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INTRODUCTION

This document provides guidance on establishing a water quality monitoring program that will demonstrate the effectiveness of best management practices (BMPs) implemented to reduce nonpoint source pollution in stream systems. Increasingly (and appropriately), water quality and land managers are asked to demonstrate that practices designed to benefit water quality have, in fact, reduced pollutants and resulted in cleaner water. Unfortunately, this has proven to be more difficult than one would imagine, not because the practices don’t work but because of poorly designed monitoring programs.

This is not a “how to” manual on specific techniques. Rather, this document guides the reader through important questions that must be answered before any practice is implemented. Too often monitoring is conducted without sufficient thought as to how the results will be used to demonstrate any change in water quality. Too often, the specific objectives of a particular implementation and the specific conditions in which the practice is installed are not considered. Too often, our enthusiasm for fixing a problem means that we do not carefully consider whether we can ever demonstrate that outcome. Too often, we reach the end of an implementation and find that the opportunity has been lost to collect appropriate baseline data or data from a control site.

We hope that this manual will result in more careful thought and planning of how impacts from the implementation of BMPs will be detected. We are certain that this will result in significant savings in monitoring programs by avoiding collection of inappropriate or unusable data. We also believe that appropriate and effective monitoring will advance the management of water quality and watersheds beyond trial and error to a true science based on real understanding of the effectiveness of different practices in different situations.

Although this manual does not provide instructions on how to conduct specific tests or field studies, it does contain references to many excellent documents that will provide this information. This document focuses on the effectiveness of BMPs implemented to reduce or prevent nonpoint source pollution, however, the information in this document can be applied to any water quality monitoring program.

The most common mistakes in developing a monitoring program include:

- **Failure to carefully consider the project objectives.** Too often it is assumed that an existing monitoring program or one designed for another purpose or location will meet the needs for a specific project. If the monitoring was not planned with the project objectives in mind, the project may reach completion with no good way to demonstrate its impact.

- **Failure to understand the dynamics and transport processes of the pollutant of concern in a particular watershed.** Different pollutants behave very differently under different conditions. The local geography and land uses within a given watershed will determine pollutant transport and transformations in a given setting. Consideration of these details before a project begins will ultimately save money and time by avoiding common mistakes such as inappropriate site selection, timing of sample collection, number of samples, parameter selection, or choice of water quality measurements.
• **Failure to consider alternate methods for demonstrating impact.** Traditional monitoring programs often measure only the pollutant of concern and/or loading. Monitoring must also include variables that will help interpret the results such as measuring discharge whenever mass loads must be calculated. Alternate methods of demonstrating impact should be considered as well. These approaches may include monitoring a system’s response to a BMP or measuring variables that are closely correlated to the pollutant of concern. Increasingly, models of varying complexity are also used to assess water quality issues and demonstrate the impacts of BMPs. For a model to be applicable to a specific site or project, typically some environmental data need to be assembled or collected. Therefore, if models are to be used, the data needed for these models must also be carefully considered before the project begins.

Sections 1 through 3 of this guidance document are intended to help better characterize the objectives of a monitoring plan, carefully consider the scale of your project, and better understand how the pollutants of concern are processed within a watershed and are transported from the source to the receiving water. These are critical considerations when developing and/or modifying a monitoring program.

Sections 4 through 7 help identify appropriate monitoring or modeling approaches for a project, choosing the correct parameters to measure, best monitoring locations, and best timing of sample collection.

Sections 8 and 9 discuss data integrity, storage and analysis. Proper quality assurance and control measures start before the first sample is collected and include field collection, lab processing, and data management. Taking these measures assures the monitoring results are credible.

Sections 10 and 11 discuss statistical approaches for analyzing water quality data and some thoughts on how to best interpret and use the results. The specific needs of a project for statistically significant findings will determine the intensity of a particular monitoring program. Considering this ahead of time will provide realistic expectations for monitoring results, given the expected uncertainty and variability in a particular waterbody.

Appendix A provides definitions of many of the technical terms used in this document. Appendix B lists other resources you may wish to use for designing a monitoring program, using specific monitoring techniques, bio-assessment techniques and specific models. Appendix C lists water quality contacts in each state.

**A note about terminology:** This document uses the term pollutant to include any discharge or activity that has caused impairment of a water body. The terms pollution and stressor are similar terms, indicating something that causes a water body to be impaired. A symptom is a characteristic of a water body indicating a problem. The term “impairment” refers to the resulting condition from a pollutant. See Appendix A for a more detailed definition of this term and related terms such as “pollution” and “stressor”.


SECTION 1 – THE IMPORTANCE OF CLEAR MONITORING OBJECTIVES

The design and implementation of a monitoring program is determined by the objectives of the project, which must be clearly defined. All subsequent decisions about the monitoring program follow directly from the monitoring objectives.

Note that often there are multiple monitoring objectives within a watershed. It is none-the-less important to design monitoring programs for individual objectives. A review and comparison of the different monitoring programs required to meet different objectives within a watershed may result in combining some field or analytical efforts for more efficiency, but the individual monitoring programs should remain distinct to assure that specific project monitoring objectives are met.

The table below demonstrates how a monitoring program may change depending on these objectives.

*Table 1. Monitoring programs are dependent on project objectives.*

<table>
<thead>
<tr>
<th>Program Objective</th>
<th>Monitoring Program Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory Compliance of an NPDES Permit</td>
<td>Typically most aspects of the monitoring program are established in the permit by a regulatory agency. The permit will often include what to sample, how often samples must be collected, what methods must be used, and who can collect the samples.</td>
</tr>
<tr>
<td>TMDL / BMP Effectiveness</td>
<td>These programs often have considerable room for creativity and flexibility, as long as the approach is justified in a valid sampling plan for the project and appropriate quality assurance and quality control (QA/QC) are identified for all steps of the process. Typically the monitoring program addresses the pollutants of concern, but may include factors, watershed characteristics, or information about the actual BMP. As with regulatory monitoring, data credibility is a primary concern.</td>
</tr>
<tr>
<td>Educational Programming</td>
<td>Monitoring programs for educational programs are typically determined by cost, ease of methods, age appropriateness, and interest of volunteers. The intent of these programs is to help participants better understand water quality and watershed science. Data may be used for preliminary screening or to enhance a monitoring program, but typically are not use for regulatory or compliance purposes.</td>
</tr>
</tbody>
</table>

Clearly defined monitoring objectives have three parts:
1. An infinitive verb (e.g., to determine, to assess),
2. an object of the verb (the effectiveness of a BMP implementation, the role of a wetland), and
3. a constraint such as a specific location or a water quality variable.
For example: “To determine the effect of implementing a specific BMP on *E. Coli* levels in a particular stream or reach.” Monitoring objectives such as: “The monitoring objective is to prove the
water quality has improved and can be removed from the state’s 303(d) list” indicates the sampler is entering the monitoring program with a preconceived bias and the monitoring effort may not be conducted or interpreted in an objective manner.
SECTION 2 – UNDERSTANDING POLLUTANTS WITHIN NATURAL SYSTEMS

To effectively monitor changes in pollutants of concern, it is extremely important to understand how these pollutants typically behave in natural systems, and in particular in a specific watershed. Equally important is an understanding of how these pollutants might respond to specific best management practices. Many of the pollutants that BMPs are intended to address, such as sediment and nutrients, are found naturally in surface and groundwater, and only become problems at high concentrations that impair the beneficial uses of these water bodies. An effective monitoring program explicitly considers how these materials may change as they move from a source into the ground or surface water. This includes an understanding of how a given pollutant may be introduced or mobilized within a watershed, how it moves across the land and within surface or ground water, and transformations that may occur during this process.

Before any successful monitoring or modeling takes place, consider the following factors:

1. What is the pollutant of concern? Will the monitoring focus on a chemical or physical pollutant (such as phosphorus or sediment), a characteristic of the water (such as temperature), or a living organism (such as bacteria or a type of algae)?

2. If the focus is on a particular pollutant, is its source clearly known (point or non-point) and is it understood how the pollutant is transported from the source to the water? As one very simple example, pollutants may be found in multiple forms (dissolved, absorbed, adsorbed or a particulate form). Dissolved forms may move easily in groundwater or subsurface flows, while particulate forms will only be transported in surface runoff.

3. What BMPs are available to address the pollutant(s) of concern and how will this affect a monitoring program? BMPs may be quite site specific, or may cover quite extensive areas. Consider also that BMPs may have unintended consequences that should be monitored, such as increased infiltration that reduces surface runoff but could increase subsurface or groundwater contamination.

4. What is the pollutant’s fate and transport within a given watershed? How is the pollutant processed and transformed in transit to a water body and once it is in the water? For example, is it taken up by plants and transformed to a different form, does it readily adsorb to soil particles, is it in a particulate form that may settle out before reaching a water body, is it extremely soluble and moves anywhere water goes, or does it float on the surface?

5. How will natural variability in the pollutant of concern be accounted for? Likewise, how will natural variability in climatic conditions affect stream flow and temperature? It is important to understand other natural changes in the system throughout a season. For example, during fall and winter, organic materials break down and release dissolved nutrients, so a nutrient monitoring plan should anticipate this natural increase.

6. Long-term changes in the watershed might mask or affect the response to a BMP implementation. Some monitoring approaches are better than others at controlling for
changes in land uses, periods of drought, recent introduction of invasive species, or other long-term impacts.

Most people who work on BMP implementation projects are not trained as aquatic scientists, and therefore cannot be expected to know all the answers to pollutant movement and variability in a given watershed. This is not a reason for ignoring these questions, however. Assistance in understanding these processes is available through agency resource specialists or Extension specialists at local Universities. See Appendix C for contact information that may help.

**Monitoring in a variable world:**

BMPs are designed and implemented to address water quality concerns or impairments. As the ability of a specific BMP to mitigate a water quality impairment in a given situation is often unknown or uncertain, it is imperative to assess the effectiveness of a BMP in addressing a specific issue. In BMP effectiveness monitoring, the objective is typically to assess and/or demonstrate the impact of the BMP on mitigating a water quality issue of concern. The ease with which this is done will depend on the magnitude of this impact relative to background conditions and background “noise”. The range of natural variability in the system must be taken into consideration because this variability may mask any change resulting from the BMP implementation. As a general rule, more frequent samples are needed in a highly variable system, but by targeting the sampling timing you may be able to greatly improve your monitoring program. Section 10 contains additional information on handling natural variability in detecting change.

Dramatic changes in chemical concentrations or physical properties of water often occur naturally, so it is important to understand this variability in the system. A common mistake in monitoring programs is to interpret these natural changes as having resulted from human impacts. In particular, a common mistake is to interpret a short-term naturally occurring reduction in a chemical concentration as a response to a BMP. See Section 11 for more information on how to interpret your data.

**Predictable seasonal changes:**

Depending on the specifics of the impairment, monitoring may not be necessary at all times of the year. Many of the chemical, physical and biological changes in a stream are a result of stream flow, so it is particularly important to understand the hydrology of the watershed and water body. Some pollutants of concern may only be transported during baseflow when the system may be more dominated by groundwater, while others are transported only during snow melt or storm events. Concentrations may vary dramatically during the year depending on location and stream system, geology and geographic location or the watershed.

The impairments in a waterbody may not be apparent during all seasons, so it may not be necessary to sample year round. For example, intensive monitoring of water temperature during the winter is not useful if the problem is high temperatures during summer low flow conditions. As another example, total annual loads of sediment are often delivered primarily during spring runoff and storm events, in which case, intensive monitoring during base flow may not be worth the time or money.
Daily changes:

Daily (diel) changes in sunlight may directly affect plant or animal behavior, air and water temperature. For example, drifting of aquatic macroinvertebrates can be significantly different between night and day. Behaviors of fish and some zooplankton are also driven by light conditions. Plants respond significantly to night and day change. Photosynthesis by aquatic plants may increase pH during the day. Oxygen, on the other hand, may drop significantly at night because of plant respiration in the absence of photosynthesis. Flow may also change between night and day, as increased daytime temperatures result in increased snowmelt and downstream flows.

Storm events:

Many non-point source particulate pollutants (such as sediment and *E.coli*) maybe transported into waterways primarily during storm events or snowmelt periods that generate surface runoff. In some systems, these short-term, episodic conditions may be the most critical periods to monitor. See Section 7 (Protocols) for more information on monitoring approaches such as continuous monitoring or flow-triggered monitoring devices that can be used in situations such as these.

Management changes:

River systems are subject to sudden changes as a result of different types of river management. In the west, irrigation diversion and return flows may result in significant changes in river flow or concentrations of sediment, nutrients or salts. Upstream reservoirs may result in modified runoff flows, releases to support downstream irrigation, or releases for power generation. Be aware of these upstream influences when designing a monitoring plan.
SECTION 3 – CONSIDER THE SPATIAL AND TEMPORAL SCALE

When designing a monitoring program, always consider the spatial and temporal scale of the project. How big an area does the particular BMP affect? How soon after implementation will any impact of the BMP be evident? How long is the BMP expected to remain effective?

The following figure shows some examples of the how both the scale of BMPs and the typical response time of BMPs can be quite different. For example, construction BMPs such as straw bales to control erosion typically are effective immediately but do not remain in place for extended periods after the construction is completed. In contrast, the results from a willow planting project are not likely to be evident within the first few months after the willows are planted, but this BMP, once established and deemed effective, should continue to be effective for years. The area affected by a BMP is also a major consideration. Manure management BMPs such as improved winter storage might only directly affect a small reach of a river. Changes in upland grazing management, on the other hand, can affect an entire watershed but may not be immediately apparent or measureable.

Figure 1. The scale of common BMPs and their typical response times should always be considered when planning a monitoring program.
SECTION 4 – MONITORING AND MODELING: DIFFERENT APPROACHES TO DETECT IMPACTS

Attempts to quantify impacts of BMPs on water quality often focus directly on the pollutant of concern. Other indirect approaches, however, may be equally or more effective. When developing a monitoring program, be aware of all methods of detecting change and choose the approach or approaches that work best in your situation. Different approaches are described below. Refer to Table 2 for a list of common monitored pollutants and summary of approaches for monitoring and modeling these different pollutants.

*Monitoring the pollutant of concern to detect a response to a BMP:*

This approach is appropriate when the pollutant or pollutants that are causing the loss of a beneficial use have been clearly identified, a reduction in this pollutant is anticipated as a direct response to a BMP implementation, and you have a sufficient time frame to monitor for change. In choosing this approach, make sure to also monitor related parameters that may be critical in interpreting the results. Examples include flow, which is often necessary to help interpret water concentrations, or water temperature and pH, which must be known to determine ammonia toxicity.

*Monitoring Surrogates or Response Variables:*

In some cases, monitoring the pollutant of concern is expensive or difficult, while monitoring a closely related parameter is relatively straightforward. Surrogates are variables that can be measured more easily and then be correlated with the pollutant of concern. For example, turbidity is easily measured in the field and in many cases can be correlated to suspended sediments in the water column. Response variables are those that change in response to changes in the pollutant of concern and may also be more easily measured than the pollutant of concern. For example, the amount of chlorophyll or plant biomass may be measured in a lake rather than measuring nutrient concentrations directly.

The challenge in these cases is to demonstrate that the variables being measured can be correlated to changes in the pollutant of concern. Note that the relationship between a surrogate or response variable and the pollutant of concern may be different in different watersheds, at different locations within a watershed or even at different times of the year. The relationship may be sufficiently described and quantified in the literature, but in some cases additional monitoring may be necessary to establish the correlation for a particular situation.

*Modeling the pollutant of concern or a response variable:*

Models often provide an excellent approach to better understand how pollutants may behave under a range of conditions that cannot be directly measured. Some models result in numeric predictions, such as expected concentrations under different flows in a stream. Other models are not good at predicting specific concentrations but may help understand how pollutants vary or respond to a change in management. It is critical that the strengths and limitations of any model are well understood before they are used.
Types of Models:

Models can vary from simple empirical models that are designed to address a simple relationship to complex distributed models that simulate changes and interaction among more than one component over a range of spatial and/or temporal scales. It is important to select a model that will address the monitoring objectives. In addition, it is critical to know ahead of time, the data and information that are necessary to run the model.

Below are some ways in which models can be described or categorized.

Deterministic: model outcome is always same given same inputs.
Stochastic: incorporates uncertainty so results are not always the same.

Analytical: results can be expressed and solved by a single mathematical equation
Simulation: lack a single, general mathematical solution; represent complex, non-linear relationships (very common in watershed hydrology and landscape ecology).

Process-based: model components represent specific hydrologic and ecological processes.
Empirical: based on simple correlations and are derived from data.

Temporal and Spatial Scales of Models:

Point scale: This point-in-space approach does not include spatial distribution (field, reach or plot scale)
Spatial: Model results vary in space (e.g., watershed models)
Static: Point-in-time approaches do not include temporal changes (e.g., event based model)
Dynamic: These models allow changes over time (such as long-term simulation model)

If you are planning to use a model, consider the following:

• What question(s) are you trying to answer using the model?
• What type of model should be used to model the system? The monitoring objectives and the pollutant of concern will determine this selection.
• What is the application scale of the model? Does it match your project scale e.g. plot, field, watershed, or basin? A complex, spatially explicit watershed scale model that uses a 30 m resolution may not be appropriate to assess the impacts of a 10 m wide buffer strip installed next to a single agricultural field.
• Is the model process-based (attempts to mimic the natural processes in a system)? If so, it is important to understand the dominant processes of the pollutant in the system to well enough so that your model will provide useful results?
• Is the model based on statistical relationships of previously collected data? If so, it is important not to extend predictions beyond the limits of these data.
• Is the model an event model (single storm response) or a long-term simulation model (month-decades)?
For any modeling effort, the following factors should be known:

- What is the accuracy and precision of the model? Many models are very accurate, but not necessarily precise.
- What data are needed to go into the model? Do you have the input parameters necessary to run the model?
- Is the model calibrated and verified for local conditions?
- How good are the numbers that go into the model (how good are the data)?
- Consider issues such as cost, complexity, and time in development of the model?
- It is important to understand the sensitivity of the model’s results to different inputs. Many process-based hydrologic models are very sensitive to the hydraulic conductivity parameter. For process-based surface erosion models, knowing (or good estimates of) the surface microtopography and roughness are very important.

Often a model documentation plan will be required for TMDL or regulatory compliance monitoring.

Models can also be helpful in prioritizing or designing BMP implementations. For example, a landowner wishes to move a corral off of a creek. The landowner’s preferred location is 10 m off of the creek. A model may suggest this location will result in a 75% reduction of nutrients to the creek. A similar project that would result in a projected 95% reduction may receive a higher funding priority, benefiting the landowner. The use of the model to inform the landowner that moving the corral 40 feet from the creek may result in a projected 95% reduction in nutrients might be sufficient information to allow the landowner to change their plans for the final corral location.

Because modeling may require unique skills, this work may be subcontracted. It is critical, however, that those involved in other aspects of managing and implementing the BMP understand modeling sufficiently to make informed decisions about the modeling process, including an understanding of the strengths and limitations of a particular modeling approach. Refer to Appendix B for some specific models to consider.

**Monitoring the state of the BMP:**

In addition to monitoring the response to implementation of BMPs, often it is important to also monitor and track the BMP itself. This includes determining whether the BMP was properly installed or implemented, whether expected changes have occurred, and whether the BMP has been properly operated and maintained over time. As with all other monitoring being conducted, it is important to consider the specifics of a particular practice and monitor with that practice in mind. Consider the expected effectiveness of a practice, how soon it is expected to be fully effective (see, Fig. 1), and whether there are critical periods during which it should be monitored. Assure that a practice is monitored and maintained throughout its expected effectiveness.
Table 2. Common pollutants and approaches for directly monitoring, monitoring surrogates, response variables, and commonly used models. This table is far from complete, but should help you understand some of the issues to consider when decide which approach or approaches will best meet your monitoring objective. *These are variables that often must also be measured in order to correctly interpret your monitoring results.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Direct Monitoring</th>
<th>Surrogate Monitoring</th>
<th>Response Variables</th>
<th>Other Important Variables *</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Probes, launched monitors (e.g. hobo), and direct measurements</td>
<td>Light / shading, ground water signal (stable isotope variables)</td>
<td>Algae, macros, and fish</td>
<td>Air temperature, flow, time of day, depth, turbidity, cloud cover</td>
<td>CEQual WASP(7) SNTEMP (USGS)</td>
</tr>
<tr>
<td>Dissolved Oxygen (DO)</td>
<td>Probes and direct measurements</td>
<td>Temperature, redox, and Flow/temperature/algal biomass</td>
<td>Macros and fish</td>
<td>Temperature will affect percent saturation, depth, flow, velocity</td>
<td>Streeter Phelps</td>
</tr>
<tr>
<td>Nutrients (phosphorus and nitrogen)</td>
<td>Grab samples and integrated samples</td>
<td>Turbidity or sediment</td>
<td>Algae, Macro-invertebrates, fish, macrophytes</td>
<td>pH, temperature, and DO might affect the solubility of phosphorus, flow (sediment transport)</td>
<td>UAFRI SWAT QUAL2K</td>
</tr>
<tr>
<td></td>
<td>In some cases use probes, or streamside auto-analyzers to collect surrogate samples</td>
<td>Turbidity</td>
<td>Physical characteristics, embeddedness, macros, and algae</td>
<td>Flow</td>
<td>PSIAC AgNPS SWAT KINEROS2 SEDMOD</td>
</tr>
<tr>
<td>Sediment</td>
<td>Grab samples and integrated samples</td>
<td>Turbidity</td>
<td>Macros and fish</td>
<td>Flow</td>
<td>QUAL2K</td>
</tr>
<tr>
<td>Salts / TDS</td>
<td>Probes and grab samples</td>
<td>Electroconductivity probe; Riparian vegetation</td>
<td>Macros and fish</td>
<td>Flow</td>
<td>QUAL2K</td>
</tr>
<tr>
<td>Pathogens</td>
<td>Grab samples and integrated samples</td>
<td>Fecal Coliform Bacteria, E.coli</td>
<td>Human health, livestock health;</td>
<td>Turbidity, nutrients, temperature</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>Grab samples</td>
<td>Bioaccumulation in living organisms; sediments</td>
<td>DO might affect total hardness, pH</td>
<td>MINTEQAQ</td>
<td></td>
</tr>
<tr>
<td>Organic pesticides</td>
<td>Grab samples</td>
<td>Bioaccumulation in living organisms</td>
<td></td>
<td>WINPST</td>
<td></td>
</tr>
</tbody>
</table>
**Existing Data:**

Considerable data may already exist for a particular water body and should be evaluated with the monitoring objectives in mind. Existing data can help guide the choice of monitoring approaches, and may also help in interpreting data. Data may exist in multiple locations, but a search of the reports, publications, and databases of agencies, universities, consulting firms and non-profits may be a good use of time and effort.

Many monitoring programs rely on comparisons of conditions prior to an implementation with conditions after a practice is installed. In some cases, relevant “pre-implementation” data may have been collected. Before deciding to rely on these data, however, assure that they are comparable with data you will collect for comparison: were the data collected at appropriate frequencies, were appropriate parameters collected, were the samples collected at an appropriate site, etc? Monitoring program QAPPs (see section 8) will include screening and analysis requirements and a process to determine if it is appropriate to use the existing data.

Spatially referenced data such as land use, vegetation, soils, ownership, and elevation are often available in different formats (photos, hard copy maps, or GIS layers). These can be particularly important in helping to select monitoring locations, making data comparisons, interpreting monitoring results or developing model inputs and interpreting results.

Existing data or studies can provide insight into how effective a BMP is likely to be. Look for USDA-ARS, NRCS, Extension, consultant and other reports for these types of studies. This information will help determine what, how long and when to monitor.

Finally, do not forget the value of “lessons learned” and apply these whenever possible. These are most useful when conditions such as climate, soils, and scale are very similar to the current project site. If conditions vary, the lessons learned may be of limited value.
SECTION 5 – CHOOSING THE BEST MONITORING DESIGN

The specific monitoring design (the choice of location and timing of sample collection) that best meets the project objectives will depend on the type and scale of the project and the degree to which you can control other variables when you monitor. The monitoring design must be selected before the study begins as it (along with the project objective) dictates many important aspects of a monitoring program including scale, number of sample locations, sample frequency and station type. It is important to evaluate the data requirements for statistical analysis and potential statistical methods (Section 10) simultaneous with the selection of monitoring design.

Monitoring for BMP effectiveness is often more targeted than other types of monitoring, and to the extent possible should isolate these projects from other influences that may complicate the results. Below, several different approaches to selecting monitoring sites are presented: above and below a management practice; before and after control implementation; comparison to a reference site/condition; and using historic data. For each approach, the assumptions inherent in that approach, as well advantages and disadvantages and additional tips on when a particular approach is the best choice are discussed. Not discussed are plot and field scale designs, which are more common in research studies.


**Upstream and downstream monitoring:**

This approach refers to sampling above and below a BMP or set of BMPs.

Assumptions:
- Any changes seen/measured are due to the implementation.

Advantages:
- This approach directly measures the change in the stream between two points.
- Typically it covers a relatively short reach of river so it may be easy to collect samples.
- If there are no changes in flow between the upstream and downstream sites, then concentration can be compared instead of load. This means that flow measurement, which is sometimes difficult to obtain, would not be absolutely necessary. However, if not difficult to obtain, flow should be taken whenever possible. It is important to note that the EPA and other agencies typically want to know how much of a pollutant has been removed, which is what a load measurement will tell you.

![Figure 2. Upstream and downstream monitoring.](image-url)
Disadvantages:
- This approach only works when water is actively moving through the BMP and into the water body. For example, an upstream and downstream plan will not pick up the improvement from a feeding operation during dry, base flow conditions.
- In some cases such as ephemeral stream systems, the best times to collect samples are when it is raining or when snowmelt is running off the land. Otherwise, the changes might be very subtle if seen at all.

When to use this approach:
- This approach works particularly well for an in-stream implementation, such as a sedimentation trap. This will also work for implementations that affect the stream’s edge, such as willow plantings, but probably only when flows are enough to inundate the planting area.
- Timing is critical for this type of monitoring. If the BMP is capturing runoff from an off-stream site, sampling during runoff events is necessary to identify the change.

Monitoring a reference site for comparison:

With this approach, second site (a baseline reference site) in a very similar watershed is monitored. Changes in the BMP site are compared to this baseline. The monitoring approach is greatly strengthened if data are collected at both sites before AND after BMP implementation (referred to as BACI or Before After Control Implementation design).

Assumption:
- Reference site is similar enough to the sample location site that it will provide a baseline for comparison. This should be evaluated before implementation of the BMP.

Advantages:
- Can compare data that are collected at the same time, so water year differences, and other seasonal and annual variation is reduced.

Disadvantages:
- It can be difficult to find a good reference site, particularly if you are looking for an “unimpaired” or “natural” site.
- Be careful about comparing sites that are not sufficiently similar. At a minimum, you will want streams that are of a similar order, flow, geology, stream type, elevation, and land use.
The size, shape, geology, climate, vegetation and land use of a watershed are all factors that can affect the response of the system.

When to use this approach:
- Use this when looking at long-term indicators (biological indicators).
- One of the challenges of this monitoring approach is finding adequate reference sites. If this approach is used to directly compare chemical data, the conditions under which the monitoring takes place need to be considered (for example, base flow compared to storm event runoff).
- It may be necessary to monitor upstream and downstream monitoring to assure that all potential impacts are captured.

Comparison to a reference condition:

Similar to the reference site approach, this approach compares the project site to a cumulative data set comprised of all reference quality sites found in the same eco-region, watershed, or sub watershed. Chemical, physical, and/or biological conditions exhibiting a high degree of variation between reference quality sites are generally discounted. The best situations to use this approach are those chemical, physical, and/or biological conditions that are consistent among reference sites but are clearly influenced by human activities.

Monitoring downstream before and after implementation:

With this approach, a site is monitored at a downstream location before and after the BMP is implemented. The difference in concentration or total loading after implementation can be attributed to the BMP.

Assumption:
- Conditions (including flow) remain the same over time and therefore all changes are attributable to the BMP implementation.

Advantages:
- This approach is most effective if using data from an existing monitoring site with a long record.

Disadvantages:
- It is often difficult to control for other activities upstream of your monitoring site; this approach will not be able to differentiate water quality changes resulting from the BMP from any other changes upstream of your BMP.
- It is also difficult to control for changes that happen over time. For example, if the “before implementation” period happens to be a drought and the “after implementation” monitoring occurs during a high water period, it will be difficult to differentiate drought and climate impacts from the changes due to the BMP.
When to use this approach:

- This is a weak monitoring approach and when possible should be avoided or used with other approaches.
- This may be a useful approach under very restricted circumstances. For example, it may be used if the BMP is intended to be effective only for a very short time (such as straw bales to capture construction runoff). Even in these cases, however, you must monitor under similar conditions (e.g. a rain event) and natural variability may complicate your results.

**Monitoring using historic data:**

This approach is very similar to “monitoring downstream before and after implementation”, but in this case results after implementation “treatment” are compared with data collected at the same location considerably before the implementation.

**Advantages:**

- More data may be available to use in “before” period. These can be used to fully establish the “behavior” of the system before implementation of the BMP.

**Disadvantages:**

- This approach has the same disadvantages as “monitoring downstream before and after implementation.” Changes in weather, hydrology, land use, and other external factors cannot be controlled. The longer the historic data set, the stronger the relationships that can be drawn from the comparison.
- Sampling and analytical techniques may change over time, which can greatly complicate comparisons. Be aware of changes in detection limits, in changes of reporting units, or methodology (for example, use of filtered versus non-filtered samples).

**Monitoring site runoff:**

This method involves measuring the runoff that comes directly off the monitoring site; before it enters the water body (e.g. return irrigation flows).

**Assumption:**

- The runoff from the site can be sampled and quantified.

**Advantage:**

- If used before and after implementation, this provides a direct measurement of the impact of the implementation of the BMP.
Disadvantages:

- Need to monitor runoff before and after the implementation to demonstrate the impact.
- Need to measure flow or adequately estimate the duration of the flow as concentration to demonstrate impact.

When to use this approach:

- Use this for smaller implementations, such as modifications in a small feeding operation or small field scale BMPs.
- Use this when the impact is likely to be fairly substantial, because otherwise it might be hard to detect.
- Use this when the BMP is off-stream and runoff does not go directly to the stream (e.g. groundwater infiltration, diversion points, etc.).
SECTION 6 - SITE SPECIFIC CONSIDERATIONS

The monitoring objectives will determine approximately where sampling must occur relative to the BMP implementation. Site specific characteristics must be considered, however, to assure that samples are representative and applicable to the project needs. Physical constraints of a site, the time required to get to a sampling location, legal and physical access to a site, and safety issues must all be considered when making site selections. Whenever possible, visit all proposed sampling locations before the first monitoring event to evaluate potential problems.

Constraints due to choice of monitoring equipment and instrumentation

When selecting a site, consider how conditions will change with season or during extreme weather events. Is access to the site adequate for the monitoring design and equipment to be used? Consider all possible flow conditions and other environmental conditions that might occur at a site. Determine whether the equipment required for the proposed monitoring plan will be adequate under all these possible conditions.

- Consider seasonal changes at the site. Can equipment be installed sufficiently above the high water mark to prevent it being flooded or otherwise damaged by high water? Is there any evidence of past standing water in the selected site? During low water conditions, will probes and other equipment still be sufficiently submerged? Will measurements be possible if surface or anchor ice forms? Will a bridge be necessary to measure discharge during high flow periods?

- If equipment is to be left at the site, determine whether it can be attached sufficiently to assure it will remain in place. Boulders in mountain streams look immovable during low flow but may become mobile during high flows. Trees, bushes, or fence posts near a stream can be uprooted by high flows.

- Power needs at the site should be evaluated when appropriate. Is electricity available from the grid? If not, will batteries be sufficient or can a solar cell provide for power needs?

- Is there road access to the site? If not, what are the challenges to carrying monitoring equipment to the monitoring sites?

- If data are to be downloaded from remote locations, determine that there is sufficient clearance or adequate repeaters to get a signal from the site. For example, it can be very difficult to transmit a signal through narrow, steep canyons; several repeater stations are often necessary.

Time constraints associated with site selection

Some sites may be ideal in many respects but quite difficult and time consuming to visit. Even “automatic” samplers and probes require regular visits to check power, calibrate equipment, and conduct other quality assurance checks. When multiple sites need to be visited, consider whether the budget and sampling plan can accommodate the time required to get to individual sites. Road or trail
conditions are also highly variable throughout a year. Consider whether site choices will require all terrain vehicles or snow machines to access during portions of the year, and whether the monitoring budget allows for these provisions.

Many pollutant samples have a maximum holding time between sample collection and analysis or further processing. For example, bacteriological samples may have a holding time of only a few hours. Exceeding the holding time generally results in data that are of limited value, so assure that site choices do not result in holding time violations. Holding times should be documented in the Sample and Analysis Plan (SAP); if not check with the laboratory that will be analyzing the samples.

**Site ownership**

Always contact the property owner or land manager responsible for the actual site location and for any land that would need to be crossed to access a site. Be respectful of all private property. Always contact private landowners for permission to cross their land. Always get permission to leave equipment at the site or to attach equipment to bridges, pilings or other structures.

Assure that all gates are left as you found them. Animals in fenced animals may change throughout a season, so always check for dangerous livestock with each visit. Alternatively, assure that your presence in no ways causes harm to crops or livestock.

**Site safety**

Carefully assess sites for safety considerations and be aware of how potential hazards and risks may change with the season. Does the access to the site cross hazardous conditions or terrain? Is the water too deep or too fast to safely collect a sample? Are there obstructions, steep banks, submerged wire or debris, poisonous plants, or dangerous holes that may place your samplers at risk?
SECTION 7 – PROTOCOLS

This guidance document is not intended to provide detailed descriptions of analytic techniques or procedures. All laboratories, consulting firms, agencies or other entities involved in sample collection should have standard operating procedures (SOPs) that provide detailed information on all protocols from sample collection to final reporting of the data. Refer to the Reference and Resource sections for references to technical details of different monitoring techniques, and for information on developing SOPs if necessary.

The goal in any monitoring program is to collect data that are representative of the water body conditions. The data should also be comparable with data collected at different times or locations. As discussed in Section 4 of this manual, there are multiple approaches to detecting change. Any of these approaches, however, may require collecting water or biological samples, monitoring physical conditions in the water body or watershed, or some combination of these approaches. Each type of sample requires different techniques and considerations.

Water Column Monitoring:

Sampling the water directly is historically the most common approach taken in monitoring programs. This type of sampling provides a direct measure of the concentrations of pollutants or other properties of the water such as temperature. These values also link directly to many water quality criteria. When coupled with flow measurements, this approach also allows the calculation of the load (mass) of a particular pollutant found in a water body for a given period of time.

Water column samples are often easy to collect although some lab analyses may be quite costly. Most of the analytic methods for water chemistry and physical properties are standardized, simplifying comparisons between different monitoring sites or sampling events.

Water samples are often collected as “grab” samples by dipping a bottle or bucket into the water. In a well-mixed water body, a single grab sample may be representative, particularly for dissolved constituents. In a stratified water body, you may wish to sample the entire water column using vertically integrated samplers, or collect at distinct depths using specialized sample buckets. Particulate constituents may also be unevenly distributed across the width of a stream or river. In these cases, a series of samples should be collected across the width of the stream.

A significant disadvantage of collecting water samples at regular intervals is the loss of any information about the water body between sampling events. Often it is assumed that conditions do not change between sampling events. This may be a reasonable assumption (although one that should be verified) in relatively stable situations, such as deep water in stratified lakes or groundwater. In many situations however, especially in rivers and streams, these “snap-shots” in time may miss significant changes in water quality conditions between sampling events.

Integrating over time requires additional special equipment. “Automatic” water samplers with pump intakes can take samples at established intervals ranging from every few minutes to weekly intervals. Take care, however, that samples sitting in the collection bay of these devices do not exceed analytical holding times. Probes, coupled with data logging capabilities, are also increasingly
available for water quality measurements. Probes must be calibrated at regular intervals, but this approach can provide essentially continuous data at a relatively low cost.

Some monitoring equipment or approaches, such as properly setting up data loggers or automatic samplers, may require specialized technical expertise. It is best to get adequate training and do “dry runs” ahead of time and/or hire or partner with people who have the requisite skills.

**Biological Monitoring:**

Biological monitoring focuses on the living organisms that are exposed to various water quality stressors or may respond to an improvement in water quality conditions. Depending on the system and the stressor, monitoring may focus on fish, birds or large aquatic plants, on periphyton, microscopic algae or aquatic macroinvertebrates, or even on specific biological pathways and processes such as the rate at which oxygen is generated during photosynthesis. Biological monitoring has become increasingly important because of the value of “indicator species”, which are organisms or groups of organisms that respond in a characteristic way to types of pollutants or other stressors. A comparison of the relative abundance of these indicator species to what is expected in comparable unpolluted water bodies (reference streams) can indicate ongoing or past pollution, even when it is not evident in water column samples. Often, support of aquatic life is the beneficial use impaired in a waterbody and biological monitoring provides a direct measure of this beneficial use.

Some types of biological samples may be relatively simple to collect but may require expensive equipment. For example, the fluorescence of chlorophyll in a water column, measures light emitted from chlorophyll molecules and is therefore correlated to the amount of plant biomass in a waterbody. This is relatively easy to measure but requires special equipment to conduct the test. Other types of organisms, such as macroinvertebrates or periphyton, are relatively easy and inexpensive to collect, but processing these samples and identifying to the appropriate taxonomic level may be time consuming, costly and require special expertise.

Organisms may be distributed quite unevenly in a water body, which presents a challenge to collecting a representative sample. Different habitats (rifles, pools, near-shore, backwaters) may also support entirely different plant and animal communities, so collecting a representative sample may require sampling in multiple areas. Temporal changes in the size and distribution of organisms must also be accounted for. Many plants die back during winter months. Aquatic insects often “drift” so are present in the water column only at night, and zooplankton and fish may “vertically migrate” from deep waters to the surface over a 24 hour period.

Detecting change in biological communities does not necessarily indicate changes in the pollutant or stressor of concern or stressor. The linkage between changes in the biological samples and the pollutant of concern must be well understood.

**Habitat Monitoring (Physical and Riparian Vegetation)**

Monitoring habitat or stream morphology can provide a “big picture” over time of upstream changes, such as changes in land uses or hydrologic changes due to irrigation diversion or reservoir construction. Many of the monitoring approaches such as stream walks or proper functioning
conditions use expert knowledge but are none-the-less somewhat subjective and qualitative. Therefore, repeatability of measurements requires special training. Other types of habitat or stream morphology/stream bed monitoring require surveying tools and specialized equipment. Even these more quantitative methods require substantial knowledge of the functioning of river and stream systems in order to collect data at appropriate locations.

The physical properties of a river or the health of riparian vegetation may respond to changes in the upstream watershed that are linked to water quality parameters such as sediment or temperature. Other types of pollutants, such as acidity or toxicants, may cause significant impairment to a water body but may not be detectable through monitoring of river morphology or sediment load.

**Monitoring outside of the water body**

Many monitoring plans are greatly enhanced by collecting additional information that will help you better understand the impact and effectiveness of the BMP, and achieve project objectives. Consider interpretation of land use patterns before and after BMP implementation, surveying or interviewing landowners and stakeholders regarding land use and BMP effectiveness.
SECTION 8 – QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Quality assurance and quality control are required for all water quality monitoring programs using EPA funding, but should be followed for all monitoring programs. By law, any EPA-funded monitoring project must have an EPA-approved QAPP before it can begin collecting samples. Water quality agencies will not use monitoring data unless the methods of data collection, storage, and analysis can be well documented.

**Quality assurance (QA)** is the overall project management system and includes the organization, planning, data collection, quality control, documentation, evaluation, and reporting or the monitoring activities. QA provides the information needed to 1) determine the quality of the data and whether they meet the requirements of the project and 2) ensure that the data will meet defined standards of quality with a stated level of confidence.

**Quality control (QC)** refers to the routine technical activities whose purpose is, essentially, error control. Because errors can occur in either the field, the laboratory or in the office, QC must be part of each of these functions.

The Quality Assurance Project Plan (QAPP) is the written record of your QA/QC program. A QAPP documents the planning, implementation, and assessment procedures for a particular monitoring project, as well as any specific quality assurance and quality control activities. It integrates all the technical and quality aspects of the project in order to provide a "blueprint" for obtaining the type and quality of environmental data and information needed for a specific decision or use. (All work performed or funded by EPA that involves the acquisition of environmental data must have an approved Quality Assurance Project Plan.). Standard Operating Procedures (SOPs) are usually included in a QAPP.

Extensive information on developing QAPPS can be found at:
http://www.epa.gov/quality/qapps.html and
http://www.epa.gov/owow/monitoring/volunteer/qapp/vol_qapp.pdf

Sample and Analysis Plans (SAP): include the sampling design, sampling method requirements, and the required analytical methods. A generic SAP template from EPA Region 3 can be found at:

Measurement Quality: typically assessed by evaluating PARCC (Precision, Accuracy, Representativeness, Completeness, and Comparability).
- Precision: a measure of the reproducibility of analyses under a given set of conditions.
- Accuracy: a measure of the bias that exists in a measurement system.
- Representativeness: the degree sampling data accurately and precisely depict selected characteristics.
- Completeness: the measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under normal conditions.
- Comparability: the degree of confidence with which data sets can be compared.
An important component of any QAPP is the built in evaluation and refinement of the project plan over time. It is very important that the effectiveness of the monitoring program be assessed and changes made as necessary. This is especially important if a BMP has been implemented or if there have been major changes in the watershed system.

**How frequently should you monitor and how many samples should you collect?**

The frequency of sample collection will depend on what you are monitoring and how variable its abundance or mass is throughout your monitoring period. The frequency of sampling will also be determined by the natural variability in your system.

If you want to show a statistically valid change (decrease) in the pollutant of concern that can be attributed to the BMP implementation, prior knowledge of the variability within the watershed is needed. To assure that your monitoring program will produce statistically valid results, check with a statistician, or the person who will be analyzing the data to assist in determining the appropriate sample size.

To help determine sample size, review the following (USGS & Patuxent Wildlife Research Center, 2005). Developing a QAPP (and SAP) requires consideration of the following questions:

- What are the monitoring objectives? Have they changed due to the implementation of a BMP or a change in the watershed system?
- What is the expected response time for the BMP implementation?
  - What is the smallest number of years over which change can be detected (see Fig. 1)?
  - What is the smallest percentage change you would like to detect over those years?
  - The fewer number of years over which you would like to detect a trend, the greater number of samples you will need.
- How will the data be analyzed?
  - Sample sizes will also be defined by the statistical test that is used to analyze the data; different tests may require different sample sizes.
  - What is the ability of the data to detect a change?
- How variable are the data likely to be?
  - Any calculation of how many samples are needed for the monitoring program should be treated simply as an educated guess. There are too many variables involved that are not controllable. The minimum sample size will depend upon the desired confidence in the data and sample variability.
  - What is the measure of uncertainty?
  - What is the type of system (e.g. perennial, ephemeral) that you are monitoring?
- How precisely do you want to measure changes or trends?
  - The lower the precision, the lower number of samples needed. Conversely, the higher the precision, the larger number of samples needed.
- How much money and labor are available?
  - A monitoring program whose objective is to detect small changes over a short period may be expensive.
  - How often does a site need to be monitored to detect change to meet the monitoring objectives?
What other steps might you need to follow (SAP)?

“Standardization of methods is a fundamental prerequisite to any monitoring program” (Karr, 1991). You will need to define your methods for sampling in the field. Please note that these methods should reflect the analytical standards and procedures of the individual laboratory that you are working with. These methods should include:

- Establishing sampling reaches,
- Selecting sampling sites and habitat types,
- Selecting reference sites,
- Determine the season for sampling, and
- The methods of monitoring your response variables (which includes defining your field QA/QC protocols and data acquisition).

Quality of data required may determine protocols:

- Do the samples need to be analyzed by a certified lab? (A list of certified labs for each state can be found at: [www.epa.gov/privatewells/labs.html](http://www.epa.gov/privatewells/labs.html))
- Do you need credible data certification?
- Does your state have certification / credible data requirements? Check with the environmental quality agency in your state.

Calibration:

Calibration of equipment, field tests, or laboratory tests is necessary to assure that the signal of the equipment remains consistent over time and provides accurate results. Keep careful records of all calibration activities.

Detection limits:

Detection limits determine the ability to differentiate between signal and noise in the samples; these are supplied by the laboratory that processes the samples. The detection limits will vary with lab protocols and standard procedures. It is very important to consider these ahead of time to determine if a test is even worth it. For example, for many years mercury detection limits were higher than the water quality criteria; therefore, if you had alarmingly high concentrations, your test would give you information. If you had less than the detection limits you could not determine whether you were above or below the criterion.

A well developed monitoring program will have considered all of these factors.
SECTION 9 – DATA MANAGEMENT

Data management should be considered before any sampling begins. Data that are poorly recorded, poorly tracked, or lost represent an enormous and often irretrievable loss in information, time and money. Loss of baseline data can preclude the benefits gained from subsequent monitoring. This, of course, depends on the monitoring objectives.

The following considerations are a minimum when managing your data.

In the field:

- Develop an identification system for sites and individual samples that is clear and unambiguous. Keep separate records that will explain this system to future monitors; this information should be included in the metadata records.

Lab or office records

- Field sheets or field notebooks are the first entry point for data. Design these sheets to guide the field sampler through a monitoring protocol, so that nothing is forgotten or overlooked. Store these original hard copies in a secure filing system. It is good practice to write down everything you observe. It may not seem important at the time but that cow you saw in the creek could help you in your data interpretation. Do not trust your memory because monitoring sites tend to look all the same after awhile.

- NOTE: even when using dataloggers with automated sensors and probes to collect monitoring data, it is important to document activities (data collection, program changes, etc.) in a field notebook.

- Keep a log of all samples and sample collection events recording when (date and time) and where (unique site IDs) the samples were collected, who collected the samples, recording important information concerning holding times and processing of samples, conditions when the sample was collected, and the final outcome of the samples.

Transcribing or transferring field data

- Transcribe field data and analytical results into a reliable electronic record file such as a database or spreadsheet. Keep in mind that electronic programs and platforms change rapidly. You may wish to store your data in several electronic formats with backups to assure that you will not lose access to data because of electronic changes or failures. Do not discard your data sheets after the data have been entered into the database.

- Make sure that the unique identification system is used in this file. The format and program you use will depend on the complexity of the data you are collecting and the analysis you intend to conduct. This becomes your raw data file.

- Double check all entries, or have a second person check your entries, to reduce the possibility of transcription errors. Define all fields in your data file. Make sure that units and detection limits are always recorded.
Quality assurance checks on data

- Scan the data for extreme values or outliers. Any decisions made to drop these values from further analysis should be documented.
- Scan similar sets of data to see if they correlate. For example, a sample with high Total Suspended Solids (TSS) likely will have high turbidity, and a sample with high Total Dissolved Salts (TDS) will likely have high conductivity.

Metadata

- Maintain a metadata file to record QAQC results, information about variances from standard procedures, other data (e.g. weather, unusual conditions, variances from protocols, etc). Include sample site locations and additional sampling information that may not be included with the data.

- Calculated data (e.g. statistical analyses, summary data, graphs, etc.) will use the data in your original raw data files but be careful to never change these original data. Always document any calculations you conduct, including conversions, sources of data for statistical tests or graphs, etc.
SECTION 10 – ANALYSIS OF DATA

Statistical methods provide a wide array of techniques for extracting information and analyzing water quality monitoring data. The specific analyses to be used will depend on the objectives of the project, the system you are working in and the type of data. The methods that will be used to analyze the water quality data should be determined at the beginning of the development of the monitoring program, before data are collected. This is critical to insure that sufficient and appropriate data are collected.

Common types of data for assessing the effectiveness of a BMP:
- Trend Data
- Time Series
- Before and After (BACI)
- Paired Watersheds

The selection of analysis method or methods should reflect the objectives of your project. Often you will need more than one analysis method to assess water quality data to determine the effectiveness of a BMP. Data analysis assumes that the data have been properly managed and organized (Section 9) and the data are in a format for conducting analyses.

The following information needs to be considered prior to data analysis (often before the monitoring program has begun):

- QA/QC – need to know if the data are defensible before data analysis. Adding bad data to a good data set compromises the entire data set.

- Has the intensity of the sampling changed from intensive monitoring to trend (or vice versa)

- It is important to know how the data were collected and by whom. It is important to know if the same methods were used or if you need to separate the data by method.

- Do you have a large enough data set or sample size (n) to evaluate your project? How much data do you have? How many monitoring stations? How many years and how often per year?

- It is important to know the details of your data and to investigate inconsistencies when necessary. For example, when analyzing stream flow data are you analyzing height or discharge measurements? Were the data collected under similar precipitation? Are they event, seasonal or annual flow data? If water quality data are collected along with stream flow, are you in the rising or falling limb of the hydrograph? Are you measuring spring runoff or base flow? And are you in the upper or lower reaches of a watershed?

- There are significant differences between no data, zero, and data that are below detection limits; these differences should be clearly defined in your datasets and be taken into account in the analysis process.
In the analysis process, it is important to be able to distinguish between independent (explanatory) and dependent (response) variables. Due to the large variability in the types of water quality data collected and questions that can be answered, it is difficult to identify specific tools that will be needed. Some very common data analysis techniques are listed below. However, it is highly recommended to contact a statistician to assist with data analysis and interpretation. Additional information on selecting the “appropriate” analysis tool can be found in the USDA, Natural Resource Conservation Service “National Water Quality Handbook.” (2003)<http://policy.nrcs.usda.gov/media/pdf/H_450_600_a.pdf

Common Descriptive and Summary Statistics:
Summary statistics are a very good place to start the analysis. However, be careful not to interpret data using only summary statistics. In addition, it is important to check the distribution of the data – most environmental data are not normally distributed.

- Arithmetic mean - sum of the observations (data) divided by the number of observations.
- Median - the midpoint of a distribution (observations in order from smallest to largest)
- Distributions (are your data normally distributed?)
- Geometric mean – often useful summaries for skewed data, such as bacteria (E. Coli).
- Measures of variability (standard deviation, coefficient of variability, skewness.)
- Box and whisker plots (5 number summary) describe the center and the spread of the data.

Mean & Median – assess the center of a distribution.
They are the same if the distribution is symmetric (Fig. 5) in skewed distribution – mean is pulled towards a tail (Fig. 6.)

![Figure 5. Normal distribution: mean and median are the same.](image1)

![Figure 6. Skewed distributions: mean and median are not the same (from http://mvpprograms.com/).](image2)
It is important to be able to identify outliers in your data and understand the implications of and data analysis with and without outliers.

**Exploratory Data Analysis:**
Simple graphs are a very good way to look for overall patterns in the data. They can help identify trends as well as deficiencies in the data. Common graphing methods are:

- Histograms
- Time series
- Comparisons
- Pie charts

**Comparative Statistics:**
Comparative statistics are used to assess the strengths of the relationships among different datasets (e.g., stream flow and sediment concentration, paired watershed, BACI.)

Some common techniques are:
- Correlations
- Regressions
- Student t-tests
- Analysis of Variance (ANOVA)

*It is important to know the difference between a correlation and a regression relationship. Both describe the strength of relationship between two quantitative variables. Correlation (r) does not distinguish between explanatory and response variables. Regressions (r²) distinguish between dependent (response) and independent (explanatory) variables.*
SECTION 11 – INTERPRETING AND USING THE DATA

Ideally, by this step you have addressed all of the issues in the previous sections and are ready to interpret the results from your analyses. To effectively use your water quality data to assess the effectiveness of a BMP you will need to analyze and interpret your data within the context of your stream system (watershed) and your project objective. However, it is important to note that this may be an iterative process. By analyzing and interpreting your data within the context of your project objective, you may come to the conclusion that you 1) are collecting the “wrong” data; 2) have not collected enough data; or 3) need additional information to fully interpret your data. In which case, you will reassess which data you need to collect and modify your SAP.

The first step will be to determine that the “correct” data are being collected to assess the effectiveness of the BMP. This is a question that should be asked during the entire process. How do you know if enough data have been collected? In many cases this is a criterion that can and should be defined a priori. A clearly written monitoring project objective will define when you have met your objective. The criterion can be set to a water quality standard, a delisting of a stream segment or a percentage decrease in a pollutant. In monitoring projects that are determining baseline, the criterion may be that additional data collected do not result in a change in the long-term mean or coefficient of variation of the water quality data of concern. Data play a critical role in understanding water quality and the processes in the stream or watershed system (Figure 7).

The following information needs to be considered when interpreting and using water quality data.

Interpreting the data:

It is important that the data be interpreted within the “proper” context (e.g., for which it was collected.) Is a specific water quality criterion being assessed? Are the data adequate to assess or determine loads (TMDL, mass balances, source ID) or concentrations? The data may show that you exceed a TMDL but are well below a specific target concentration.

Using the data:

Is the monitoring working (i.e., are you detecting what you want to detect)? Has there been a sufficient timeframe to use the data? What do the data illustrate regarding the water quality of the system and changes over space or time? Are the data telling you what you want to know? Are you able to detect trends? Are these the expected trends based on your system, the BMP and the climatic conditions?

Future work:

Ideally, a successful, well-executed monitoring program that meets its objectives will lay the groundwork for future projects. These may include implementation of new BMPs or similar BMPs with in the same watershed system, if they proved successful. A good, well documented water quality dataset can be invaluable for locating future projects. It can also be used to determine if the monitoring program needs to be changed or modified. This could mean changing a monitoring program from intensive to trend (or vice versa). As always, this will depend on how the monitoring objectives are defined.
Figure 7. Role of monitoring data in understanding water quality and system responses in a stream system.
SECTION 12 - REFERENCES


<www.pwrc.usgs.gov/monmanual/samplesize.html> (this link is referred to the in the text, but it does not work)


APPENDIX A. TERMS AND DEFINITIONS

Accuracy: the closeness of an observed value or test response to the true or acceptable reference value specified in a reference method. Accuracy is influenced by both random error (precision) and systematic error (bias) (EPA, 2007).

Anomalies: data that deviate or are departures from the normal or common order, form, or rule

Baseflow: stream discharge that is not a result of direct runoff from precipitation or melting snow, and it is usually sustained by groundwater.

Baseline reference site: when using a comparison to a reference site for the site you are monitoring, this site is the second site in a similar watershed.

Best Management Practices (BMPs): conservation and land management practices that reduce or prevent movement of pollutants to surface and groundwater. Some examples of BMPs may include safe management of animal waste, control of pests and nutrients, contour farming, crop rotation, and vegetative buffers near streams.

Biological indices: indicators of biological integrity that directly measure the aquatic community.

Detection limit: the lowest concentration of a chemical that can dependably be distinguished from a concentration of zero (EPA, 2006).

Direct monitoring: collecting samples to measure physical, biological, and chemical variables.

Dissolved pollutant: a pollutant that will disintegrate in solution.

Embeddedness: the amount of substrate material (sand, clay, and silt) covering river rock.

Ephemeral stream: a stream channel that carries water only during and immediately after periods of rainfall or snowmelt.

Grab samples: samples collected at a particular location and time that represents the composition of the water, air, or soil only at that location and time (EPA, 2006).

Impairment: cause to diminish or degrade in strength, value or quality.

Integrated samples: samples collected at particular time and different locations (e.g. different sections of the same river) that represent the composition of the water, air, or soil as a less variable sample over a period of time.

Intermittent stream: a stream that carries water only during wet periods of the year (30-90% of the time).

Metadata: “data about data” i.e., the understanding, documentation use, and management of data.
National Pollution Discharge Elimination System (NPDES) Permit: a permit program to control water pollution by regulating point sources that discharge pollutants into waters of the United States. The NPDES permit program is administered at a state level (EPA, 2007).

Nutrient pollution: contamination of water resources by excessive amount of nutrients, specifically nitrogen and phosphorus.

Outlier: an observation that is numerically distant from the rest of the data.

Parameter (statistical): a statistical quantity, usually unknown, such as a mean or a standard deviation, which characterizes a population or defines a system (EPA, 2007).

Particulate pollutant: a pollutant that will not dissolve in solution, but remains in distinct particles.

Perennial stream: a stream channel that has continuous flow throughout the year.

Pollutant: substance that contaminates (pollutes) a water body.

Pollutants of concern: substances introduced into the environment that adversely affect the use of a resource or the health of humans, animals, or ecosystems, in the watershed or water body the where the effectiveness the BMP will be assessed (EPA, 2007).

Pollution: the introduction of contaminants into an environment that causes instability, disorder, or harm to the system.

Precision: A measure of mutual agreement between two or more individual measurements of the same property, obtained under similar conditions.

Probes: onsite instruments (sensors) used to collect chemical or physical water data. These data can be stored in a data logger and projected as real-time data, or collected as a grab sample.

Protocols: a series of formal steps for conducting a test, service, or procedure (EPA, 2006).

Quality Assurance and Quality Control (QA/QC): actions performed to ensure the quality of a product, service, or process.

Quality Assurance Project Plan (QAPP): a written document that outlines the procedures a monitoring project will use to ensure samples collected and analyzed, the management of the data, and the consequent reports are of high enough quality to meet the projects needs (EPA, 2006).

Sample and Analysis Plan (SAP): a document detailing procedural and analytical requirements for sampling events performed to collect samples.

Sampling frequency: the time between successive sampling events.
Standard Operating Procedure (SOP): written documents that describe, in great detail, the routine procedures to be followed for a specific operation, analysis, or action.

Stressors: physical, chemical, or biological entities that can induce adverse effects on ecosystems or human health.

Surrogate monitoring: monitoring one variable that correlates to the actions of another variable (i.e. the pollutant of concern) that may not be easily measured.

Total Maximum Daily Load (TMDL): is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources (EPA, 2007).

Total Phosphorus (TP): a measure of the concentration of phosphorus including soluble phosphorus and the phosphorus in the organic material suspended in wastewater, effluent, or water bodies.

Total Suspended Solids (TSS): a measure of the suspended non-filtered solids (e.g. sediment or organic matter) in wastewater, effluent, or water bodies (EPA, 2006).

Turbidity: a cloudy condition in water due to suspended solids (EPA, 2006).
APPENDIX B – ADDITIONAL MONITORING RESOURCES

Resources for Monitoring Programs:


Resources for monitoring protocols:

NRCS products and tools from the National Waters and Climate Center:
http://www.wcc.nrcs.usda.gov/products.html

Monitoring protocols: National Water Quality Monitoring Handbook, specifically Section 614
<http://policy.nrcs.usda.gov/media/pdf/H_450_600_a.pdf>


Resources for Bioassessment Protocols:


Resources for Specific Models:

Agricultural Non-Point Source Pollution Model (AGNPS): continuous simulation surface runoff model designed to assist with determining BMPs, the setting of TMDLs, and for risk & cost/benefit analyses (http://www.ars.usda.gov/Research/docs.htm?docid=5199).
Soil Water Assessment Tool (SWAT): a river basin scale model developed to quantify the impact of land management practices in large and complex watersheds. SWAT is a public domain model supported by the USDA Agricultural Research Service (http://www.brc.tamus.edu/swat/).

Kinematic runoff and erosion model (KINEROS2): is an event oriented, physically based model describing the processes of interception, infiltration, surface runoff and erosion from small agricultural and urban watersheds (http://www.tucson.ars.ag.gov/kineros/).

Revised Universal Soil Loss Equation (RUSLE): an online soil assessment tool using the soil loss equation \( A = R \times K \times LS \times C \times P \) (http://www.iwr.msu.edu/rusle/).


SNTEMP: http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=sntemp

Streeter Phelps - Dissolved Oxygen Model: http://cedb.asce.org/cgi/WWWdisplay.cgi?5014377

River and Stream Water Quality Model (QUAL2K): a one dimensional river and stream water quality model for a well mixed, vertically and laterally channel with steady state hydraulics (http://www.epa.gov/athens/wwqtsc/html/qual2k.html).


US EPA Water Quality Models and Tools: This site includes information and guidance on several simulation models and tools for watershed and water quality monitoring (http://www.epa.gov/waterscience/models/).
Appendix C: Contacts

Northern Plains and Mountains Region State Water Coordinators:

Dr. Reagan Waskom
Regional Water Coordinator
Colorado Water Institute
(970) 491-6308

Troy Bauder
Colorado Water Coordinator
Colorado State University
(970) 491-4923

Dr. James Bauder
Montana Water Coordinator
Montana State University
(406) 994-5685

Dr. Tom Scherer
North Dakota Water Coordinator
North Dakota State University
(701) 231-7239

Dr. Dennis Tody
South Dakota Water Coordinator
South Dakota State University
(605) 688-5678

Nancy Mesner
Utah Water Coordinator
Utah State University
(435) 797-2465

Dr. Ginger Paige
Wyoming Water Coordinator
University of Wyoming
(307) 766-2200

USDA-NIFA National Water Program:
