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Best Management Practices Monitoring Guide for Stream Systems

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Applying knowledge to improve water quality
Northern Plains & Mountains Regional Water Program
A Partnership of USDA NIFA & Land Grant Colleges and Universities

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for Stream Systems

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INTRODUCTION

Best Management Practices Monitoring Guide for Stream Systems provides guidance on establishing a water quality monitoring program that will demonstrate the effectiveness of Best Management Practices (BMPs) 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 document is not a "how to" manual on specific techniques. Rather, it is intended to guide 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, specific objectives of a particular implementation and 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. And 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 time and cost 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 provide this information. This document focuses on the effectiveness of BMPs implemented to reduce or prevent nonpoint source pollution. This information can also 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 must 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 guide are intended to help users better characterize the objectives of a monitoring plan, carefully consider the scale of the project, and better understand how 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, the correct parameters to measure, best monitor locations, and best timing of sample collection.

Sections 8 and 9 discuss data integrity, storage, and analysis. Proper quality assurance (QA) and quality control (QC) measures start before the first sample is collected and include field collection, lab processing, and data management. Taking these measures assures that 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 help provide realistic expectations for monitoring results, given the expected uncertainty and variability in a particular water body.

Appendix A provides definitions of many of the technical terms used in this document. Appendix B lists helpful resources for designing a monitoring program, using specific monitoring techniques, bio-assessment techniques, and specific models. Appendix C lists water quality contacts with the USDA National Water Program and land grant universities.

A note about terminology: This document uses the term "pollutant" to include any discharge or activity that causes impairment of a water body. The terms "pollution" and "stressor" are similar, both 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 these and other terms.

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 from the onset. All subsequent decisions about the monitoring program follow directly from the monitoring objectives.

Note that often there are multiple monitoring objectives within a watershed monitoring program. Therefore, it is important to design such programs to meet individual objectives. A review and comparison of 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. Table 1 demonstrates how a monitoring program may change depending on these objectives.

Table 1. Monitoring programs are dependent on project objectives

Program Objective	*Monitoring Program Considerations*
Regulatory compliance of a NPDES permit	Typically most aspects of the monitoring program are established in the National Pollutant Discharge Elimination System (NPDES) permit by a regulatory agency. The permit will regularly include what to sample, how often samples must be collected, what methods must be used, and who can collect the samples.
Total Maximum Daily Load (TMDL)/ BMP effectiveness	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 it may also include factors, watershed characteristics, or information about the actual BMP. As with regulatory monitoring, data credibility is a primary concern.
Educational programming	Monitoring programs for educational programs are typically determined by cost, ease of methods, age appropriateness, and interest of volunteers. The intent 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 they are not used for regulatory or compliance purposes.

Clearly defined monitoring objectives include 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 objectively.

SECTION 2 – UNDERSTANDING POLLUTANTS WITHIN NATURAL SYSTEMS

To effectively monitor changes in pollutants of most concern, it is extremely important to understand how these pollutants typically behave in natural systems and, in particular, in specific watersheds. Equally important is an understanding of how these pollutants might respond to specific BMPs. Many of the pollutants BMPs are intended to address, such as sediment and nutrients, are found naturally in surface and groundwater, and they 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 groundwater, and the transformations that may occur during this process.

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

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 nonpoint) 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 particulate). 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 does it move 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 streamflow 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 a 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 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, however, is not a reason for ignoring these questions. Assistance in understanding these processes is available through agency resource specialists and university Extension specialists. See Appendix C for contact information.

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 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," such as natural variability of flow in the intermountain west. The range of natural variability in the system must be taken into consideration because this variability may mask any change resulting from BMP implementation. As a general rule, more frequent samples are needed in a highly variable system, but, by targeting the sampling timing, the monitoring program may be greatly improved. 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 a 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 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 streamflow, 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 snowmelt 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 water body 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 intensive monitoring during baseflow may not be worth the time or money.

Daily changes:

Daily (diel) changes in sunlight may directly affect plant and animal behavior and 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 nonpoint source particulate pollutants (such as sediment and *E. coli*) may be 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, and 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?

Figure 1 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 construction or other projects are 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, 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 measurable.

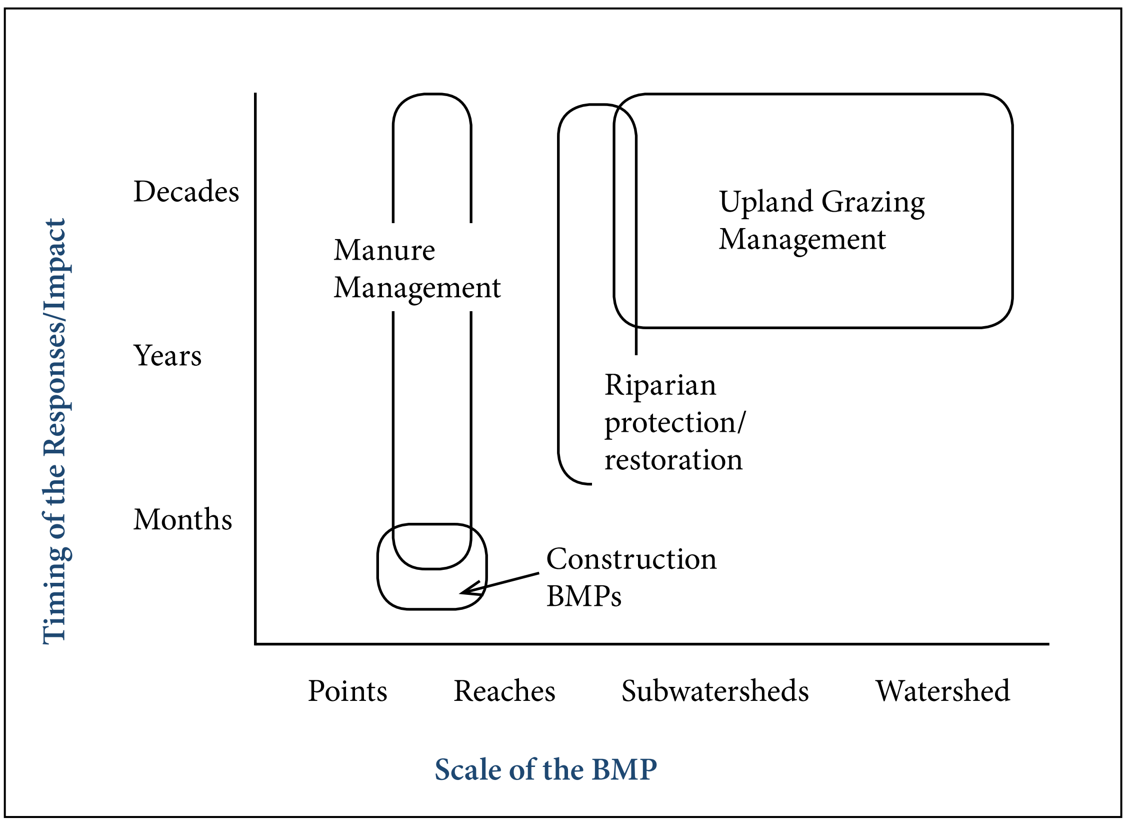


Figure 1. The scale of common BMPs and their typical response times should always be considered when planning a monitoring program.

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 a given situation. Different approaches are described below. Refer to Table 2 for a list of common monitored pollutants and a 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 there is 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 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 ones 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 necessary to run the model.

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

Deterministic: 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: lacks a single, general mathematical solution; represents complex, non-linear relationships (very common in watershed hydrology and landscape ecology).

Process-based: 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 the project scale, e.g., plot, field, watershed, or basin? A complex, spatially explicit watershed scale model that uses a 30-meter resolution may not be appropriate to assess the impacts of a 10-meter-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 well enough that the 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 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 it?
- 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 having good estimates of) the surface microtopography and roughness are very important.

Often a model documentation plan will be required for Total Maximum Daily Load (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 meters from the creek. A model may suggest this location will result in a 75 percent reduction of nutrients to the creek. A similar project that would result in a projected 95 percent reduction may receive a higher funding priority, benefiting the landowner and many others. The use of the model to inform the landowner that moving the corral 40 feet from the creek may result in a projected 95 percent reduction in nutrients might be sufficient information to allow the landowner to change his or her 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 specific models to consider.

Table 2. Common pollutants and approaches for directly monitoring, monitoring surrogates, response variables, and commonly used models. This table only includes some pollutants, but it should help in understanding some of the issues to consider when deciding which approach or approaches will best meet the monitoring objective. (For an explanation of "grab samples" and other sampling methods, see Section 7, Protocols.)

Pollutant	Direct Monitoring	Surrogate Monitoring	Response Variables	Other Important Variables *	Models
Temperature	Probes, launched monitors (e.g., HOBO), and direct measurements	Light/shading, groundwater signal (stable isotope variables)	Algae, macros, and fish	Air temperature, flow, time of day, depth, turbidity, cloud cover	CE-QUAL WASP(7) SNTEMP (U.S. Geological Survey)
Dissolved oxygen (DO)	Probes and direct measurements	Temperature, redox, and flow/temperature/algal biomass	Macros and fish	Temperature will affect percent saturation, depth, flow, velocity	Streeter-Phelps
Nutrients (phosphorus and nitrogen)	Grab samples and integrated samples In some cases use probes, or streamside auto-analyzers to collect surrogate samples	Turbidity or sediment	Algae, macro-invertebrates, fish, macrophytes	pH, temperature, and DO might affect the solubility of phosphorus, flow (sediment transport)	UAFRI SWAT QUAL2K
Sediment	Grab samples and integrated samples	Turbidity	Physical characteristics, "embeddedness", macros, and algae	Flow	PSIAC AGNPS SWAT KINEROS2
Salts/total dissolved solids (TDS)	Probes and grab samples	Electroconductivity probe; riparian vegetation	Macros and fish	Flow	QUAL2K
Pathogens	Grab samples and integrated samples	Fecal coliform bacteria; *E. coli*	Human health, livestock health	Turbidity, nutrients, temperature	
Metals	Grab samples	Bioaccumulation in living organisms; sediments		DO might affect total hardness, pH	MINTEQAQ
Organic pesticides	Grab samples	Bioaccumulation in living organisms			WINPST

**These are variables that often must also be measured in order to correctly interpret monitoring results.*

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 Figure 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.

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 reports, publications, and databases of agencies, universities, consulting firms, and nonprofits 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 being collected for comparison: were the data collected at appropriate frequencies, were appropriate parameters collected, were the samples collected at an appropriate site, etc.? Monitoring program Quality Assurance Project Plans (QAPP), which are discussed in Section 8, 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, land ownership, and elevation are often available in different formats (photos, hard copy maps, and/or Geographic Information Systems [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 reports from the U.S. Department of Agriculture’s (USDA) Agricultural Research Service (ARS), USDA’s Natural Resources Conservation Service (NRCS), Extension, consultants, and others. 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 project objectives will depend on the type and scale of the project and the degree to which other variables can be controlled when monitoring. 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, it 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.

Additional information on selecting an appropriate monitoring design can be found in the NRCS National Water Quality Handbook at <http://www.wsi.nrcs.usda.gov/products/w2q/water_qual/docs/NatWQhandbookNRCS.pdf>

***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

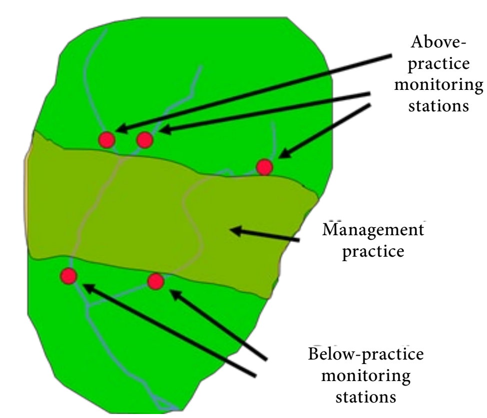


Figure 2. Upstream and downstream monitoring.

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 U.S. Environmental Protection Agency (EPA) and other agencies typically want to know how much of a pollutant has been removed, which is what a load measurement reveals.

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, baseflow 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, a 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 **B**efore **A**fter **C**ontrol **I**mplementation design).

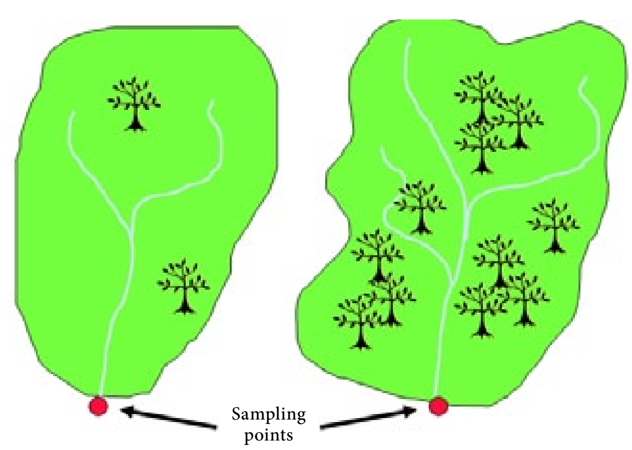


Figure 3. Comparison to a reference site.

Assumption:

- The 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:

- Data that are collected at the same time can be compared 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 seeking an "unimpaired" or "natural" site.
- Be careful about comparing sites that are not sufficiently similar. At a minimum, streams of a similar order, flow, geology, stream type, elevation, and land use should be compared. 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 should be considered (for example, baseflow 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 the monitoring site; this approach will not be able to differentiate water quality changes resulting from the BMP from any other changes upstream of the BMP implementation.
- 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 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 the 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.

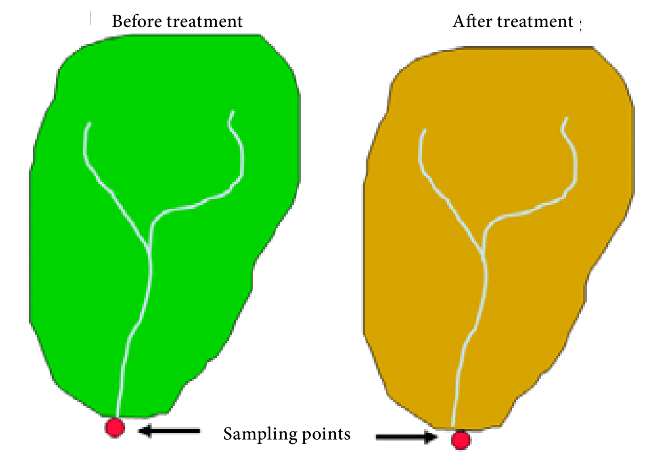


Figure 4. Monitoring using historic data.

Advantages:

- More data may be available to use in the "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, 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.

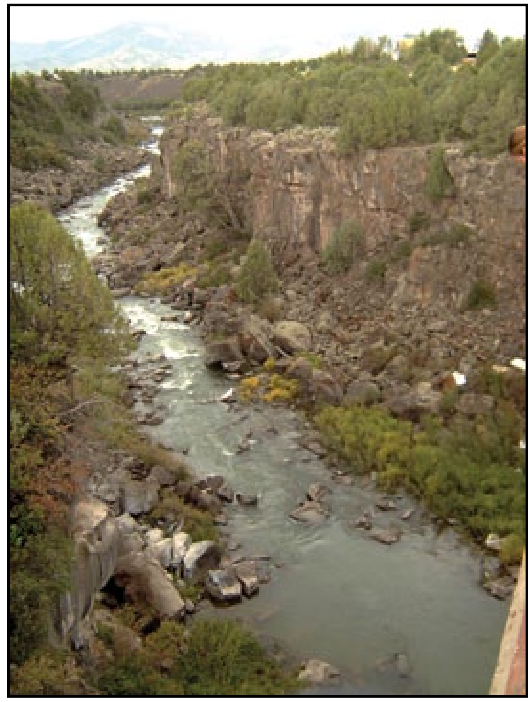
Advantage:

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

Disadvantages:

- Runoff must be monitored before and after the implementation to demonstrate the impact.
- Runoff must be measured or adequately estimated during the duration of the flow to measure concentration and load 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 reach a sampling location, legal and physical access to a site, and safety issues must 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. 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. 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 from being flooded or otherwise damaged by high water? Is there evidence of past standing water in the selected site? During low water conditions, will probes and other equipment 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 flow. Trees, shrubs, and 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 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 QA 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(s) or land manager(s) responsible for the actual site location and for any land that would need to be crossed to access the 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. If an unopened gate is found, alert the property owner if possible. Animals in fenced areas 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 animals, or dangerous holes that may place samplers at risk?

SECTION 7 – PROTOCOLS

This guide 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 Section 12 (References) and Appendix B (Additional Monitoring Resources) 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, there are multiple approaches to detecting change. Any of these, however, may require collecting water or biological samples, monitoring physical conditions in the water body or watershed, or some combination. Each type of sample requires different techniques and considerations.

Water Column Monitoring:

Sampling the water directly is historically the most common monitoring approach. This type of sampling provides a direct measure of the concentrations of pollutants and

other properties of the water such as temperature. These values also link to many water quality criteria. When coupled with flow measurements, this approach allows the calculation of the load (mass) of a particular pollutant found in a water body for a given period.

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 and 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, consider sampling 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, especially in rivers and streams, these "snapshots" 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. Take care 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 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, large aquatic plants, 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 water body, and biological monitoring provides a direct measure of this 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 water body. This is relatively easy to measure but requires special equipment. 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, may be costly, and may require special expertise.

Organisms may be distributed quite unevenly in a water body, which presents a challenge to collecting a representative sample. Different habitats (riffles, pools, nearshore, 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. 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/streambed monitoring require surveying tools and specialized equipment. Even these more quantitative methods necessitate 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 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

Quality assurance and quality control (QA/QC) are required for all water quality monitoring programs using EPA funding, but it should be followed other monitoring programs, too. By law, any EPA-funded monitoring project must have an EPA-approved QAPP before sample collection begins. 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 (QC), documentation, evaluation, and reporting of 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 the field, laboratory, or office, QC must be part of each of these functions.

The QAPP is the written record of a QA/QC program. A QAPP documents the planning, implementation, and assessment procedures for a particular monitoring project, as well as any specific QA/QC activities. It integrates all the technical and quality aspects of the project 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 QAPP.) 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 (SAPs) include the sampling design, sampling method requirements, and required analytical methods. A generic SAP template from EPA Region 3 can be found at: http://www.epa.gov/reg3hscd/bf-lr/granteereporting/sap_generic.pdf.

Measurement Quality is 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 that 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 monitoring take place, and how many samples should be collected?

The frequency of sample collection will depend on what is being monitored and how variable its abundance or mass is throughout the monitoring period. The frequency of sampling will also be determined by the natural variability in the 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 the 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 *Managers' Monitoring Manual* published by the U.S. Geological Survey's Patuxent Wildlife Research Center in Maryland. The manual is available at http://www.pwrc.usgs.gov/monmanual/samplesize.htm.

Developing a QAPP (and SAP) requires consideration of the following:

- 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 Figure 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 will be needed.
- How will the data be analyzed?
    - Sample sizes will also be defined by the statistical test used to analyze 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 is being monitored?
- 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 need to be followed (SAP)?

"Standardization of methods is a fundamental prerequisite to any monitoring program (Karr, 1991)." Methods for sampling in the field should be defined. Please note that these methods should reflect the analytical standards and procedures of the laboratory 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 response variables, which include defining 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)
- 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 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 there were alarmingly high concentrations, a test would reveal that information. But if concentrations were less than the detection limits, it could not be determined if they 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 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 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 observed. It may not seem important at the time but that cow seen in the creek, for example, could help with data interpretation. Do not trust your memory because monitoring sites tend to look all the same after awhile.

- NOTE: even when using data loggers 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 identifications) 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 data in several electronic formats with backups to assure access to data will not be lost because of electronic changes or failures. Do not discard 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 used will depend on the complexity of the data being collected and the analysis you intend to conduct. This becomes the raw data file.
- Double check all entries, or have a second person check the entries, to reduce the possibility of transcription errors. Define all fields in the data file. Make sure that units and detection limits are always recorded.

QA checks on data:

- Scan the data for extreme values or outliers. 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 QA/QC 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 the original raw data files, but be careful to never change the original data. Always document any calculations that are conducted, 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 being worked in, and the type of data. ***The methods 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
Time series
Before After Control Implementation (BACI)
Paired watersheds

The selection of analysis method or methods should reflect the objectives of your project. Often, more than one analysis method will be needed 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 the data needs to be separated by method.
- Is there a large enough data set or sample size (n) to evaluate the project? How much data is available? How many monitoring stations? How many years and how often per year?

- It is important to know the details of the data and to investigate inconsistencies when necessary. For example, when analyzing streamflow data, are height or discharge measurements being analyzed? Were the data collected under similar precipitation? Are they event, seasonal, or annual flow data? If water quality data are collected along with streamflow, are you in the rising or falling limb of the hydrograph? Is spring runoff or baseflow being measured? 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 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 NRCS’s *National Water Quality Handbook* at http://www.wsi.nrcs.usda.gov/products/w2q/water_qual/docs/NatWQhandbookNRCS.pdf.

Common Descriptive and Summary Statistics:
Summary statistics are a 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 (is the 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 (five number summary) describe the center and the spread of the data.

Mean and median – assess the center of a distribution.
They are the same if the distribution is symmetric (Figure 5); in a skewed distribution, the mean is pulled towards a tail (Figure 6).

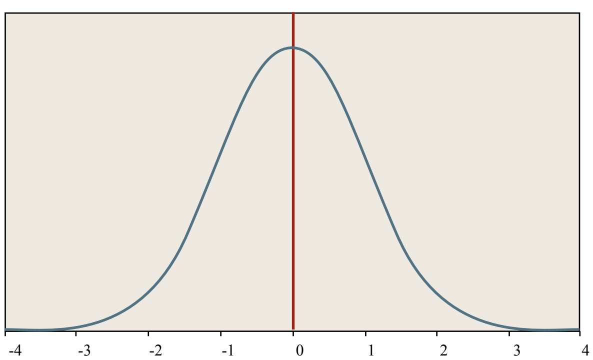


Figure 5. Normal distribution: mean and median are the same.

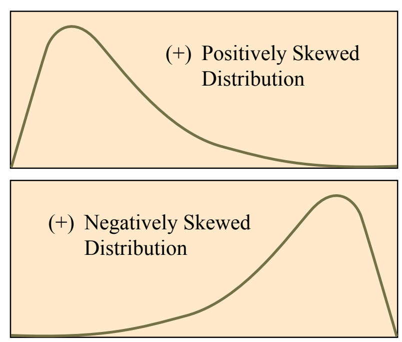


Figure 6. Skewed distributions: mean and median are not the same (from http://mvpprograms.com/).

It is important to be able to identify outliers in 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. 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., streamflow and sediment concentration, paired watersheds, 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 (r^2) distinguish between dependent (response) and independent (explanatory) variables.

SECTION 11 – INTERPRETING AND USING THE DATA

Ideally, by this step all of the issues in the previous sections have been addressed and you are ready to interpret results from the analyses. To effectively use the water quality data to assess the effectiveness of a BMP, the data must be analyzed and interpreted within the context of the stream system (watershed) and project objective. It is important to note that this may be an iterative process. By analyzing and interpreting data within the context of the project objective, you may conclude that you 1) are collecting the "wrong" data; 2) have not collected enough data; or 3) need additional information to fully interpret your data. If this happens, reassess which data must be collected and then modify the 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're the objective has been met. 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).

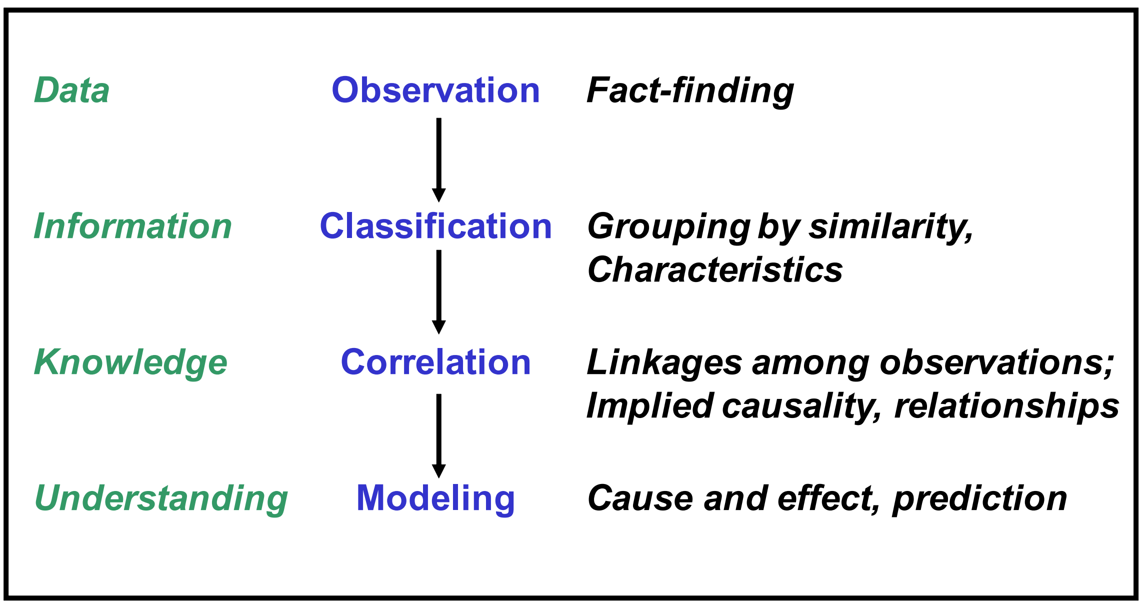


Figure 7. Role of monitoring data in understanding water quality and system responses in a stream system.

The following information should 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 identification) or concentrations? The data may show that a TMDL was exceeded but is 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 revealing what you want to know? Are trends detectable? Are these the expected trends based on the system, BMP, and climatic conditions?

Are you able to assess if the BMP is working? These are often statistical tests but need to be assessed within the context of the objective and the stream system.

Future work:

Ideally, a successful, well-executed monitoring program that meets objectives will lay the ground work for future projects. These may include implementation of new BMPs or similar BMPs with in the same watershed system, if they proved successful. A complete, 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.

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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 being monitored, 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. 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 an 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 a 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 percent of the time).

metadata: "data about data," i.e., the understanding, documentation use, and management of data.

National Pollutant 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 amounts 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 where the effectiveness the BMP will be assessed (EPA, 2007).

pollution: the introduction of contaminants into an environment that cause 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 they can be 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 needs of a project (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 dissolved solids (TDS): a measure of the combined content of all dissolved inorganic and organic substances in water. The solids are primarily minerals and salts, but can also include organic matter.

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:

U.S. Environmental Protection Agency. *Guidance for Preparing Standard Operating Procedures (SOPs)*. 2007. <http://www.epa.gov/QUALITY/qs-docs/g6-final.pdf>

U.S. Environmental Protection Agency. *The Volunteer Monitor's Guide to Quality Assurance Project Plans*. 1996. <http://www.epa.gov/owow/monitoring/volunteer/qapp/vol_qapp.pdf>

Resources for Monitoring Protocols:

U.S. Department of Agriculture, Natural Resources Conservation Service. *National Water Quality Handbook*, specifically Section 614, "Design of Water Quality Monitoring Systems." 2003.

<http://www.wsi.nrcs.usda.gov/products/W2Q/water_qual/docs/NatWQhandbookNRCS.pdf>

U.S. Department of Agriculture, Natural Resources Conservation Service. *Products of the National Water and Climate Center.* <http://www.wcc.nrcs.usda.gov/products.html>

U.S. Environmental Protection Agency. *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Measures – Urban*. 2001. <http://water.epa.gov/polwaste/nps/urban2.cfm>

Resources for Bioassessment Protocols:

U.S. Environmental Protection Agency. *Biocriteria – Bioassessment and Biocriteria*. 2007. <http://www.epa.gov/waterscience/biocriteria/>

U.S. Environmental Protection Agency. *Guidance for Preparing Standard Operating Procedures (SOPs)*. 2007. <http://www.epa.gov/QUALITY/qs-docs/g6-final.pdf>

U.S. Environmental Protection Agency. *Online Training in Watershed Management*. 2007. <http://www.epa.gov/owow/watershed/wacademy/acad2000/>

U.S. Environmental Protection Agency. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish – Second Edition*. 1999. EPA 841-B-99-002. <http://www.epa.gov/owowwtr1/monitoring/rbp/index.html>

Resources for Specific Models:

American Society of Civil Engineers. *Parameter Estimation of Streeter-Phelps Models*. <http://cedb.asce.org/cgi/WWWdisplay.cgi?5014377>

Michigan State University, Institute of Water Research. *Revised Universal Soil Loss Equation (RUSLE)*: an online soil erosion assessment tool using the soil loss equation (A = R * K * LS * C * P). <http://www.iwr.msu.edu/rusle/>

Soil and 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 U.S. Department of Agriculture, Agricultural Research Service. <http://www.brc.tamus.edu/swat/>

U.S. Department of Agriculture, Agricultural Research Service. *A kinematic runoff and erosion model (KINEROS2)*: 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/>

U.S. Department of Agriculture, Agricultural Research Service. *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 and cost/benefit analyses. <http://www.ars.usda.gov/Research/docs.htm?docid=5199>

U.S. Department of Agriculture, Agricultural Research Service. *Rangeland Hydrology and Erosion Model (RHEM).* <http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=406982&showpubs=true>

U.S. Environmental Protection Agency. *Better Assessment Science Integrating Point and Nonpoint Sources (BASINS 4)*: a free GIS tool for watershed analysis and monitoring. <http://www.epa.gov/athens/wwqtsc/html/basins.html>

U.S. Environmental Protection Agency. *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>

U.S. Environmental Protection Agency. *Water Quality Models*: This site includes information and guidance on several simulation models and tools for watershed and water quality monitoring.
<http://www.epa.gov/waterscience/models/>

U.S. Geological Survey. *Surface Water and Water Quality Models Information Clearinghouse (SNTEMP).*
<http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=sntemp>

APPENDIX C – WATER QUALITY CONTACTS

National Water Program

The national directory of water quality coordinators includes the NIFA Committee for Shared Leadership, National Water Resource Project coordinators, Water Quality coordinators and contacts, and Regional Coordination Project associates). http://www.usawaterquality.org/directory/WQCDirectoryMar09.pdf

Northern Plains and Mountains Regional Water Program

http://region8water.colostate.edu/
The Northern Plains and Mountains Regional Water Program is a partnership of the U.S. Department of Agriculture's National Institute of Food and Agriculture (NIFA) and land grant colleges and universities. The region comprises Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. Its purpose is to integrate research, education, and Extension programs to address high-priority water issues, and it strives to establish a collaborative, structured process that develops and shares new and existing water resource practices and management techniques throughout the region and nationally.

Region 8 Water Program Coordinator:

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Director, Colorado State University Water Center (http://watercenter.colostate.edu/)
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Region 8 State Water Program Coordinators:

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