An Interactive Guide to Nonpoint Source Monitoring

508-compliant content

U.S. Environmental Protection Agency (EPA)

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1. INTRODUCTION

1.1 The Guide's Target Audience

This guide is primarily for those who develop and implement monitoring plans for watershed projects, but it can also be used by those wishing to evaluate the technical merits of nonpoint source (NPS) pollution monitoring proposals they might sponsor.

Leveraging existing work from your group's strategy and monitoring documentation (e.g., standard operating procedures, quality assurance project plans [QAPPs] with similar objectives) will help you make the most of this interactive guide and develop an effective plan for your project.

Note: If you are using Clean Water Act section 106 or 319(h) funds:

- Review your monitoring approach to determine if it conforms to your state's/tribe's water quality monitoring strategy.
- Determine quality assurance needs early, including developing and approving a QAPP before collecting any samples.

1.2 Why Do We Need Nonpoint Source Monitoring?

- Identify water quality problems, designated use impairments and causes, and pollutant sources.
- Develop total maximum daily loads (TMDLs), including load and waste load allocations.
- Analyze trends.
- Assess the effectiveness of best management practices (BMPs) or watershed projects.
- Assess permit compliance.
- Validate or calibrate models.
- Conduct research.

1.3 Fundamentals of Good Monitoring

- **Good monitoring**
  - Provides fundamental information about the water resource and its impairments.
  - Documents changes through time.
  - Shows response to NPS pollution reduction practices and programs.
  - Confirms achievement of management objectives.
  - Provides basis for evaluating progress (adaptive management).
- **Poor monitoring**
  - Fails to meet objectives.
  - Creates confusion.
  - Leaves critical questions unanswered.
  - Wastes time and money.
  - Leads to bad decisions.

For more information, go to guidebook page 2-4.

1.4 This Interactive Guide Approach

- This interactive guide offers a high-level overview of USEPA's NPS monitoring guidebook, *Monitoring and Evaluating Nonpoint Source Watershed Projects* (referred to in this document as the *guidebook*); it primarily focuses on Chapters 2 and 3.
- By using the map on the next page, users may easily navigate directly to the details that are most pertinent to their monitoring objectives.

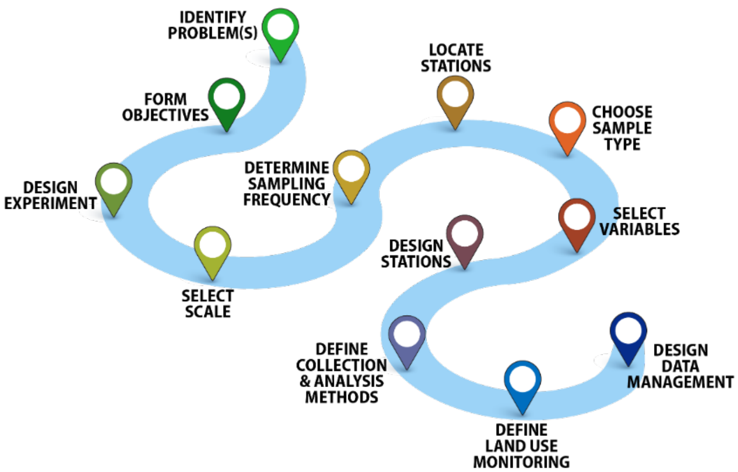
For more information, go to guidebook page 2-4.

1.5 Quality Assurance Project Plan

- Prepare your QAPP before data collection begins and refer to it during all phases of the monitoring program.
- A QAPP documents the planning, implementation and assessment procedures for a particular project, as well as any specific quality assurance and quality control activities.
- Use a QAPP to document planning results for environmental data operations and to provide a project-specific "blueprint" for obtaining the type and quality of environmental data needed for a specific decision or use.
- For more on QAPPs, refer to the Design Data Management section or page 8-1 of the Guidebook.

2. MONITORING PLAN DESIGN ELEMENTS

- The following sections discuss monitoring plan design elements:
  - Identify Problems (Section 2.1)
  - Form Objective (Section 2.2)
  - Design Experiment (Section 2.3)
  - Select Scale (Section 2.4)
  - Determine Sampling Frequency (Section 2.5)
  - Locate stations (Section 2.6)
  - Choose Sample Type (Section 2.7)
  - Design Stations (Section 2.8)
  - Define Collection and Analysis Methods (Section 2.9)
  - Defined Land Use Monitoring (Section 2.10)
  - Design Data Management (Section 2.11)



2.1 Identify Problems

- Identify the causes of impairment and the pollutant sources that need to be controlled.
- Considerations:
  - How might the characteristics of your watershed affect water quality?
  - How would you identify specific pollution problems?

2.1.1 Overview

- Designing a monitoring program to assess response to NPS control programs requires a thorough understanding of the system.
- Questions that should be addressed during this step:
  - What are the critical water quality impairments or threats?
  - What are the key pollutants involved?
  - What are the sources of these pollutants?

  - How are pollutants transported through the watershed?
  - What are the most important drivers of pollutant generation and delivery?
  - What are the areas that are ecologically or culturally significant, or critical, to your community?

For more information, go to guidebook page 2-4.

2.1.2 Understand the System

- Monitoring design influences:
  - 2.1.2.1 Causes and sources of pollution
  - 2.1.2.2 Pollutant transport
  - 2.1.2.3 Seasonality
  - 2.1.2.4 Water resource types
  - 2.1.2.5 Climate
  - 2.1.2.6 Soils, geology and topography

For more information, go to guidebook page 2-4.

2.1.2.1 Causes and Sources of Pollution

- What, where and when should you sample?
- Knowing the pollution source(s) allows you to apply the correct pollution control measures and to monitor the watershed's response.

2.1.2.2 Pollutant Transport Considerations

- How are pollutants transported from the source to the receiving water?
  - Particulate pollutants (e.g., sediment) generally move in surface waters.
  - Dissolved pollutants (e.g., nitrate-nitrogen) can be transported in both surface and ground waters.
- The distinct pollutant pathways need to be understood to decide where and when to sample. (There might be pollutant sources upstream of your watershed.)
- The timing of sampling during storm events can also be informed by knowledge of pollutant pathways.
- Monitoring for sediment or particulate phosphorus is often best focused on surface runoff and streamflow.
- In many cases, additional details regarding pollutant pathways must be understood to fine-tune monitoring plans.
  - Example: Monitoring decisions require an understanding of how pollutants move through the system, such as whether to focus on high-flow events (e.g., for particulate pollutants delivered episodically in surface runoff or storm flows) or base flows (e.g., for dissolved pollutants that tend to be delivered continuously via groundwater).
- The timing of sampling during storm events can also be informed by knowledge of pollutant pathways.

For more information, go to guidebook page 2-5.

Agricultural runoff (photo by NRCS)

Field irrigation (photo by NRCS)

2.1.2.3 Seasonality Considerations

- Seasonal patterns like snowmelt, rainfall, drought and humidity are often critical factors in monitoring design because NPS pollution is highly weather-driven.
  - In northern regions, snowmelt and spring rains are often the dominant hydrologic feature of the annual cycle, and most of the annual pollutant load could be delivered in a few weeks.
- In cases where available water quality data are not sufficient to assess seasonality in a specific watershed, it might be necessary to perform seasonal synoptic surveys, collect year-round samples initially, or rely on watershed modeling to better define seasonality and facilitate fine-tuning of the monitoring design.
- Examples of seasonality:
  - Seasonality Considerations—Example 1:
    - February accounted for 23% of the total phosphorus (P) load in a 2-year study in the Clear Lake watershed in Iowa, indicating that the snowmelt period is a time of significant P loss from fields (Klatt et al. 2003).

Iowa winter (photo by NRCS)

- Seasonality Considerations—Example 2:
  - A 7-year study on corn-cropped watersheds in southwestern Iowa showed that most of the average annual total nitrogen and phosphorus losses occurred during the fertilizer application, seedbed preparation and crop establishment period from April through June (Alberts et al. 1978).

Iowa cornfield (photo by Lynn Betts, NRCS)

- Seasonality Considerations—Example 3:
  - For herbicides such as atrazine, losses from agricultural fields in humid areas are highly episodic, with most of annual losses occurring in transient storm events soon after herbicide application.
  - A significant portion of the load of some pesticide degradation products, however, can be transported under base-flow conditions in humid environments.
    - Here, a monitoring effort would need to reliably monitor short, intense and unpredictable events during specific seasons (depending on seasonal & agronomic factors).
    - Sampling of base flow would be needed to track degradation products.

For more information, go to guidebook page 2-6.

Pesticide application (photo by C. Loper, USGS)

2.1.2.4 Water Resource Considerations

Waterbody type	Waterbody-specific considerations
Rivers and streams	Spatial flow patterns Variability Sampling selection
Lakes, reservoirs and ponds	Stratification Shape Flow patterns
Wetlands	Variability Strategies and tools
Estuaries	Dynamics Variability
Coastal nearshore waters	Dynamics Variability
Groundwater	Variability Sampling options

For more information, go to guidebook page 2-7.

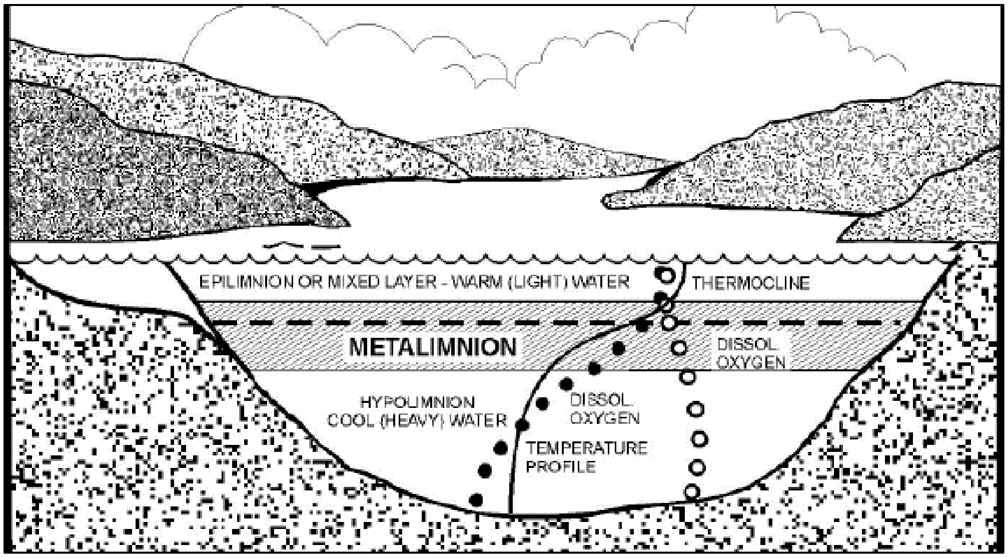
Water resource examples (photos by USEPA)

2.1.2.4.1 Rivers and Streams

- **Spatial Flow Patterns**
  - Accurate flow measurement is essential to estimating pollutant loads. Therefore, it's important to understand spatial flow patterns in the monitored stream or river.
    - Streams can be perennial or intermittent.
    - Water velocity varies horizontally and vertically.
    - Tributaries can add pollutant loads, dilute pollutant loads and create horizontal gradients.
    - Suspended solids, dissolved oxygen and algal productivity can vary with depth.
- **Variability**
  - Vertical variability is particularly important during runoff events and in slow-moving streams because pollutants can vary substantially with depth (Brakensiek et al. 1979).
  - Contaminant levels in bed sediment vary horizontally and vertically, as deposition and scouring are strongly influenced by water velocity.
  - Biological communities in stream systems vary with many factors, including landscape position, type of substrate, light, water temperature, current velocity, and amount and type of aquatic and riparian vegetation.
- **Sampling Selection**
  - If a representative sample of a river is required, it is important to select a sampling point where the flow is uniform and well-mixed, without sharp flow variations or distinct tributary inflow plumes.
  - If more detail is required, segmentation of a stream into fairly homogeneous segments before monitoring might be necessary, with one to several monitoring stations located in each segment (Coffey et al. 1993).

2.1.2.4.2 Lakes, Reservoirs, and Ponds

- Stratification
  - The physical, chemical and biological characteristics of lakes vary horizontally, vertically, seasonally and throughout the day.
  - These characteristics are strongly determined by hydrology and geomorphology (Wetzel 1975).



Thermally stratified lake in mid-summer (image by USEPA 1990)

- **Shape**
  - Lake shape has major implications for monitoring design.
    - Simple, rounded shapes tend to be well-mixed at most times and might require only a single sampling station to provide an accurate representation of water quality.
    - Complex interconnected basins or dendritic shapes (e.g., reservoirs) tend to exhibit significant spatial variability as mixing is inhibited; such lakes may require numerous sampling stations to represent the more uneven water quality characteristics.
- **Flow**
  - Vertical variability can affect water quality and consequently monitoring design choices.
    - Uniformly shallow lakes tend to be well-mixed vertically and have extensive photic zones, yielding a fairly homogeneous water column that can be effectively sampled at a single depth.
    - Deeper lakes tend to stratify seasonally because of the temperature-density properties of water.
    - Monitoring at different points with depth during periods of peak stratification is sometimes appropriate. Other times, sampling during the periods when the water column is completely mixed (e.g., at spring or fall turnover) may yield information on the general character of the lake for that year.
  - Tributary inflows and effluent discharge points contribute to horizontal variations in water quality.
    - Localized inputs of large water or pollutant loads can influence localized water quality. Currents influence the dispersal of pollutants.

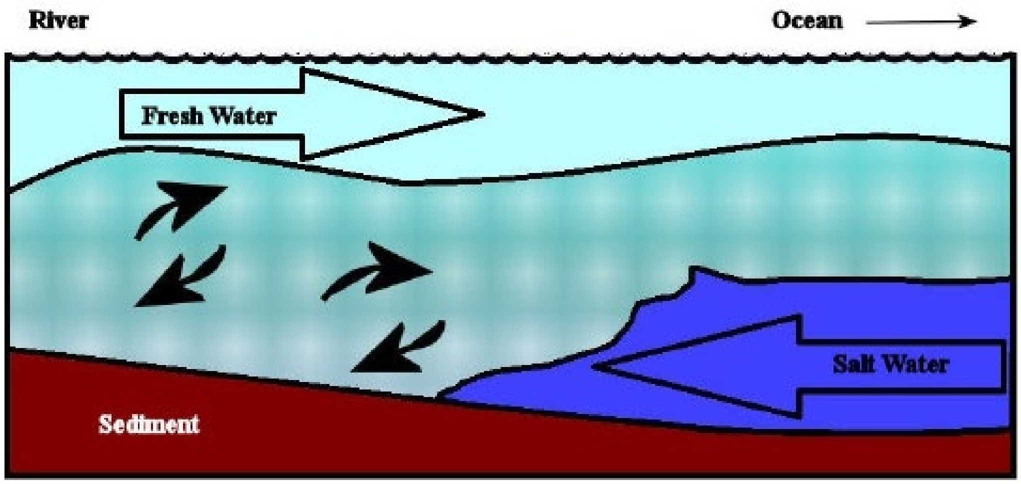
        - Locations of such discharges are key factors in placing monitoring stations—either to deliberately sample them to represent important localized impairments or distinct components of total lake inputs, or to deliberately avoid them as unrepresentative of the broad lake, depending on program objectives.
    - Sediment/water interactions exert strong controls on some pollutant dynamics.

2.1.2.4.3 Wetlands

- **Variability**
    - Due to the diversity among natural wetlands, a wetland monitoring program must be based on a specific wetland's attributes.
    - Key consideration for wetlands monitoring: define the assessment area (i.e., is it the entire wetland or just a portion?)
    - Wetlands cycle sediments, nutrients and other pollutants vary actively among physical (e.g., sediment), chemical (e.g., water column) and biological (e.g., vegetation) compartments.
    - Vegetation is a key element of wetland systems (seasonality of vegetation growth and senescence may be an important driver for nutrient cycling) and therefore important for monitoring design (USEPA 2002).
- **Strategies and Tools**
    - Strategies for designing an effective monitoring program build from a hierarchy of three levels that vary in intensity and scale:
        - Level 1: Broad, landscape-scale assessments.
        - Level 2: Rapid field methods.
        - Level 3: Intensive biological and physio-chemical measures (USEPA 2004).
    - Rapid assessment procedures are sensitive tools to assess anthropogenic impacts to wetland ecosystems; they can be used to:
        - Evaluate best management practices.
        - Assess restoration and mitigation projects.
        - Prioritize wetland-related resource management decisions.
        - Establish aquatic life use standards for wetlands.

2.1.2.4.4 Estuaries

- **Dynamics**
    - Estuaries differ from freshwater bodies largely due to the mixing of fresh water with salt water and the influence of tides on the spatial and temporal variability of chemical, physical, and biological characteristics.
        - Incoming tides push salt water shoreward.
        - Outgoing tides pull water toward the ocean and freshwater fills the gap left by the receding submerged salt water.
        - Because of the dynamic interaction of fresh water and salt water, pollutants in the water and sediment remain in the estuary for a long time.



Mixing of salt and fresh water in an estuary (Chesapeake Bay Program 1995)

- **Variability**
  - Basin shape, mouth width, depth, area, tidal range, surrounding topography and regional climate all help to determine the nature of an estuary.
  - The earth's rotation, barometric pressure and bathymetry affect circulation and spatial variability.
  - Freshwater inflow is a major determinant of the physical, chemical and biological characteristics.
    - Freshwater inputs can vary seasonally and affect the concentration and retention of pollutants, the distribution of salinity, and the stratification of fresh water and salt water.
  - Temporal variability is also influenced by factors other than freshwater inputs.
    - Temperature profiles vary seasonally
    - Tidal cycles can affect the mixing of fresh and salt waters and the position of the fresh water-salt water interface.

2.1.2.4.5 Coastal Nearshore Waters

- **Dynamics**
  - Nearshore waters include an indefinite zone extending away from shore, beyond the breaker zone; the term applies to both coastal waters and large freshwater bodies such as the Great Lakes.
  - The interplay of wind, waves, currents, tides, upwelling, tributaries and human activities influence water quality and monitoring requirements.
    - Wind and tides are the primary sources of energy.
    - Waves play a central role in the transport and deposition of coastal sediments as well as the dispersion of pollutants and nutrients.
- **Variability**
  - Upwelling brings cold, nutrient-rich waters to the surface, encouraging biological growth.
    - Extremely variable in space and time, depending on winds and topography.

- Tributaries introduce fresh water and can alter nearshore currents depending on tide stage, wind conditions, and flow rate.
    - Headlands, breakwaters, and piers can affect the circulation pattern and alter the direction of nearshore currents.
    - Current patterns must be sufficiently understood to determine the best locations for monitoring and to establish pollutant pathways and the likely relationships between land-based activities and nearshore water quality.
    - Because circulation and pollutant transport is so variable in nearshore areas, designing monitoring plans based on assumptions about current patterns is not recommended.
    - The current system drives the relationship between land-based pollutant sources and receiving water quality.
        - Monitoring should include provisions to track variables needed to characterize the current enough to aid interpretation of other chemical, biological, and physical data that are generated.
        - Basic data on salinity, water temperature, and depth are often essential to identifying the source of the sampled water and characterizing current patterns.

2.1.2.4.6 Groundwater

- **Variability**
    - Occurs in either confined or unconfined aquifers.
    - Water quality is influenced by aquifer type, native geology, precipitation patterns, flow patterns, land use, pollutant sources, and pollutant characteristics.
    - The interaction of surface water and groundwater can be considered from the perspective of:
        - Surface water recharging groundwater, which is important when determining the impact of surface water on a groundwater resource.
        - Groundwater discharging to a stream or lake, which should be a key element of monitoring when groundwater comprises a significant portion of the water or contaminant budget of a surface water body.
    - Karst systems (a geologic condition shaped by the dissolution of channels or layers of soluble bedrock due to the movement of water) present special challenges because sources of aquifer contamination may be widely dispersed and difficult to map.
- **Sampling**
    - Regional or statewide groundwater level recording and water quality monitoring networks are common across the nation, especially in areas where groundwater is a primary source of drinking and irrigation water.
        - These networks often detect contaminants via well monitoring and model contaminant transport based on groundwater level data.
        - Watershed-level monitoring of groundwater is still relatively rare.

- Successful monitoring design begins with an understanding of the groundwater system and the establishment of specific monitoring objectives.
- Monitoring often requires a two-stage approach:
  - First stage is a hydrogeologic survey.
  - Second stage is an investigation of water quality.

Artesian well in Sycamore Valley, MO (photo by J. Baughn, USGS)

2.1.2.5 Climate Considerations

- What is the expected range of climate conditions? Note: Climate change is discussed in future sections
- The frequency, intensity and duration of runoff-producing storm events affect:
  - Sampling frequency and duration
  - Equipment selection
  - Automatic sampler programming
  - Many other elements of a monitoring program

For more information, go to guidebook page 2-21.

Photo by USEPA

Photo by USEPA

Photo by Tetra Tech

2.1.2.6 Soils, Geology and Topography

- What are the soil and substrate like? Is the area flat or sloped?
- Soil, geology, and topography influence the hydrologic budget, pollution sources and loading, and other factors that drive monitoring program design.
  - Soil groups affect runoff and pollutant yields.
  - Geomorphology and substrate geology determine riparian zone function and pollutant delivery to nearby waters.
  - Slope must be factored into the monitoring design:
    - Height and slope length affect (1) the rate and duration of runoff from a watershed, (2) rate of erosion, (3) depth of soil, and (4) stream characteristics.
    - Slope influences the likelihood of landslides and debris flow, erosional processes and weathering rates.

For more information, go to guidebook page 2-22.

Soil types may vary across the landscape (photos by NRCS)

2.1.3 Identify Problem(s)—Summary

- Have you completed the following?
    - Identified the critical water quality impairments or threats
    - Identified the key pollutants
    - Identified the sources of the key pollutants
    - Identified methods of pollutant transport
    - Identified the most important drivers of pollutant generation and delivery

2.2 Form Objectives

- Formulating clear monitoring objectives is an essential first step in developing an efficient and effective monitoring plan.
- Considerations:
    - What questions do you want to answer?
    - How do your objectives fit into your overall program?

2.2.1 Overview

- Well-formulated monitoring objectives drive the rest of the monitoring study design and are critical to a successful monitoring project.
- NPS monitoring data can be used to:
    - Identify water quality problems, use impairments and causes, and pollutant sources
    - Develop TMDLs and load or wasteload allocations
    - Analyze trends

- Assess the effectiveness of BMPs or watershed projects
    - Assess permit compliance
    - Validate or calibrate models
    - Conduct research

2.2.2 Monitoring Objectives

- Questions that a monitoring program can answer:
    - Has a waterbody's condition changed over time?
    - Is there an emerging problem area that needs additional regulatory and/or nonregulatory actions to support water quality management decisions?
- Example**:** Little Miami River, Ohio
    - Each year Ohio EPA (OEPA 2021) collects data from streams and rivers in five to seven different areas of the state. About 400–450 sampling sites are examined, and each site is visited more than once per year.
    - During these studies, technicians collect chemical samples, examine and count fish and aquatic insects, and take measurements of the stream.
    - There are three major objectives for the studies:
    - Determine how the stream is doing compared to goals assigned in the Ohio Water Quality standards;
    - Determine if the goals assigned to the river or stream are appropriate and attainable; and
    - Determine if the stream's condition has changed since the last time the stream was monitored.

Little Miami River, OH (photo by Ohio EPA)

2.2.3 Program Objectives

- All monitoring programs should be designed to answer questions.
- Monitoring objectives should be directly linked to overall program or project objectives.
- Note: You might need to adapt monitoring objectives based on available resources.
- Program objectives should be linked to management decisions/actions.
- At the start of the project, ensure necessary resources are available.

Example program objective	Complementary monitoring objective
Reduce annual phosphorus loading to the lake by at least 15% in 5 years using nutrient management.	Measure changes in annual phosphorus loading to the lake and link the changes to management actions.
Reduce *E. coli* load to stream to meet water quality standards within 3 years.	Measure changes in compliance with water quality standards for *E. coli.*

2.2.4 Form Objectives—Summary

- Have you formed your monitoring objectives?
- Do your monitoring objectives fit into your overall program?

2.3 Design Experiment

- Choose a monitoring design <u>before</u> monitoring begins to ensure you can collect the data needed to best meet your objectives.
- Considerations:
  - Will your design generate the data you need?
  - Is your design financially and technically feasible?

2.3.1 Overview

- Your monitoring objectives will drive decisions about your monitoring program.
  - Several experimental study designs can be applied to meet monitoring objectives, and some of the choices are obvious.
- Select a monitoring design that:
  - Best matches available resources.
  - Presents the fewest logistical obstacles.

2.3.2 Monitoring Design as a Function of Objective

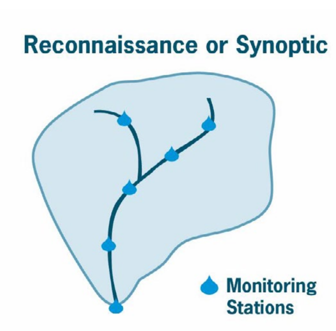
For more information, go to guidebook page 2-44.

Design options	Short description	Objectives			
		Problem assessment	TMDL loads	Trends	BMP effectiveness
Reconnaissance/ synoptic	Multiple sites distributed across study area; monitored for short duration (<12 months)	X			
Plot	Traditional research study design; BMPs replicated in randomized block design				X
Paired	Treatment and control watersheds monitored during control and treatment periods		X		X
Single watershed before/after	Single station at study area outlet monitored before and after BMP implementation		X	X	
Single-station long-term trend	Single station at study area outlet monitored before and after BMP implementation		X	X	
Above/below	Stations with paired sampling upstream and downstream of BMP(s)	X	X		X
Side-by-side	Same as single watershed because there are no calibrating paired samples		X	X	
Multiple	Multiple watersheds monitored in two or more groups: treatment and control				X
Input/output	Stations located at input and output of BMP				X

2.3.2.1 Reconnaissance or Synoptic Design

- Use to:
  - Determine magnitude and extent of problem.
  - Target critical areas.
  - Obtain preliminary data where none exist.

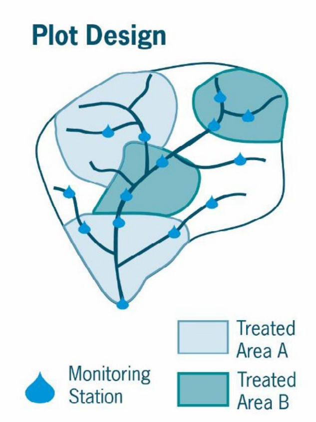
For more information, go to guidebook page 2-34.



2.3.2.2 Plot Design

- Use to:
    - Assess soil conditions, including nutrient levels.
    - Assess pollutant transport pathways.
    - Determine the effects of BMPs on pollutant transport.

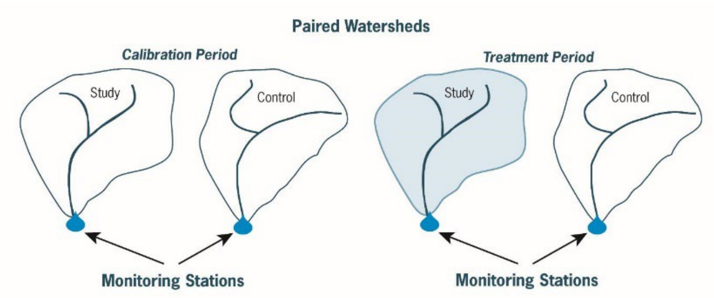
For more information, go to guidebook page 2-35.



2.3.2.3 Paired Design

- Use to compare data from two watersheds (treatment and control)

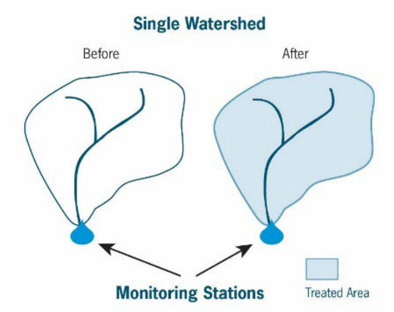
For more information, go to guidebook page 2-36.



2.3.2.4 Single Watershed Before/After Design

- Use to measure pollutant loads before and after implementation of the TMDL.
    - A single monitoring station is located at the outlet of the study area.
    - Sampling is performed before and after BMP implementation.
    - This design is not recommended for BMP effectiveness studies because:
    - There are no control stations (as in the paired design described earlier).
    - BMP effectiveness cannot easily be distinguished from other confounding effects (USDA-NRCS 2003). Example: If the “before” years are relatively dry and the “after” years are relatively wet, the differences in water quality and loads could be due to differences in weather rather than the effects of implemented BMPs.

For more information, go to guidebook page 2-38.



2.3.2.5 Single Station Long-Term Trend Design

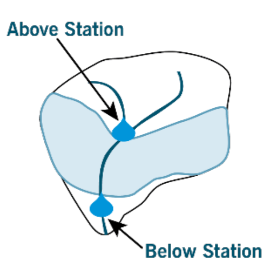
- Use to determine changes in water quality or pollutant loads over time.
  - Advantages:
    - Single monitoring station
    - Wide applicability
    - Ability to account for lengthy lag times
  - Challenges:
    - Requires a long duration

For more information, go to guidebook page 2-39.

2.3.2.6 Above/Below Design

- Use to compare data from above and below treatment area.
  - Design stations are located upstream (or upgradient) and downstream (or down-gradient) of the area or source that will be treated with BMPs.

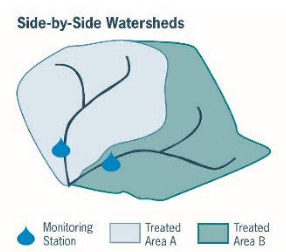
For more information, go to guidebook page 2-39.



2.3.2.7 Side-By-Side Before/After Design

- Use to monitor adjacent watersheds without calibrating paired samples before treatment.
  - Not recommended for evaluating BMPs or watershed projects
  - Very likely you'll be unable to distinguish among causal factors such as BMPs or land treatment, inherent watershed differences, or an interaction between BMPs and watershed differences.

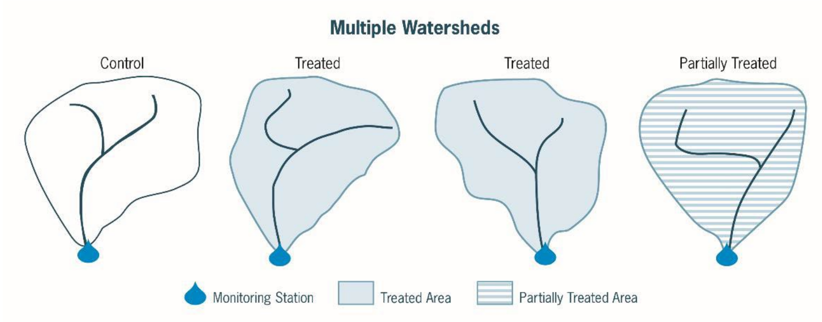
For more information, go to guidebook page 2-41.



2.3.2.8 Multiple Watersheds Design

- Use to estimate the variability in a large group of watersheds
  - Requires that more than two watersheds are selected for monitoring within geographic area of interest.
  - Two different treatments, and sometimes a control, are replicated across the monitored watersheds in roughly equal numbers.
- Challenges:
  - Often not a practical choice
  - Several years of monitoring is often necessary
  - Cost can be high
- Example: Multiple watersheds
  - Lewis (2006) describes a multiple-watershed approach in which:
    - Three of 13 watersheds are used as controls
    - Five are fully treated
    - Five are partially treated
  - He argues that this design has a significant advantage over paired-watershed studies in that it allows for prediction under different conditions or treatment levels, whereas prediction based on paired-watershed study results requires the assumed treatments are identical to the treatments used in the study.

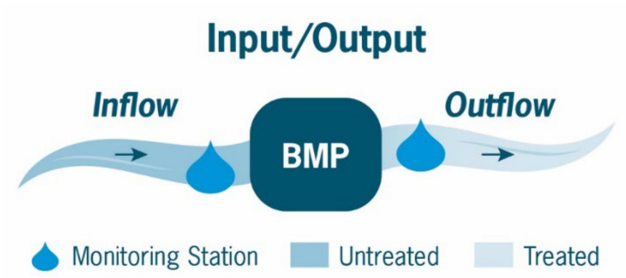
For more information, go to guidebook page 2-41.



2.3.2.9 Input/Output Design

- Use to compare data from before and after water moves through a BMP.

For more information, go to guidebook page 2-41.



2.3.3 Critical Areas

- Data collected in the problem assessment phase can be used to help define **critical source areas** for pollutants—this is key to understanding the watershed, prioritizing land treatment, and evaluating project effectiveness. A critical source area is defined as an area within a watershed that can contribute a disproportionately large amount of pollution. Generally located where high-magnitude pollutant sources (e.g., eroding hillsides) overlap or interact with land areas that have a high pollutant transport potential (e.g., areas prone to generating high volumes of runoff).
- Example: With concurrent data from monitored subwatersheds or tributaries, you can use statistical tests to identify significant differences in pollutant concentration or load among multiple sampling points. These data can be displayed graphically in a map to show watershed regions that could be major contributors of pollutants.

For more information, go to guidebook page 7-42.

2.3.4 Design Experiment—Summary

- Have you selected a design for your experiment?
  - **Reconnaissance** is best for the assessment phase of a watershed project.
  - **Above/below monitoring** can help provide information about an isolated source or area.

- **Paired, above/below-before/after, plot** and **input/output designs** are generally best for evaluating the effectiveness of BMPs or watershed projects.
- The **paired, single watershed before/after, single-station long-term trend, above/below, side-by-side and multiple study designs** can provide useful load estimation in support of TMDLs if flow and relevant variables are monitored.
- **Single-station long-term trend design** is often used for trend detection at certain points in time.

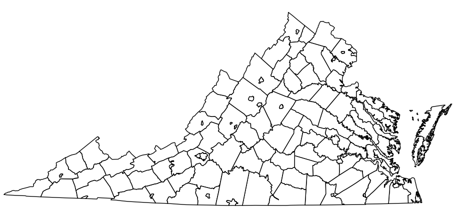
2.4 Select Scale

- Determine the size of the area you will monitor.
- Considerations:
  - What are the objectives of your study?
  - What resources are available to you?
  - What is your timeframe?

2.4.1 Overview

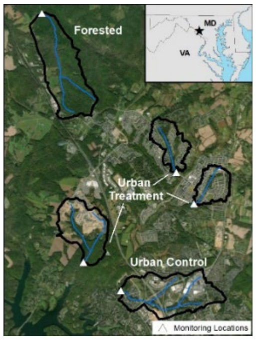
- The choice of scale affects monitoring costs, duration and logistics.
- Questions to address during this step:
  - What is the study duration?
  - What type of water resource will be monitored?
  - How complex is the project?
  - What are the available resources?

2.4.2 Options for Scale Selection



Statewide or regional

Watershed



BMP or practice

Note: The ability to isolate the factors of interest (e.g., BMP effectiveness, transport pathways) generally increases as scale decreases, but the transferability of results generally decreases as scale decreases.

For more information, go to guidebook page 2-29.

2.4.3 Summary of Scale Options

Choosing monitoring scale as a function of objective:

	Objective				
Monitoring scale	**Problem assessment**	**TMDL loads**	**Trends**	**BMP effectiveness**	**Watershed project evaluation**
Statewide/regional	X				
Watershed	X	X	X		X
BMP: Plot				X	
BMP: Field	X	X		X	

Note: Monitoring can be performed at scales ranging from national to single points, but the primary options for the types of NPS monitoring studies addressed in detail by USEPA's guidebook are the watershed and BMP scales, the latter of which includes plot-scale and field-scale studies.

For more information, go to guidebook page 2-29.

2.4.3.1 Statewide or Regional-Scale Monitoring

- A statewide or regional-scale study generally emphasizes larger streams and rivers, public lakes and watershed outlets.
- Studies are typically designed to assess current conditions.
- Monitoring is often done near USGS gauging sites to take advantage of flow data.

- Cost and logistical constraints limit most monitoring efforts to the collection of grab samples, a few field measurements (e.g., temperature, dissolved oxygen, conductivity), and biological and habitat monitoring.
- Monitoring frequencies are generally low.
- Trend analysis is difficult to perform.

For more information, go to guidebook page 2-29.

2.4.3.2 Watershed-Scale Monitoring

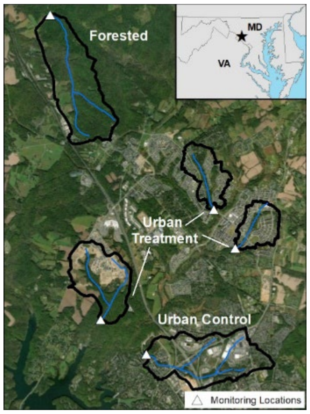
- A key difference between watershed- and state-level monitoring is the narrowing of focus and increased intensity of watershed-level monitoring.
- Important questions to ask include:
  - What are the study's specific objectives?
  - What is the size of the watershed?
  - What are the parameters of concern?
- ***Initial efforts*** generally focus on refining the problem definition, including:
  - Better characterizing the water quality problem
  - Determining the major sources and causes of the problem
  - Providing data to help design a plan to solve the problems
- ***Monitoring*** during the pre-implementation phase of a watershed project may include:
  - A synoptic survey (see guidebook p. 2-34)
  - Tests for toxicity (see guidebook p. 3-84)
  - Flow measurements to support a load analysis (guidebook p. 3-10)
  - Detailed habitat assessments (see guidebook p. 3-27)

For more information, go to guidebook page 2-29.

2.4.3.3 BMP- or Practice-Scale Monitoring

- Monitoring at this scale:
  - Is typically the most intensive type.
  - Ranges from plot-scale monitoring to larger, field-scale monitoring.
- Questions to ask:
  - What type of BMP is being used?
  - What specific sources are being treated by the BMP?
  - Is the monitoring only storm-event driven or does base flow need to be considered?
  - Is adequate funding available to support the higher cost of monitoring at the BMP/practice scale?

For more information, go to guidebook page 2-31.



Clarksburg monitoring study: watershed types (image by USGS)

2.4.3.3.1 Plot-Scale Monitoring

- Generally used in designs that feature replication (e.g., to meet research objectives).
- Can be used for preliminary assessment of BMP effectiveness.
- Focuses on storm events and generally requires:
  - Automatic samplers
  - Continuous flow measurement
  - Considerable annual expense

2.4.3.3.2 Field-Scale Monitoring

- Samples are taken from episodic runoff rather than from waterbodies.
- Study units are larger than individual plots but vary in size, such as:
  - Parking lots
  - Rooftops
  - Street segments
  - Cropland segments
  - Paddocks
  - Barnyards

2.4.4 Selecting Scale—Summary

- Have you selected the scale of your monitoring project that best meets your project objectives?
- Does the scale meet your budget and logistical constraints?
  - Statewide or regional
  - Watershed
  - BMP or practice
    - Plot
    - Field

2.5 Determine Sampling Frequency

- Determine how often to collect samples and determine the duration of your sampling program.
- Considerations:
    - What types of waterbodies are involved?
    - What variables need to be measured?
    - What is the system's variability?
    - What is your budget?

2.5.1 Overview

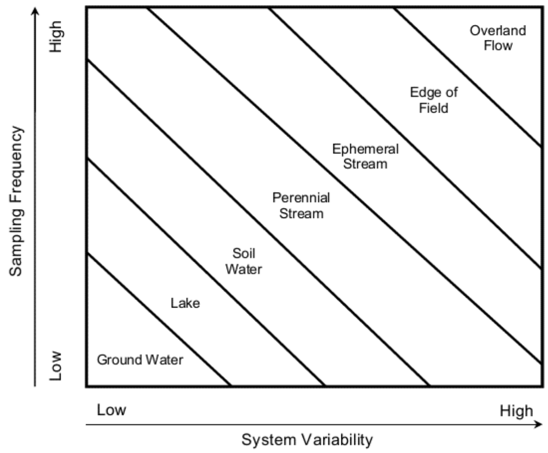
- This section covers two critical questions:
    - How often to collect samples (what is the sampling frequency or interval between samples)?
    - How long to conduct a sampling program (what is the sampling duration)?
- Decisions will depend on program objectives, type of water body involved, variables measured and available budget.
- Sampling frequency must be relatively high (e.g., daily to weekly) to evaluate effectiveness of a single BMP or to document the mechanisms controlling water quality at a particular site.
- A program with an objective of detecting a long-term trend or evaluating watershed program effectiveness can accept longer intervals (e.g., weekly to monthly) between samples.

For more information, go to guidebook page 3-43.

2.5.2 Selecting a Sampling Interval

- This schematic of sampling frequency as a function of system type offers a general guide to the relationship between system variability and sampling interval.

For more information, go to guidebook page 3-43.



(Source: USDA-NRCS 2003)

2.5.3 Calculating the Appropriate Frequency

- Calculating the appropriate sampling frequency varies with the statistical objective for the monitoring data and sampling regime.
- The following slides provide examples of how sampling frequency in the context of simple random sampling can be calculated for estimating the mean and detecting trends.

For more information, go to guidebook page 3-43.

2.5.4 Estimating the Mean

- **Estimating the Mean**—A common monitoring objective is to be able to estimate the mean value of a water quality variable (with a specific level of confidence).
- You can calculate the necessary sample size using this equation:

$$n = \frac{t^2 s^2}{d^2}$$

where:
n = the calculated sample size
t = Student's t at n-1 degrees of freedom and a specified confidence level
s = estimate of the sample standard deviation
d = acceptable difference of the estimate from the estimate of the true mean, or ½ of the confidence interval from the mean

For more information, go to guidebook page 3-44.

2.5.5 Detecting a Change or Trend

- Another common monitoring objective is to detect a change or trend in the value of a water quality variable (with a specific level of confidence).
- Two types of change can occur in the water quality variable being studied:
    - A ***step change*** that compares the pre- and post-water quality mean values
    - A ***linear*** (gradual, consistent) trend over time

For more information, go to guidebook page 3-45.

> *Trend analysis can answer questions like: "Are streamflows increasing as urbanization increases?" or "Have nutrient loads decreased since the TMDL was implemented?"*

2.5.5.1 Detecting a Step Change

- To determine the sample size needed to detect a ***step change***, the detectable change must first be calculated based on the standard deviation of the difference between the pre- and post-mean values with an anticipated number of samples.
    - See guidebook p. 3-50 for an example calculation
- The sample size needed to detect a step change difference of acceptable magnitude can be estimated using an iterative process of trying different pre- and post-sample sizes.

2.5.5.2 Detecting a Linear Change

- Monitoring for trend detection must be sensitive enough to detect the level of water quality change likely to occur in response to management changes.
- For a ***linear trend***, this monitoring is based on the confidence interval on the standard deviation of the slope.
    - For equations and calculations, see guidebook p. 3-45.
- Calculate sample size interactively by trying various sample frequencies and durations until your monitoring approach would be able to detect the amount of change expected by implementing BMPs.

2.5.6 Minimum Detectable Change (MDC)

- **MDC**—the minimum change in a pollutant concentration (or load) during a given time period required for the change to be considered statistically significant.
- You can use the MDC to:
  - Estimate the required sampling frequency based on the anticipated change in pollutant concentration or load.
  - Estimate the change in pollutant concentration or load needed for detection with a monitoring design at a specified sampling frequency.

For more information, go to guidebook page 3-47.

Minimum detectable change analysis can answer questions like: "How much change must be measured in a water resource to be considered statistically significant?"
or
"Is the proposed monitoring plan sufficient to detect the change in concentration expected from BMP implementation?"

2.5.7 Sampling Duration

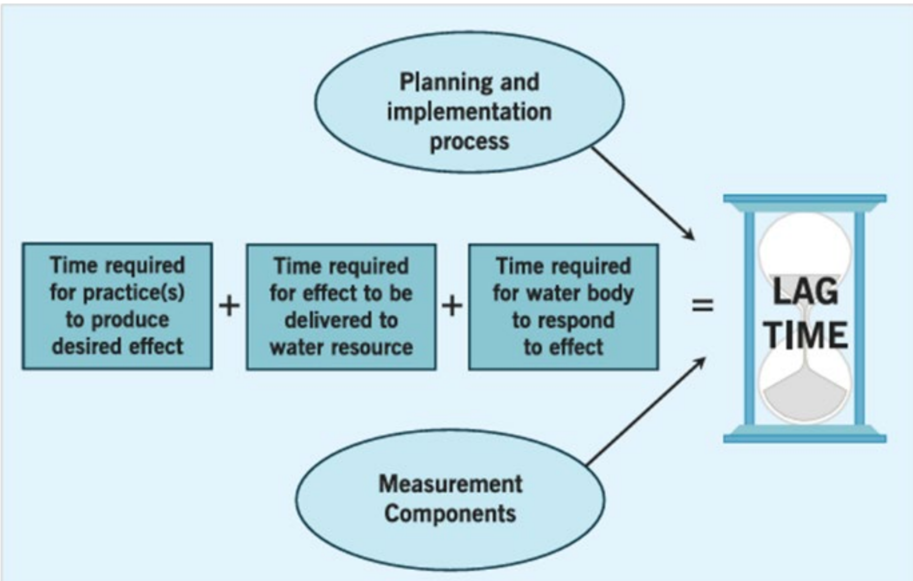
- A monitoring program should be conducted long enough to achieve objectives or document a change.
- Basic guidelines for choosing a sampling duration include:
  - Capture at least one full cycle of natural or cultural variability (e.g., weather, construction management)
  - Use statistical tests to evaluate a monitoring period's adequacy
  - Consider the lag time

For more information, go to guidebook page 3-56.

2.5.8 Lag Time

- Lag time—the time elapsed between when you install/adopt management measures at the level projected to reduce NPS pollution and when you see the first measurable improvement in water quality in the target waterbody.

- Knowledge of key lag time factors can help determine the required duration of a monitoring program.
  - **Example 1:** If groundwater travel time from an agricultural field through a riparian forest buffer to a stream is known to be 5 to 10 years, it's reasonable to expect to continue monitoring at least that long.
  - **Example 2:** A lake with a flushing rate of 1.5 years might respond much more quickly to changes in pollutant inputs, so a shorter monitoring program could suffice.
- Components of lag time experienced in land treatment/water quality projects:



For more information, go to guidebook page 6-4.

2.5.9 Overcoming Limited Resources

- Financial resources should not be the primary basis for deciding on sampling frequency.
- To achieve desired objectives when resources are limited, determine whether you can:
  - Reduce the list of variables analyzed
  - Reduce the number of stations
  - Use less expensive surrogate variables
  - Simplify field instrumentation
  - Take composite samples
- *Reminder:* When developing your monitoring program objectives, ensure that necessary resources are available.

2.5.10 Determine Sampling Frequency—Summary

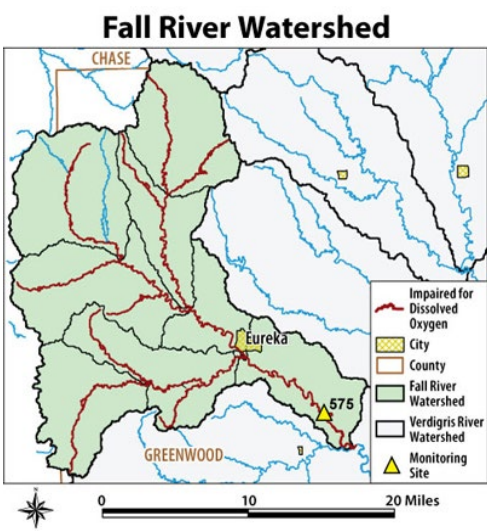
- Have you determined the variability of your system?
- Have you chosen your sampling frequency?
- Have you chosen the duration of your project?
- Have you factored in lag time?
- Do you have the necessary resources?

2.6 Locate Stations

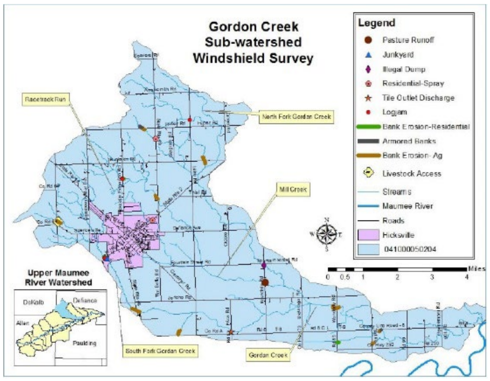
- Choose the specific locations where you will collect samples.
- Considerations:
  - What is the waterbody type?
  - Will samples represent the conditions being monitored?
  - Are there logistical constraints?

2.6.1 Overview

- Monitoring station locations must be determined at two distinct scales:
  - **Macro-scale—**sampling locations are determined by:
    - Experimental design and monitoring objectives
    - Waterbody type
  - **Micro-scale—**sampling locations are determined by:
    - Site accessibility
    - Physical configuration



(Image from USEPA 2012)

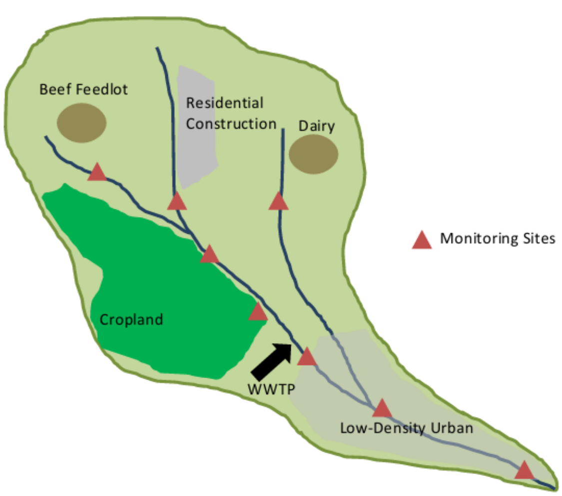


(Image from Dressing 2018)

2.6.2 Macro-Scale Factors: Design and Objectives

- Reminder—Monitoring design and objectives will control station location and can differ depending on waterbody type. (For more information, refer to the Monitoring Design as a Function of Objective section).
  - **Reconnaissance or synoptic**: Needs many stations located in places that can isolate particular drainage areas or NPS pollutant source areas (an example is provided below).
  - **Single watershed or trend**: Requires that a station be located at a watershed outlet to represent the entire drainage area.
  - **Above/below or input/output**: Calls for two or more stations to bracket a treated area or BMP to allow comparison of concentrations or loads entering and leaving the area.
  - **Groundwater monitoring**: Requires an extensive network of monitoring wells to determine flow into and out of the area and to map the aquifer's hydrogeologic properties.

For more information, go to guidebook page 3-38.

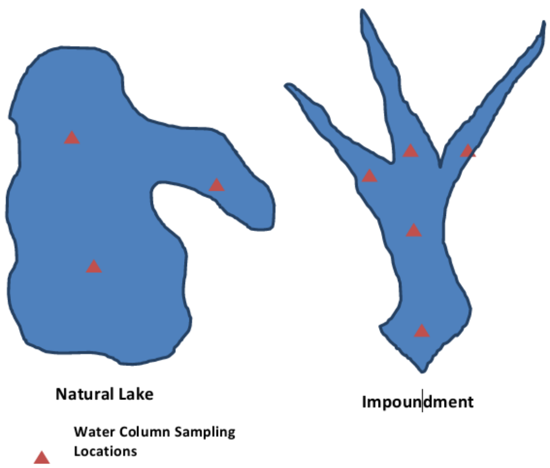


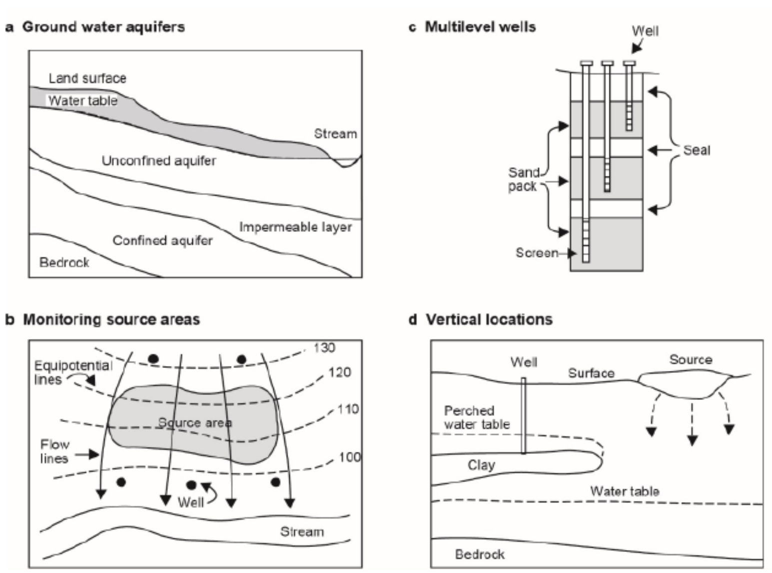
Example macro-scale design: Synoptic – possible sampling locations for a synoptic survey.

2.6.3 Macro-Scale Factor: Waterbody Type

- On ***streams or rivers***, station locations might be selected to capture or avoid the effects of tributary streams, to isolate subcatchments, or to focus on areas with particular characteristics.
- In ***lakes and reservoirs***, monitoring stations at each major tributary discharge might be required to measure load for a TMDL. Lake morphology, vertical stratification, and currents might require samples in several lake regions and/or at several depths.
- For ***groundwater systems***, the location of stations is determined by aquifer type and by vertical, horizontal, and longitudinal variability in both water quality and water quantity.

For more information, go to guidebook page 3-38.





(Images from USDA 2003)

2.6.4 Micro-Scale Factors: General

- Site should be representative of the conditions being monitored.
  - What type of flow are you measuring?
  - Are you collecting biological measurements?
- Consider site accessibility and physical configuration. Site should:
  - Be easily accessible
  - Be safe for field staff
  - Have available power and communication links
  - Have permission granted from property owners and state or local transportation agency
  - Be secure from both human interference and natural threats (e.g., flooding)

For more information, go to guidebook page 3-41.

2.6.5 Micro-Scale Factors: Flow Measurement

- Special consideration for locating stations when flow is measured in an open channel:
  - Want:
    - Select a reach that's unobstructed and straight, has a flat streambed, and is located away from the influence of changes in channel width.
    - Choose an area with a stable cross-section and where depth and velocity measurements can be conducted safely at low flows.
    - Seek an area where a bridge crossing or walkway allows safe velocity measurements at high flows.
    - Look for areas where the stage can be measured and/or recorded continuously (e.g., a protected area for a staff gauge).
  - Avoid:
    - Avoid culverts, waterfalls and bridges where obstructions or degraded structures could cause hydraulic anomalies.
    - Avoid areas that are subject to frequent sediment deposition or severe bank erosion.
- When flow is measured at an edge using a weir or flume, look for sites where:
  - Flow can be collected and/or diverted into the device.
  - Ponding caused by a weir will not cause problems.
  - Any concentrated discharge from a flume can be safely conveyed away downstream.

For more information, go to guidebook page 3-42.

120º V-notch weir, Englesby Brook, Burlington, VT (USEPA 2016)

2.6.5 Micro-Scale Factors: Biological Monitoring

- Several important considerations for locating biomonitoring sites are:
    - Ensure a comparable habitat at each station.
    - Avoid locally modified sites unless project objectives include assessing their effects.
    - Avoid sampling near the mouths of tributaries entering large waterbodies (these will not be representative of the entire waterbody).
    - Include a reference site to provide data on the best attainable biological conditions in a local or regional system of comparable habitat.

For more information, go to guidebook page 3-43.

Field processing of fish sample: taxonomic identification and data recording (USEPA 2016)

2.6.6 Locate Stations—Summary

- Have you selected the location for your monitoring stations based on both the macro-scale and micro-scale?
    - **Macro-scale**: sampling locations must be determined by experimental design, monitoring objectives and waterbody type.

  - **Micro-scale**: sampling locations must be determined by site accessibility and physical configuration.

For more information, go to guidebook page 3-43.

USGS Sampling station (photo by A. McGowan, USGS)

2.7 Choose Sample Type

- Determines the spatial representation of each sample taken at the specific location.
- Considerations:
  - What is the waterbody type?
  - Will samples represent the conditions being monitored?
  - Are there logistical constraints?

2.7.1 Overview

- The goal of collecting water samples is to obtain information representative of the target population for the monitoring effort.
- Questions to ask include:
  - Is monitoring directed only at storm flows?
  - Are base flow conditions important to know?
  - Do you need to estimate pollutant loads?
  - Is monitoring directed at specific conditions that threaten or harm aquatic life?

2.7.2 Basic Types of Samples

- Four basic types of water quality samples:
  - **Grab**—A discrete sample taken at a specific point and time.
  - **Composite**—A series of grab samples collected at different times and mixed together.
    - **Time-weighted**—A fixed volume of sample collected at prescribed time intervals and then mixed together.
    - **Flow-weighted**—A series of samples, each taken after a specified volume of flow has passed the monitoring station, that are then mixed together.

- **Integrated**—Multi-point sampling that accounts for spatial variations in water quality within a water body.
- **Continuous**—Truly continuous or very frequent sequential measurements using electrometric probes.

For more information, go to guidebook page 3-33.

2.7.3 Sample Type as a Function of Monitoring Objective

For more information, go to guidebook page 3-33.

Objective	Monitoring type				
	Grab	Time-weighted composite	Flow-weighted composite	Integrated	Continuous
Problem identification & assessment	X	X	X	X	X
NPS load allocation			X		
Point source wasteload allocation		X	X		
Trend analysis	X	X	X	X	
Assess watershed project effectiveness		X	X		
Assess BMP effectiveness		X	X		
Assess permit compliance	X	X	X		
Validate or calibrate models		X	X	X	
Conduct research		X	X	X	X

2.7.3.1 Grab Samples

- **Definition**—Discrete samples taken at a specific point and time.
  - Give a narrow representation of spatial and temporal variability.
  - Are obtained manually or through automatic samplers using plastic or glass bottles/jars.
  - Are used for wadeable streams, from boats on lakes, or from bridges during high flows.
- **Challenges** of grab samples include:
  - Exact location must be documented.
  - Sample content is significantly influenced by the specific method used.
  - See Isokinetic vs. Nonisokinetic grab sample methods

For more information, go to guidebook page 3-35.

Collecting grab samples (photo by USEPA)

2.7.3.1.1 Grab Samples: Isokinetic vs. Nonisokinetic

- Wilde et al. (2014) define samples for which the velocities of the stream and water entering the sampler intake are the same and different as isokinetic and nonisokinetic, respectively.
- Example: **Isokinetic** vs **nonisokinetic** samples of stream water.
  - Because the suspension of particulate materials depends largely on the stream velocity, an isokinetic sample might have a different and more accurate sediment concentration compared to a nonisokinetic sample.
- Nonisokinetic samplers include the hand-held bottle, the weighted-bottle sampler, the biological oxygen demand (BOD) sampler, and the so-called "thief samplers" such as the Kemmerer and Van Dorn samplers that are often used for lake sampling at specific depths.

2.7.3.2 Composite Samples

- **Definition**—A series of grab samples collected at different times and mixed together (collection is time-weighted or flow-weighted).
  - Usually collected with automatic samplers.
  - ***Time-weighted*** composites are used when flow is not a factor or is constant.
  - ***Flow-weighted*** samples are better for capturing the influence of peak concentrations and peak flows.
- **Challenges** of composite samples include:
  - Collecting flow-weighted samples requires an established stage-discharge relationship, prediction of flow conditions during sample collection, continuous flow measurement, and instantaneous and continuous calculation of flow volume that has passed the sampling station.
  - Combining simple grab samples at a single location will not reflect spatial variability.
  - Sample preservation (acidification, refrigeration) is often required.

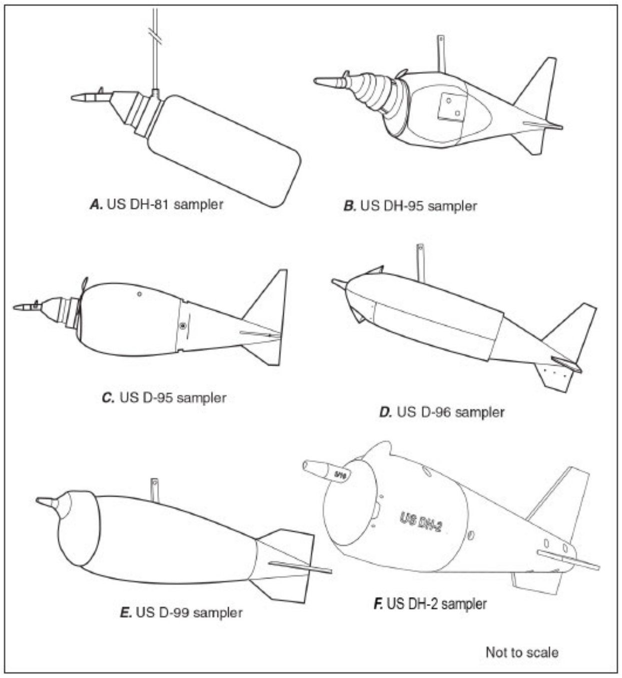
For more information, go to guidebook page 3-35.

2.7.3.3 Integrated Samples

- **Definition**—Multi-point sampling that accounts for spatial variations in water quality within a water body.
- Choose ***integrated samples*** when water quality is known to be ***spatially variable***.
    - Horizontal integration for rivers
    - Vertical integration for lakes
- **Rivers and streams**—Collecting isokinetic, depth-integrated, discharge-weighted samples is standard procedure.
- **Lakes**—Mix grab samples taken from each stratum by obtaining a simultaneous sample of the entire water column with a hose or by automatic devices that collect water at different depths over time.
- Integrated grab samples are a useful sample type for lakes because the temporal variability of lake conditions is generally not as large as that found in streams.
- Grab samples at various lake depths can provide additional information not captured by integrated grab samples.
- Combining seasonal, integrated and simple grab samples taken at representative depths is a preferred approach for problem assessment and trend analysis for lakes and other still water bodies.
- Isokinetic, depth-integrating methods are designed to produce a discharge-weighted (velocity-weighted) sample.
- Using this method, each unit of stream discharge is equally represented in the sample, either by dividing the stream cross-section into intervals of equal width (EWI) or equal discharge (EDI) (Wilde 2006).

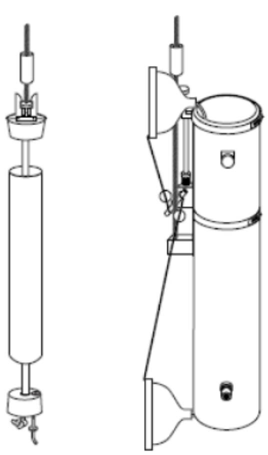
Lake sampling (photo by USEPA)

- ***Isokinetic depth-integrated samplers***—Accumulate a representative water sample continuously and isokinetically (water approaching and entering the sampler intake does not change in velocity) from a vertical section of a stream while transiting the vertical at a uniform rate.
    - These are often used for suspended sediment sampling.



- **Challenges** of depth-integrated samplers:
  - Some devices can require frequent maintenance.
  - Can be impractical in northern climates because of ice.
- ***Nonisokinetic samplers***—The sample enters the device at a velocity that differs from ambient.
  - Types include hand-held open-mouth bottles, weighted bottles on cables, and specialized biological oxygen demand and volatile organic compound samplers.
- ***Depth-specific samplers***—Used to collect discrete samples from lakes, estuaries and other deep water at a known depth.
  - Common types include the Kemmerer and Van Dorn samplers.

For more information, go to guidebook page 3-36 and page 3-71.



A. Kemmerer sampler *B.* Van Dorn sampler

2.7.3.4 Continuous Samples

- **Definition**—Truly continuous or very frequent sequential measurements using electrometric probes.
    - Useful for trend analysis or to assess BMP or watershed project effectiveness (e.g., tracking exposure of aquatic organisms to harmful levels of DO).
    - Can track the duration of values exceeding thresholds (in particular, those with significant diurnal variability).
    - Can measure flow or in situ parameters (e.g., temperature and DO).
- **Challenges** of continuous sampling include:
    - Requires careful field observation and sensor cleaning/calibration.
    - Provides no details about the spatial aspects of water quality conditions.
    - Collecting too much data requires conducting data reduction and addressing the problem of autocorrelation.

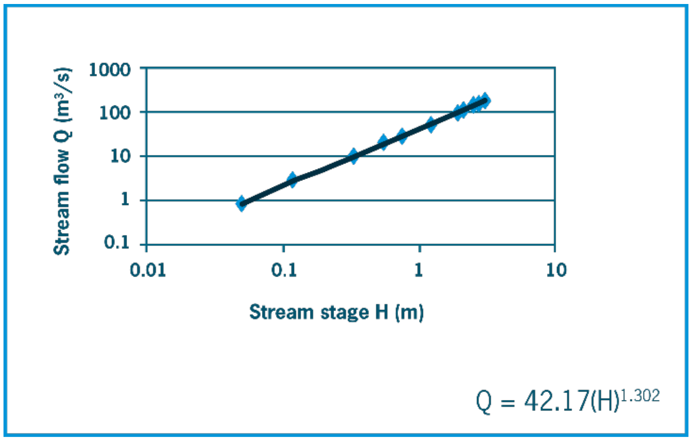
For more information, go to guidebook page 3-37.

Continuous water quality monitor deployed off a bridge in Westerly, RI (photo by J. Morrison, USGS)

2.7.4 Stage-Discharge Relationship

- Continuous discharge measurement in open channels usually requires that the stage-discharge relationship is known, either by installing a weir or flume or developing a stream rating.
- A stage-discharge relationship is an equation determined for a specific site that relates discharge to stage, based on a linear regression of a series of concurrent measurements of stage and discharge.
- As shown here, stage-discharge relationships usually take on a log-log form. With a valid stream rating, discharge can be determined simply from a stage observation plugged into the equation or read from a table.

For more information, go to guidebook page 3-20.



2.7.5 Choose Sample Type—Summary

- Have you decided which of the following sample types are most appropriate for your study?
  - Grab
  - Composite
  - Integrated
  - Continuous

2.8 Select Variable

- Determine variables that best meet the program objectives with due consideration to available resources.
- Considerations:
  - Which variables best support your project goals?
  - How many variables should you choose? (Note: It's sometimes better to focus efforts on monitoring a small set of variables.)

2.8.1 Overview

- Monitoring variables are often grouped into three main categories:
  - Physical (e.g., flow, temperature, suspended sediment)
  - Chemical (e.g., dissolved oxygen, total phosphorus, pesticides)
  - Biological (e.g., bacteria, benthic macroinvertebrates, fish)
- Issues to keep in mind:
  - Use resources carefully by selecting only those variables that are necessary.
  - Pick specific variables that are important to the study instead of a generic list of traditionally monitored variables.

2.8.2 Select Variables

This section will cover the following factors related to selecting variables:

Factor	Questions to ask
Program objectives	Are the objectives well-defined?
Waterbody designated use	What are the waterbody's designated uses and is it impaired?
Water resource type and pollutant source	What is the type of water? What is causing the pollution, and can you measure the water's response to treatment?
Cost of analysis	What analytical methods are available, and are there ways to reduce analytical costs?
Logistical constraints	How will you manage holding times and constraints?
Covariates	What are the important covariates to measure?

2.8.2.1 Program Objectives

- In many cases, the program objective will clearly indicate the appropriate variable(s) to monitor.
  - Example: If your objective is to reduce phosphorus loading to a lake, suggested variables would be phosphorus and flow because measuring both concentration and flow are required to calculate load.
- It's more challenging to select monitoring variables when program objectives are less specific.
  - For monitoring aimed at assessing water quality standards compliance, your variables should focus on what is required to assess violations of water quality standards.
  - For monitoring objectives that involve watershed reconnaissance or characterization, your choice of variables must consider the nature of the impairment, type of water resource, and likely pollutant sources.

For more information, go to guidebook page 3-2.

2.8.2.2 Waterbody: Designated Use

- Variable selection can be driven by a waterbody's ***designated use***. Designated uses are one of three elements contained in water quality standards. Typical designated uses include:
  - Protection and propagation of fish, shellfish, and wildlife
  - Recreation
  - Public drinking water supply
  - Agricultural, industrial, navigational and other purposes
- States and Tribes designate water bodies for specific uses based on their goals and expectations for their waters.

- Water quality criteria are set to protect each designated use by describing the chemical, physical and biological conditions necessary for safe use of waters by humans and aquatic life.
- These criteria should help guide variable selection and other monitoring details (e.g., sampling period, frequency) where use attainment or protection is the primary monitoring concern.
- Monitoring waterbodies with use impairments can differ substantially from monitoring to assess use attainment or protection.
    - Example: The impairment could be the result of a single pollutant, rather than a failure to meet all applicable water quality criteria.
- Monitoring can be focused on the specific variables that are violating criteria instead of all potential variables.
- Although the variable list associated with criteria can be narrowed, additional variables should be considered to address the causes of the violation(s).

For more information, go to guidebook page 3-2.

2.8.2.3 Water Resource Type and Pollutant Source

- **Type of Water Resource**—Appropriate variables often differ between surface and groundwater and between streams and lakes.
- **Pollutant Source**—Variables monitored should reflect the NPS pollutants known or suspected to be present in the watershed.
    - Crop agriculture is likely to influence suspended sediment, turbidity, nutrients and pesticides measured in water.
    - Intensive livestock agriculture in a watershed would justify measuring biological oxygen demand, nutrients and indicator bacteria.
    - Urban stormwater sources are likely to influence variables such as discharge, temperature, turbidity, metals and indicator bacteria.

For more information, go to guidebook page 3-3.

2.8.2.4 Cost of Analysis

- The choice of suitable variables can be influenced by the cost of analysis if you have budget constraints.
- Ways to reduce costs:
    - Use an in-house laboratory, such as a university or a state agency.
    - Select alternate variables that cost less.
        - Turbidity instead of suspended sediment.
        - Specific conductance instead of total dissolved solids.
    - Use a less-costly analytical method (if sensitivity is acceptable).

For more information on overall monitoring costs see Chapter 9 of the guidebook.

2.8.2.5 Logistical Constraints

- Most water quality variables have specified permissible holding times and holding conditions (i.e., refrigeration), which determine the length of time a sample can be stored between collection and analysis without significantly affecting the analytical results.
- Questions to ask:
    - Is refrigeration necessary?
    - Is there adequate power to planned locations of automated samplers or continuous flow measurements?
    - Can the samples be delivered to the lab under the required conditions within the specified holding time?

For more information, go to guidebook page 3-2.

2.8.2.6 Covariates

- **Covariates** are variables that are not directly required by project objectives or pollutant sources but might be important in understanding or explaining the behavior of other critical variables.
- Examples of covariates:
    - Precipitation and other weather variables are often collected to explain pollutant loading and transport.
    - Flow or stage measurements can help explain observed patterns of suspended sediment or particulate phosphorus that are delivered predominantly in surface runoff during high-flow events.
    - Temperature, chlorophyll *a* and algae are related to nutrient loading in lakes.

For more information, go to guidebook page 3-9.

2.8.3 Response to Treatment

- When a monitoring program is designed to evaluate water quality response to implementation of a management measure, you must monitor variables that focus on the dimensions of water quality expected to change in response to treatment.
    - Example: For an agricultural watershed that uses a suite of conservation practices to address an erosion problem, your monitoring program should measure flow, peak flow, suspended sediment and turbidity because these variables are likely to respond to widespread changes from conventional cropping practices.

For more information, go to guidebook page 3-4.

2.8.4 Method Comparability

- Advances in sampling and analytical methods can reduce interference and improve reliability and accuracy.
- Difficulties can arise when advances occur during a current project or when trying to design a new project that uses historical data.
- Ensuring that samples can be compared is critical.
  - One option is to perform a comparability study by implementing both methods with laboratory splits and comparing the resulting paired data.
  - For a project of limited duration, sometimes it's best to continue with an older method rather than updating to a new method.

For more information, go to guidebook page 3-7.

2.8.5 Set Priorities

- Because there are many water quality variables to choose from, it's important to take a deliberate approach to setting priorities when designing a monitoring program.
  - Prepare a justification for each candidate variable.
  - Consider a ranking system where:
    - A minimum set of essential variables are identified.
    - A set of additional, justifiable variables is included if other constraints allow.
  - Conduct a systematic evaluation of correlations among candidate variables to determine:
    - Are any variables highly correlated?
    - If so, do they both need to be measured?

For more information, go to guidebook page 3-9.

2.8.6 Select Variables—Summary

- Have you considered the following when selecting your variables?
  - Program objectives
  - Type of water resource
  - Pollutant source
  - Cost of analysis
  - Logistical constraints
  - Covariates

2.9 Design Stations

- Determine the best way to design and operate the physical facilities* involved in fixed monitoring stations.
- Considerations:
  - What are your project objectives?
  - Is there a need for fixed monitoring stations?

2.9.1 Overview

- Not all monitoring designs require fixed station facilities. When they are required, several important principles apply:
  - **Select monitoring sites according to specific criteria based on program objectives and needs.**
  - Design the station to collect representative samples from the target population under foreseeable circumstances.
  - Strive for simplicity.
  - Include redundancy.
  - Provide security.

For more information, go to guidebook page 3-56.

2.9.2 Grab Sampling Stations

- Monitoring programs based solely on grab sampling might not require stations with physical facilities; however, the selected monitoring site must be located and identified so that samples can be repeatedly collected from the same location.
  - Make sampling sites easy to find (e.g., road crossings on streams, pipes delivering flow to or from a stormwater treatment system).
  - Record stations on a map or in a standard operating procedure.
  - Use GPS coordinates for more challenging locations, such as in a lake.
  - For depth location, use a weighted line or an electronic depth sounder.
- Lake and wetland monitoring typically require grab sampling.

For more information, go to guidebook page 3-57.

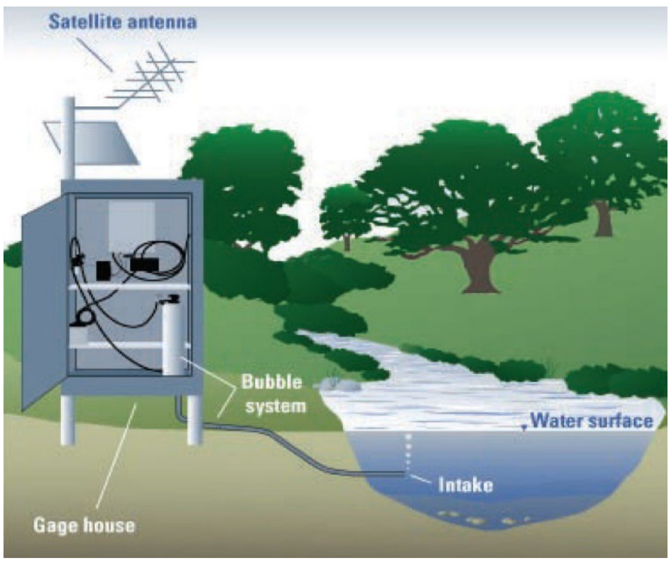
2.9.3 Fixed Station Design Aspects

The next slides will cover important aspects of fixed station design for several common applications. (Note: Although fixed stations can be used to monitor groundwater, they are not covered in the NPS guidebook.)

Application	Measurement types
Perennial streams and rivers	Stage/discharge equipment, automated samplers, water quality data loggers, wingwalls, berms
Edge-of-field	Stage/discharge equipment, automated samplers, water quality data loggers
Structure/BMPs	Passive first flush sampler, flume inserts for pipes
Meteorological	Meteorological station, rain gauge

2.9.3.1 Perennial Streams and Rivers Sampling

- Long-term stations used to continuously record streamflow and collect periodic water samples require structures and facilities to house monitoring equipment.
- ***Continuous flow measurements*** require a staff gauge and a way to continuously record stage, using:
  - A stilling well with a float bubbler. These are highly reliable and are protected from turbulence, ice and debris in the stream channel.
  - A bubbler, pressure transducer or ultrasonic device. These can be placed directly in the stream channel, data can be logged electronically, and flow data can be linked to an autosampler.



Stream sampling station (image by L.S. Coplin, USGS)

- Water samples at continuous monitoring stations are typically collected by autosamplers, which can:
  - Pump samples from the stream through plastic tubing and collect the water in one or more bottles.
  - Collect timed samples of specific volume or storm-event or flow-proportional samples when linked to a flow recorder or other triggering device.
  - Operate unattended for extended periods.
  - Be linked together with a data logger for sampling control and data storage.
  - Be equipped to communicate through cell phone systems or the Internet in real time, allowing data to be downloaded and commands for sampling or recording data to be sent remotely.
- ***Challenges*** with using autosamplers:
  - Sampler intake is usually fixed at a single point in the stream; samples collected might not be representative of vertical or horizontal variability.
  - Depth-integrated intake devices can require frequent maintenance and can be impractical in northern climates where ice is a problem.

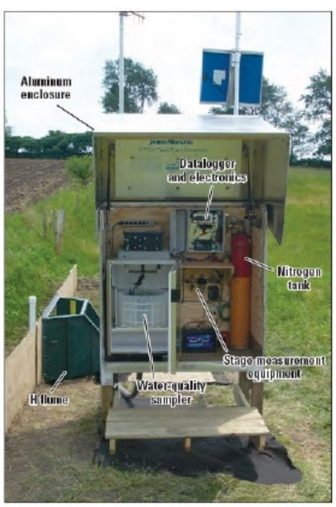
    - They require electrical power or deep-cycle automotive or marine batteries, which need servicing and recharging.
    - Operation in winter weather might require robust shelter and heating tape or propane heaters.
    - Operation in hot climates might require special cooling/ ventilation.

For more information, go to guidebook page 3-58 or page 3-77.

2.9.3.2 Edge-of-Field Sampling Stations

- At **edge-of-field,** flow is intermittent, and channels might not be defined.
- **Challenges** include:
    - The need to measure flow (when it occurs).
    - The need to collect representative water samples and other data.
    - The need for power to run equipment.
    - Extreme weather events.
- Typical edge-of-field stations include:
    - Enclosures to house equipment designed to measure stage, collect samples and provide telecommunication.
    - Stage and discharge equipment.
    - Sampling equipment.
    - Data logging and control instruments
    - Communications
    - Power
    - Camera
- Stations will be dormant for extended periods but need to be ready for activation. Regular maintenance visits are required.

For more information, go to guidebook page 3-60.



Edge-of-field monitoring station, Wisconsin Discovery and Pioneer Farms (Stuntebeck et al. 2008)

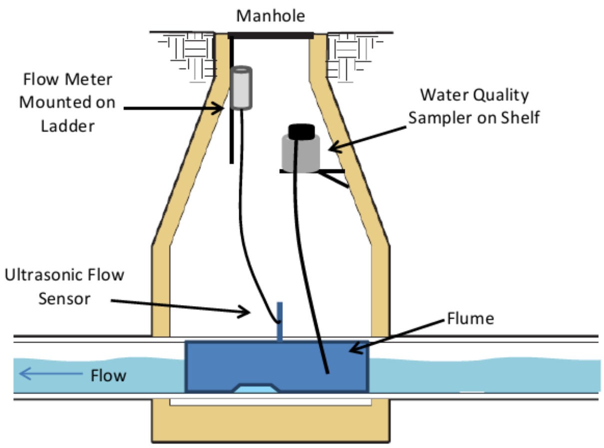
Edge-of-field monitoring station, Wisconsin Discovery and Pioneer Farms (Stuntebeck et al. 2008)

Edge-of-field monitoring station, Vermont (Meals et al. 2011)

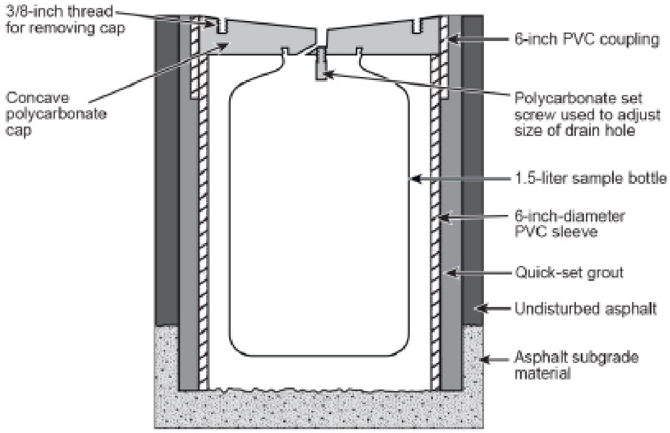
Edge-of-field monitoring stations, VT (photo by Meals et al. 2011)

2.9.3.3 Structures/BMPs Sampling Stations

- Many individual BMP monitoring efforts have similar requirements for flow measurement, water sampling, data logging, communications and security as other station types, but are often constrained by physical characteristics.
- Examples:
  - Monitoring inflow and outflow from a constructed wetland is generally comparable to monitoring flow in an intermittent stream.
  - Runoff from a parking lot entering an infiltration BMP may be difficult to quantify and sample; outflow from the BMP may be carried in an underground pipe.
- Some specialized equipment for such monitoring has been developed, including passive runoff samplers and flume inserts for pipes with integrated stage sensors.



Flow measurement and water quality sampling in stormwater pipes (USEPA 2016)



Street runoff sampler (image from Waschbusch et al. 1999)

- In urban runoff monitoring, the first-flush phenomenon requires special consideration because pollutant loads during the first part of an event may be much larger than those in the later flows.
- Examples of first flush runoff samplers are shown below.
- Monitoring the ***input/output*** of a BMP requires two monitoring stations that are coordinated but not simultaneous.
- If sampling is conducted simultaneously at the entrance and exit of a BMP, the outflow sample may represent “old” water pushed out of the BMP by “new” inflow, rather than new inflow after treatment by the BMP.
- *Time of travel* or residence time in the BMP must be considered in setting up monitoring stations. Establishing links between the upstream and downstream stations allow for better coordination between them. An example of time of travel is below.

For more information, go to guidebook pages 3-60 to 3-61.

Images from USEPA 2016

2.9.3.3.1 Time of Travel Example

- Stuntebeck et al. (2008) modified the basic above/below design in a Wisconsin barnyard runoff study by setting the samplers to be activated by precipitation and programming them to collect time-integrated samples for an initial period.
    - This modification allowed for sampling of barnyard runoff in the receiving stream before stream water level increases could be sensed, thereby effectively isolating the barnyard runoff from nonpoint pollution sources upstream.
    - This approach allowed sampling during small storms in which local inputs from the barnyard were apparent, but little storm runoff from the upstream areas of the watershed were observed.
    - A second modification took advantage of the close proximity of the two stations to create a direct electronic connection between the stations for collection of concurrent samples.

2.9.3.4 Meteorological Sampling Stations

- Meteorological data, particularly precipitation data, are nearly always relevant to NPS monitoring projects.
- Most important criterion for precipitation measurement = **location**.
    - For BMP or field monitoring efforts, a single meteorological station may be sufficient.
    - For larger watershed monitoring, multiple stations are usually necessary to account for variations of weather with elevation and other geographic factors.
    - Multiple precipitation stations are used when data are needed for model application.
    - Stations must be unobstructed to obtain accurate measurements.

- Instrumentation:
    - Electronic instruments record directly into dataloggers.
    - Tipping bucket rain gauges measure both total accumulated rainfall and rainfall rate. They can be connected to other monitoring instruments to log data and/or trigger sample collection.

For more information, go to guidebook page 3-67.

Meteorological monitoring station (Meals et al. 2011)

2.9.4 Design Stations—Summary

- Are fixed stations necessary in your program for the following types of continuous monitoring?
    - Perennial streams and rivers
    - Edge-of-field
    - BMPs/structures
    - Meteorological measurements

2.10 Define Collection & Analysis Methods

- Collection and analysis of samples requires training, appropriate equipment, careful adherence to standard procedures and detailed record keeping.
- Considerations:
    - Can you align your proposed methods with those used in the past?
    - Are the methods you want to use approved by a reliable source?

2.10.1 Overview

- Documentation and records
    - Use field sheets, SOPs and logbooks.
- Preparation for sampling
    - Cleaning, calibrating and testing equipment.

- Cleaning
    - Use clean sample containers to avoid contamination.
- Safety
    - Don't work alone.
    - Pay attention to weather.
    - Use safety devices when flow is high.

Collecting samples from a bridge (photo by NRCS)

2.10.2 Data Collection and Analysis Options

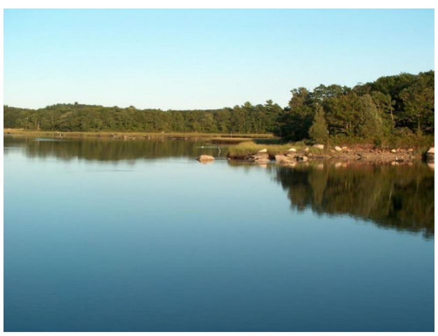
This section covers different types of field measurements, methods of sample collection, information on sample handling and transport, and laboratory considerations.

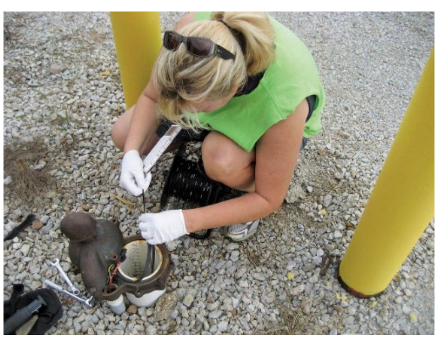
Field measurements	Sample collection	Sample processing, transportation and analysis	Laboratory
Single point	Grab	Processing	Type of lab
Multiple points	Passive	Storage, preservation and transport	Methods used
In situ or onsite	Autosampling	Chain-of-custody	Certifications
Groundwater	Benthic macroinvertebrates	Performance audits	
	Aquatic habitat		
	Fish		
	Aquatic plants		
	Pathogens		
	Specialized		

2.10.2.1 Field Measurements

- Variables such as water temperature and DO concentration must be measured directly in the waterbody; properties such as pH, specific conductance and turbidity can be measured either in situ or immediately on the site using a sample taken from the source.
- In flowing water, a single sampling point in a well-mixed area is generally used to represent an entire cross-section.
- In lakes or other still water, field measurements might be made at multiple locations and depths.
- Groundwater generally requires purging the monitoring well of standing water and then taking field measurements.

For more information, go to guidebook page 3-70.





2.10.2.2 Sample Collection

2.10.2.2.1 Sample Collection: Grab Sampling Collection Methods

- Grab sampling can be done manually by dipping a sample bottle by hand under the water at a certain depth. Proper procedures must be followed.
- As already described in the Choose Sample Type section, a variety of devices are available to collect grab samples from waterbodies for different purposes:
    - Isokinetic depth-integrated samplers
    - Nonisokinetic samplers
    - Depth-specific samplers

For more information, go to guidebook page 3-71.

2.10.2.2.2 Sample Collection: Passive Sampling Collection Methods

- Passive samplers collect unattended grab samples without relying on external power or electronic activation. The exact time and circumstance of sampling is unknown unless other data are taken at the same time.
- Examples of passive samplers include:
    - Runoff samplers
    - Single-stage samplers
    - Tipping-bucket samplers
    - Coshocton wheel samplers
    - Lysimeters

For more information, go to guidebook page 3-73.

Passive runoff sampler/flow splitter, University of Georgia, Tifton, GA (photo by D. Meals, USEPA)

2.10.2.2.3 Sample Collection: Autosampling Collection Methods

- Autosamplers generally consist of:
    - An intake line submerged in the waterbody or the flow through a pipe or flume
    - A peristaltic or submersible pump that pumps water to the sampler
    - One or more bottles to contain collected samples
    - Electronic controls to initiate sample collection and record data
- Some autosamplers might be refrigerated to preserve samples for extended periods.
- Some autosamplers might be designed specifically to fit into storm drains and catch basins.
- Most autosamplers operate with either DC or AC power.
- Autosamplers can be set to take time-based samples either continuously (e.g., collect a sample every 8 hours) or as initiated by an external trigger (e.g., detection of rainfall, rising stream stage).
- When connected to a flow meter, autosamplers can take flow-proportional samples.
- Autosamplers can collect discrete samples in individual bottles or a composite sample in one large container.

A portable autosampler (photo by Teledyne Isco, 2013)

- Disadvantages with autosamplers include the following:
    - Intakes are generally fixed in one position in a waterbody and therefore might not fully represent variability, especially where strong vertical or horizontal gradients exist.
    - The size of the intake line and the velocity achieved by the autosampler pump, as well as the position in the streamflow, might prevent collection of a representative sample, especially of suspended sediment and particulate-bound pollutants.
    - Monitoring for some pollutants like volatile organics or pathogens could be challenging because of special limitations for materials that contact the sample and requirements for sterilization between sample-intake events.
    - Because samples are taken at intervals, regardless of whether an autosampler collects on a time- or flow-based program, the possibility always exists that a transient pulse of a pollutant (e.g., from a spill or first-flush) may pass by unsampled. (This, of course, is also a risk in manual sampling.)

For more information, go to guidebook page 3-77.

2.10.2.2.4 Sample Collection: Benthic Macroinvertebrate Sampling

- Sampling of benthic macroinvertebrates from stream bottoms and lake beds must consider:
  - How to physically collect samples.
  - The diversity of stream habitats that influence the numbers and types of organisms.
- The habitats sampled should be based on monitoring objectives and regional stream or lake characteristics.
- In streams, two distinct habitats are generally sampled: riffles and pools.
- In lakes, substrates and habitats vary between near-shore areas and deeper lake regions; thus, organisms will differ, and different sampling approaches will be needed.

Using a D-frame net to sample a gravel-bottom stream for benthic macroinvertebrates (USEPA 2016)

- **Active sampling:**
  - In rivers and streams, active collection is often accomplished by disturbing the streambed and capturing the dislodged organisms in a net as the current carries them downstream.
    - Kick-seines, D-frame nets and Surber square-foot samplers are common devices used.
    - It's important to quantify both the area of the streambed disturbed and the time/effort of sampling so that results can be quantified (e.g., organisms/m^2), repeated and compared over time.
  - In lakes, active sampling in shallow areas can be done by similar methods.
    - Grab samplers, such as the petite ponar or larger dredges, are used for collecting sediment samples from hard bottoms (e.g., sand and gravel).
- **Passive sampling:**
  - Uses artificial substrates like the Hester-Dendy plate sampler or rock baskets that are anchored in the waterbody. After organisms colonize them, they are retrieved and counted.

For more information, go to guidebook page 3-78.

2.10.2.2.5 Sample Collection: Aquatic Habitat Assessment Methods

- Assessing aquatic habitat is important for interpreting data collected from monitoring of benthic invertebrates and fish. Habitat characteristics can be response variables for land treatment or stream restoration efforts.
- Habitat quality is typically measured in three dimensions:
  - ***Habitat structure:*** Includes physical characteristics of stream environment, such as channel morphology, gradient, instream cover, substrate types, riparian condition and bank stability.
  - ***Flow regime***: Defined by velocity and volume of water moving through a stream, both the average and during extreme events (wet or dry).
  - ***Energy source:*** Energy enters stream systems through nutrients from runoff or groundwater (as leaves/other debris falling into streams) or from photosynthesis by aquatic plants and algae.

For more information, go to guidebook page 3-78.

2.10.2.2.6 Sample Collection: Fish Sampling Collection Methods

- As with benthic macroinvertebrates, distinct fish assemblages are found in different habitat types.
- Water temperature, flow, dissolved oxygen, cover and shade, and substrate type are important habitat characteristics.
- Major habitat types like riffles, pools and runs should be sampled.
- Habitats and the size of sampling areas should be consistent between sampling events to allow for long-term comparisons.
- Fish are most commonly sampled by electrofishing, but seines, gill nets, traps or underwater observations are also used.

For more information, go to guidebook page 3-80.

Backpack electrofishing (photo by USEPA)

2.10.2.2.7 Sample Collection: Aquatic Plant Sampling Collection Methods

- Aquatic plants sampled for water quality monitoring include:
  - Algae: small free-floating plants
  - Periphyton: the community of algae, microbes and detritus attached to submerged surfaces
  - Macrophytes: large plants rooted in aquatic sediments
- Many of these plants are good indicators of nutrient enrichment and ecosystem condition.
- Algae are sampled using a plankton net towed through the water column; organisms are identified and counted under a microscope.
- As a surrogate for algal biomass, chlorophyll *a* can be measured.
- Periphyton biomass is usually measured in streams, either by scraping known areas of rock surfaces or by using artificial substrates.
- Nearshore aquatic macrophytes might be surveyed to assess species composition, quantified in small plots, or mapped by remote sensing to document areal extent of growth.

For more information, go to guidebook page 3-82.

Aquatic plants in a Washington wetland (photo by NRCS)

Trawling with a plankton net (photo by NOAA 2005)

2.10.2.2.8 Sample Collection: Bacteria/Pathogen Sampling Collection Method

- Indicator bacteria, pathogens, or other microorganisms are usually collected by grab sampling.
    - Example sample volumes:
        - *E. coli* bacteria analysis requires small volumes (e.g., 100 mL).
        - *Giardia* and *Cryptosporidium* might require up to 20 L.
- Requires sterile sample containers (e.g., pre-sterilized, single-use bags/bottles, or autoclaved polyethylene containers).
- Sample collection should be done by clean technique, with samples allowed to contact only sterile surfaces; field personnel should wear gloves.
- Samples typically require more rapid delivery to the laboratory than samples from physical and chemical analyses.

For more information, go to guidebook page 3-82.

2.10.2.2.9 Sample Collection: Specialized Sampling Collection Methods

- Specialized sampling techniques are sometimes needed for unusual or emerging pollutants.
    - Microbial source tracking requires water sampling and can involve collecting fecal material from human and animal sources in the watershed.
    - Urban stormwater monitoring can involve tests for optical brighteners as indicators of wastewater or septic effluent contamination—this requires cotton pads to be deployed in streams for several days, collected, and then tested for fluorescence with an ultraviolet light source.
    - Sentinel chambers, dialysis membrane diffusion samplers, polar organic chemical integrative samplers (POCIS), and other passive sampling devices have been used to passively sample low-concentration pollutants like VOCs, estrogen analogs, endocrine disruptors, and other emerging pollutants in a variety of settings.

For more information, go to guidebook page 3-83.

2.10.2.3 From Field to Laboratory: Sample Processing, Transportation and Analysis

- There are several important steps to consider between sample collection and analysis, including:
    - Sample processing
    - Sample preservation and transport
    - Sample custody tracking
    - Performance audits

For more information, go to guidebook page 3-84.

2.10.2.3.1 Sample Processing

- Sample processing refers to the measures taken to prepare and preserve a water sample at or after collection, but before it's delivered to the laboratory for analysis.
- Goals are to prepare samples for analysis, prevent contamination and cross-contamination, and preserve sample integrity until analysis.
    - Samples requiring filtration must be filtered during or immediately after collection.
    - Surface water samples might be composited or subsampled in the field using an appropriate device, such as a churn or cone splitter.
    - Groundwater samples are not composited but are pumped either directly through a splitter or through a filtration assembly into sample bottles (unless a bailer or other downhole sampler is used to collect the sample).

Cone filter (photo by FISP 2014)

2.10.2.3.2 Sample Storage, Preservation and Transport

- Water samples to be analyzed for most water quality variables have specified permissible holding times and holding conditions
    - For more details, see Table 3-12 in the guidebook.
- Storage and preservation for most analytes involve:
    - Cooling
    - Using chemical preservatives
    - Getting sample to the lab quickly
    - Using proper packaging when shipping
    - Using proper labeling and documentation

2.10.2.3.3 Sample Chain of Custody

- The location and status of collected samples must be tracked at all points to:
    - Prevent loss of samples and data.
    - Document the conditions under which the samples were held.
    - Preserve sample and data security and integrity.

- Sample custody starts with a consistent numbering and labeling system that uniquely identifies each sample's source, monitoring program, date and time of collection, responsible person(s) and desired analysis.
- Custody is tracked using forms and other records that are signed and dated by each individual in the chain.

2.10.2.3.4 Performance Audits

- Regular field operations performance audits should be part of the overall quality assurance/quality control process. These audits include:
  - **Sample container and equipment blanks:** Distilled/deionized water is processed through sampling equipment and sample containers to rule out contamination.
  - **Trip blanks:** Distilled/deionized water is transported from the laboratory through the field sampling process to document any potential contamination acquired during travel and transport.
  - **Field duplicates:** Two grab samples are collected in quick succession to assess repeatability of sampling.
  - **Field splits:** A collected sample is split into two subsamples to assess analytical performance by the laboratory or to make comparisons between labs.

2.10.2.4 Laboratory Considerations

- **Type of lab**: The accuracy and precision generally required in NPS monitoring programs require formal laboratory analysis. Laboratories are typically operated by state agencies, universities or private companies.
- **Methods used**: Analyses should be conducted using accepted laboratory methods.
- **Certification**: Use a laboratory certified either by a state program or the USEPA Drinking Water Program.
- In addition to the above considerations, also look for a laboratory that:
  - Participates in regional comparative proficiency testing programs.
  - Provides documentation of methods and QA/QC protocols used.
  - Provides assurance that samples will be handled and processed expeditiously.

For more information, go to guidebook page 3-90.

2.10.3 Define Collection and Analysis Methods—Summary

- Have you determined which of the following collection methods you will need?
  - Field measurements
  - Grab sampling
  - Passive sampling
  - Autosampling
  - Benthic macroinvertebrate sampling
  - Aquatic plant sampling
  - Bacteria/pathogen sampling
  - Habitat sampling

    - Specialized sampling
- Have you planned for all steps from sample processing to laboratory analysis?

2.11 Define Land Use Monitoring

- Determine what land use activities are generating NPS pollution and how to effectively monitor them.
- Considerations:
    - How will you track both land use and land treatment?
    - How will you link land treatment to water quality response?

2.11.1 Overview

- NPS pollution is generated by activities on the land that vary in location, intensity and duration.
    - ***Land use*** refers not only to the general category of land use or cover (e.g., residential, row crop) but also to land management or source activities (e.g., street sweeping, agrichemical applications, tillage).
    - ***Land treatment*** refers not just to the existence of a specific treatment or BMP (e.g., sediment basin, reduced tillage) but also to the management of the BMP (e.g., sediment basin clean-out, tillage dates, nutrient application rate, timing and method).

For more information, go to guidebook page 3-91.

2.11.2 Link Land Treatment to Water Quality Response

- Linking land treatment to water quality response requires both land use/treatment and water quality monitoring.
- Specific needs can differ by monitoring type.
- Understanding pollutant loading patterns requires information about both the spatial and temporal variability of source activities.
- It's necessary to track land use/treatment when planning to attribute water quality trends to activities on the land.
- Because monitoring for trend analysis can continue for decades, consider costs when deciding about the scope, level of detail, and frequency of monitoring that will be done.

For more information, go to guidebook page 3-91.

2.11.3 Define Land Use Monitoring

The following sections will cover these different aspects of land use monitoring.

Topic	Example
Activities to monitor	Consider land use/land cover and BMPs—and the associated management of each.
Methods of data collection	Options include direct observation, logbooks, interviews, agency reporting and remote sensing.
Temporal and spatial scale	What land area contributes to the water being sampled? Should you match the temporal scale to that of the water quality monitoring?
Variables	Match the land use/treatment variables to the water quality variables.
Frequency	Choose frequency based on whether your land use/treatment data is static or dynamic.

For more information, go to guidebook page 3-91.

2.11.4 Important Things to Document

- For individual BMP effectiveness monitoring, it's important to document:
  - The design specifications of the practice evaluated.
  - The degree to which the practice was implemented, maintained and operated according to specifications.
  - Management activities conducted under the scope of the practice.
  - Any situations where the BMP operated under conditions outside of the design range.

For more information, go to guidebook page 3-91.

2.11.5 Basic Methods

- The basic methods used to monitor land use and land treatment are:
  - Direct observation
  - Logbooks
  - Interviews
  - Agency reporting
  - Remote sensing

For more information, go to guidebook page 3-92.

2.11.6 Direct Observations

- Personal observations might be the best way to track land use/treatment for plot and field studies.
- Common types of observations include:
  - Tracking forms
  - Windshield surveys
  - Photography

- Disadvantages of direct observation methods:
    - Potential for bias due to lack of understanding of activities
    - An established schedule misses important events
    - The inability to assess information about rate or quantity

For more information, go to guidebook page 3-92.

Photo by Minnesota Department of Natural Resources

2.11.7 Logbooks

- Logbooks can be given to landowners and managers to record activities relevant to the monitoring study.
- Advantage of this method: the same individual who is responsible for the activity does the reporting.
- Disadvantage: it's difficult to guarantee compliance or consistent reporting between individuals.

For more information, go to guidebook page 3-93.

2.11.8 Interviews

- When conducted in person, interviews offer the opportunity to gather additional information that is important to the study.
- Disadvantages of interviews include:
    - Potential for less-than-complete reporting of information by the person interviewed.
    - Potentially inadequate or uneven interview skills by those conducting the interviews.
    - A combination of the logbook and interview approach works well in small watersheds with a relatively small number of participants.

For more information, go to guidebook page 3-93.

2.11.9 Agency Reporting

Land use data are available through many different agencies, including:

Data source *(Summaries provided in following section)*	**Link to more information** (*Click to visit Web page*)
Soil and Water Resources Conservation Act (RCA) Report–Interactive Data Viewer	https://www.nrcs.usda.gov/wps/portal/nrcs/rca/national/technical/nra/rca/ida/
USDA's National Resources Inventory (NRI)	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/
Census of Agriculture	https://www.nass.usda.gov/Publications/AgCensus/2012/
NOAA's Coastal Change Analysis Program's (C-CAP)	https://coast.noaa.gov/digitalcoast/data/ccapregional.html
National Land Cover Database (NLCD)	https://www.mrlc.gov/
U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) Program	https://www.census.gov/programs-surveys/geography/guidance/tiger-data-products-guide.html
Water Quality Portal	https://www.waterqualitydata.us/

For more information, go to guidebook page 3-94.

2.11.9.1 RCA Report–Interactive Data Viewer

- USDA maintains data on conservation practices implemented with USDA cost-share funds or technical assistance. State-level information can be obtained through the Soil and Water Resources Conservation Act (RCA) Report–Interactive Data Viewer.
- The RCA authorizes USDA to report on the condition of natural resources, and to analyze conservation programs and opportunities. The Interactive Data Viewer provides data from a variety of sources, including data on the status and trends of natural resources, conservation efforts (funding and conservation practices applied), and the agricultural sector.

2.11.9.2 USDA's National Resources Inventory

- USDA's National Resources Inventory (NRI) provides survey-based inventories of land use information.
- The NRI program collects and produces scientifically credible information on the status, condition, and trends of land, soil, water, and related resources on the Nation's non-federal lands in support of efforts to protect, restore, and enhance the lands and waters of the United States.
- NRI survey results are based upon a particular set of definitions, protocols, and instructions. These have been developed to support NRCS programs and USDA analytical needs, so they differ in some cases from those used by other agencies. These differences need to be considered when analyzing/interpreting the data.

2.11.9.3 Census of Agriculture

- USDA's National Agricultural Statistics Service (NASS) conducts the Census of Agriculture once every 5 years. It's a comprehensive summary of agricultural activity for the U.S. and for each state. It includes the number of farms by size and type, inventory and values for crops and livestock, operator characteristics, and other information.
- NASS publishes only aggregated data. NASS is bound by law (Title 7, U.S. Code, and CIPSEA, Public Law 107-347)—and pledges to every data provider—to use the information for statistical purposes only.

2.11.9.4 NOAA's C-CAP

- NOAA's Coastal Change Analysis Program (C-CAP) has a nationally standardized database of land cover and land change information for U.S. coastal regions, derived from the analysis of multiple dates of remotely sensed imagery.
- Two file types are available: individual dates and change files.
- C-CAP data form the coastal expression of the National Land Cover Database (NLCD) and the A-16 land cover theme of the National Spatial Data Infrastructure. The data are updated every 5 years.

2.11.9.5 National Land Cover Database

- The National Land Cover Database (NLCD) and USGS's Land Use and Land Cover data provide historical GIS datasets.
- The Multi-Resolution Land Characteristics (MRLC) Consortium is a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a variety of environmental, land management and modeling applications. Maps of the lower 48 states, Hawaii, Alaska and Puerto Rico have been compiled into a comprehensive land cover product from decadal Landsat satellite imagery and other supplementary datasets.

2.11.9.10 U.S. Census Bureau's TIGER Program

- The U.S. Census Bureau (USCB) through the TIGER (Topologically Integrated Geographic Encoding and Referencing) program provides GIS data for mapping human population.
- It includes land features (roads, rivers and lakes), counties, census tracts and census blocks. Some of the geographic areas represented in TIGER are political areas, while others are statistical areas.
- The TIGER program was developed to support USCB's mapping needs for the Decennial Census and other programs. Every 1–3 years, USCB creates an extract from this database and releases a TIGER update. These extracts are known as TIGER/Line files.

2.11.9.11 Water Quality Portal

- The Water Quality Portal (WQP) is a cooperative service sponsored by the U.S. Geological Survey (USGS), USEPA, and the National Water Quality Monitoring Council (NWQMC). It serves data collected by over 400 state, federal, tribal and local agencies.
- The WQP combines physical, chemical and biological water quality data from multiple data sources at one location and provides the data in one format. It provides a single, user-friendly web interface to access more than 250 million water quality data records collected by over 400 federal, state and tribal agencies and other water partners.

2.11.10 Remote Sensing

- Remote sensing can be useful for tracking practices and land management that are monitored visually.
- Many remote sensing datasets are available:
    - Data products at the USGS's National Map Viewer and Download Platform or Earth Resources Observation and Science (EROS) Data Center.
    - Landsat data, elevation, greenness, "Nighttime Lights," and coastal and Great Lakes Shorelines (USEPA 2008).
    - Low-altitude aerial photography to assess compliance with crop insurance programs are done annually by the USDA Farm Service Agency.
    - Commercial web-based resources such as Bing Maps and Google Earth can be useful tools for land use monitoring.

For more information, go to guidebook page 3-95.

2.11.11 Temporal and Spatial Scale

- Land use/treatment monitoring should address the entire area contributing to flow at the water quality sampling point. Some parts of a larger area might be emphasized more than others.
    - Example: Land nearest to the sampling point can have a major effect on the measured water quality, so these areas must be monitored carefully. Spatial coverage of land use monitoring might range from a single field (or portion of a field) up to an entire river basin.
- There is often the mistaken assumption that the temporal scale of land use/treatment monitoring should match that of the water quality monitoring when the data are to be combined for analyses. Also consider the inherent variability of what is being measured.
    - Example: Road salt is applied under icing conditions, while wash-off tends to occur during periods of thawing or rainfall. Matching weekly water quality and land use/treatment in this case could result in associating high salinity levels with periods of no road salt application.
- The following multi-level monitoring approach can address certain issues with matching the temporal scales of land use/treatment monitoring to that of water quality monitoring:

- **Characterization:** An initial snapshot of land use/land cover, focusing on static parameters (e.g., water bodies, highways, impervious cover).
    - **Annual:** A survey for annually varying features such as crop type.
    - **Weekly:** Weekly observations to identify specific dates/times of critical activities (e.g., manure or herbicide applications, tillage, construction).
    - **Quantitative:** Data collection on rates and quantities (e.g., nutrient or herbicide application rates, number of animals on pasture).
- The guiding principle of timing is to collect land use/treatment data at a fine enough time resolution to be able to explain water quality results as they occur.

For more information, go to guidebook page 3-97.

2.11.12 Monitoring Variables

- The appropriate set of land use/treatment variables for any monitoring plan will depend on the monitoring objectives, monitoring design, and characteristics of the watershed or site to be monitored.
- The set of variables needed for problem assessment is usually broad, whereas the set of variables for BMP effectiveness monitoring is tailored to the BMP and the conditions under which it's being evaluated.
- Refer to the guidebook for:
    - Information on the appropriate selection of land use/treatment variables (Table 2-2).
    - Examples of pairing water quality and land use/treatment variables (Table 3-13) shows.

For more information, go to guidebook page 3-98 and page 2-4.

2.11.13 Sampling Frequency

- The frequency for sampling dynamic data will vary depending on the type and magnitude of the variable's impact on measured water quality.
    - For BMP effectiveness studies at the plot or field scale, observations should be made each time the site is visited.
    - Although construction activities might occur daily at any given construction site, note that certain phases of construction might warrant closer attention.
- The availability of records should be considered when determining sampling frequency.
    - Many nutrient management plans require producers to keep field-by-field records of manure and chemical nutrient applications; therefore, sampling can theoretically be done on an annual basis assuming that the records are clear and accurate.

For more information, go to guidebook page 3-98.

2.11.14 Challenges

- Challenges associated with tracking land use/treatment include:
  - Gaining access to locations for direct observation or communication with landowners or managers.
  - Obtaining cooperation on field logs, especially when confidential business information is involved.
  - Checking all source activities of potential interest in a mixed-use watershed can be logistically difficult, labor intensive and complicated.
  - Assuring confidentiality of data to landowners.
  - Addressing data gaps when using large-scale agency data.

For more information, go to guidebook page 3-99.

2.11.15 Define Land Use Monitoring—Summary

- Have you done the following?
  - Determined which land use activities you will monitor.
  - Selected methods for collecting data on each activity.
  - Considered spatial and temporal scale.
  - Selected variables.
  - Selected sampling frequency.

For more information, go to guidebook page 3-99.

2.12 Design Data Management

- Developing, executing and supervising plans, policies, programs and practices that control, protect, deliver and enhance the value of data and information assets. (Mosley et al. 2009)
- Considerations:
  - How will you acquire, store and backup your data?
  - Are you using any publicly available data?
  - Have you developed a quality assurance project plan (QAPP)?

2.12.1 Overview

- Data management must be part of initial project planning. It includes:
  - The path the data follows, from generation to final use or storage.
  - Standard record-keeping procedures.
  - Document control system.
  - Approach used for data storage and retrieval on electronic media.
  - Control mechanism for detecting and correcting errors and preventing loss of data during data reduction, data reporting and data entry.
  - Examples of forms or checklists.

    - Descriptions of data-handling equipment and procedures for processing, compiling and analyzing data.
    - Performance requirements for computer hardware and software.
- Describe the aspects of data management in a QAPP.

For more information, go to guidebook page 3-105.

2.12.2 Design Data Management

The following aspects of data management are presented in the following sections.

Data management topic	Considerations
QA/QC	Develop a QAPP at the beginning of the project and implement and maintain it throughout the project.
Data acquisition	Consider different issues with manual vs. electronic data entry and measured data versus data acquired from other sources (e.g., databases, literature, other programs or agencies).
Data storage	Store manual and electronic data safely. Back up all data.

For more information, go to guidebook page 3-105.

2.12.2.1 Quality Assurance/Quality Control

- A QAPP details the technical activities and quality assurance/quality control (QA/QC) procedures that should be implemented to ensure data meet specified standards. A QAPP should identify:
    - Who will be involved in the project and their responsibilities and the nature of the study or monitoring program.
    - The questions to be addressed or decisions to be made based on the data collected.
    - Where, how and when samples will be taken and analyzed.
    - The requirements to ensure data quality.
    - The specific activities and procedures to be performed to obtain the requisite level of quality (including QC checks and oversight).
    - How data will be managed, analyzed and checked to ensure that they meet the project goals.
    - How the data will be reported.
- The QAPP should be implemented and maintained throughout a project.

For more information, go to guidebook page 8-1.

2.12.2.2 Data Acquisition

- The data generated must be collected (data acquisition) and transferred to the data management system for storage and analysis.
- Transcribing field-logged data into a database is a potential source of typographic errors, switched digits and other errors in data entry.
- All data must be error-checked after being entered into electronic forms but before analyses and reporting occurs.
- Newer methods of data acquisition include the use of data loggers, laptops, tablets and smartphones.
- Advantages of Data Acquisition:
  - Manual data entry and the associated transcription errors are avoided.
  - Remote access allows direct transfer of field data from a data logger to the main data storage site.
- Disadvantages of Data Acquisition:
  - Storage capacity is limited.
  - Once storage capacity is full, any new data might not be recorded, or older data might be overwritten and thus lost.
- Other sources of data include computer databases, programs, literature and historical databases.
  - Determine the sufficiency of these data for project purposes. You might need to ground-truth or fill gaps in the data.
- Data provided by others might have been collected at different locations, by different methods or to serve different objectives.
  - Carefully review the data and methods used for its collection.
  - In the QAPP, include acceptance criteria for the use of such data, as well as any limitations on data use.

For more information, go to guidebook page 3-105.

Inputting benthic macroinvertebrate sampling data into field sheets (photo by NRCS)

2.12.2.3 Data Storage

- All field and laboratory notebooks must be fully documented and stored safely. Consider creating scanned images.
- Use spreadsheets for simple projects.
- Use a relational database for complex projects involving many sites or variables.
- Back up all computerized data and project files.

For more information, go to guidebook page 3-106.

2.12.3 Design Data Management—Summary

- Have you done the following?
    - Developed a QAPP.
    - Included data management in the project planning phase.
    - Determined how you will acquire data.
    - Determined how you will store data.

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