. Environmental Protection Agency. Methods for volunteer monitoring of estuarine waters.

Volunteer Lake Monitoring: A Methods Manual, USEPA440-4-91-002. (1991). U.S. Environmental Protection Agency. Methods for volunteer monitoring of lakes.

Volunteer Stream Monitoring: A Methods Manual, USEPA 841-B-97-003. (1997) U.S. Environmental Protection Agency. Methods for volunteer monitoring of streams.

Volunteer Wetland Monitoring: An Introduction and Resource Guide, USEPA 843-B-00-001. (2000) U.S. Environmental Protection Agency. Describes a selection of handbooks and manuals that offer detailed information on volunteer wetland monitoring.

Water Quality Indicators Guide: Surface Waters, SCS-TP-161. (1991) Charles R. Terrell and Patricia Bytnar Perfetti. USDA-Soil Conservation Service

Water Quality Monitoring Guidebook. (1999) The Oregon Plan for Salmon and Watersheds, Salem.

Internet Resources

ADEQ's Water Quality Division: www.adeq.state.az.us/environ/water/index.html
Standard Methods for the Examination of Water and Wastewater: www.standardmethods.org/
Federal water-quality criteria from the USEPA: www.USEPA.gov/water/
University of Arizona Biology Project: biology.arizona.edu/biochemistry/problem_sets/ph/ph.html
USEPA Watershed Academy Web: www.USEPA.gov/watertrain/nonpoint.html
USEPA Standard Methods for Measuring Water Quality:www.USEPA.gov/waterscience/methods/
Volunteer Monitoring Methods: www.USEPA.gov/owow/ monitoring/volunteer/
USDA CSREES Volunteer Water Quality Monitoring Project: www.usawaterquality.org/volunteer/

Youth Activities or Curricula

Healthy Water Healthy People: Water Quality Educators Guide. (2003) Watercourse at Montana State University, Bozeman, MT. The purpose of the publication is to raise educator's awareness and understand of water quality topics and issues by demonstrating the relationship of water quality to personal, public, and environmental health.

The Stream Scene: Watersheds, Wildlife and People. Oregon Department of Fish & Wildlife. (1992) For grades 6-12, produced to look at watersheds from many perspectives. The arrangement of the curriculum will guide the user from the broad spectrum of watershed systems, riparian areas, and their respective components to the specific nature of streams and the aquatic life they support.

Utah Stream Team. Utah State University Extension. The Utah Stream Team program monitors a stream's physical characteristics, the stream's chemistry, the "bugs" that live in these streams, and the plants and animals that live next to the stream. The detailed stream monitoring manual explains how to sample, and also explains how to interpret your results. http://extension.usu.edu/waterquality/UST.htm

Watershed Science for Educators. (1999) Karen Edelstein, Nancy Trautmann, and Marianne Krasny, Cornell Cooperative Extension, Ithaca, NY. For high school and middle school teachers and students who wish to incorporate watershed monitoring into both science and humanities classes or into after-school environmental or science clubs.