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PRO-WASH Practices, Research and Operations in Water, Sanitation and Hygiene

UNC WATER INSTITUTE

Technical Guide on Drinking Water Quality Monitoring

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PRO-WASH
PRO-WASH is an initiative funded by the U.S. Agency for International Development's (USAID's) Bureau for Humanitarian Assistance (BHA) and led by Save the Children. PRO-WASH aims to improve the quality of activities strengthen the capacity and skills of BHA implementing partners in water, sanitation and hygiene (WASH) and improve WASH practices.

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How to Use This Guide

This guide to water quality monitoring (WQM) is intended for USAID Bureau for Humanitarian Assistance (BHA) funded partners seeking to improve drinking water safety as part of Resilience Food Security Activities (RFSAs). It has been developed under the USAID BHA funded Practices, Research, and Operations in Water, Sanitation and Hygiene (PRO-WASH) Award as a direct response to challenges identified by implementing partners.

The goal of this guide is to provide a relevant, quick-start manual for USAID Bureau for Humanitarian Assistance partners and their staff. This guide aims to support RFSAs to develop and implement a WQM program consistent with USAID's Water Quality Assurance Plan (WQAP).

Ensuring and improving water safety requires gathering reliable data and using these data to identify and address problems. This can only occur if 1) partners collect high-quality WQM data and 2) partners use those data to improve water safety. Quality assurance and quality control procedures can help ensure trustworthy data that are fit-for-purpose are obtained from monitoring efforts. A systematic approach to using data to improve water safety, such as a WQAP or water safety plan (WSP) can ensure that the collected data are translated into action.

This guide covers planning, analyzing and using results from WQM. It details the typical responsibilities and activities for WQM program enumerators (on-the-ground staff or contractors), who collect and analyze water quality samples, conduct field surveys, report results and other operational data collection roles. It is important to accompany this guide with in-depth and hands-on training and supervised practice of water quality monitoring skills and activities.

Improving water quality through monitoring is a continuous process. As monitoring programs collect data over time, they will find new problems and opportunities and take new steps to improve water safety. While this guide provides options and suggestions, and links to external resources that can help partners identify actions to take based on monitoring data, ultimately partners are responsible for determining how best to use WQM data to improve water safety through a dynamic and participatory process such as those encompassed by the WQAP or WSP frameworks, together with community, government and other stakeholders. No manual can address every possible scenario, and partners must remain adaptive and proactive as they work to ensure safe water.

If additional help and support are needed, partners may contact PRO-WASH, USAID, the authors or other potential resources for additional support and suggestions as feasible and appropriate. QR codes and hyperlinks throughout the text direct readers to additional content where relevant.

Please note that the contents of this work are accurate to the best of the authors' knowledge and provided in good faith. However, it is the responsibility of partners and implementers to take all necessary steps to ensure they are protecting the health, safety and rights of water system users, water quality monitoring staff and stakeholders and other participants, as well as complying with all applicable national, subnational and other laws, regulations and requirements. Furthermore, while this guide summarizes instructions for some water quality test methods, manufacturer's instructions should always be consulted for any test method or product.

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Abbreviations and Acronyms

BHA	USAID Bureau for Humanitarian Assistance
CFU	coliform forming units
CQI	continuous quality improvement
EPA	United States Environmental Protection Agency
FCR	free chlorine residual
GIS	geographic information system
ICP-MS	inductively coupled plasma mass spectrometry
IDC	initial demonstration of capability
IWA	International Water Association
MST	mobile survey tool
NGO	nongovernmental organization
NTU	nephelometric turbidity units
PPE	personal protective equipment
QA/QC	quality assurance and quality control
RFSA	Resilience Food Security Activity
TDS	total dissolved solids
USAID	United States Agency for International Development
WaSH	water, sanitation and hygiene
WHO	World Health Organization
WI	The Water Institute at the University of North Carolina
WQAP	Water Quality Assurance Plan
WQ	water quality
WQM	water quality monitoring
WSP	water safety plan

Microsoft Powerpoint was used to generate some of the graphics in this document.

Introduction

What is water quality monitoring?
Why do we do it?

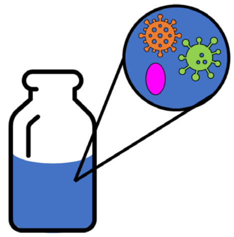
1. What Is Water Quality?

Definition

Water quality (WQ) refers to how safe water is for human use, especially for drinking. Ensuring water quality is an important part of the activities of most resilience food security activities (RFSAs), because safe water is vital to many RFSA aims. It includes a description of water's chemical, biological and physical characteristics known as **parameters** (see box). Unwanted substances in water are called **contaminants**.

Types of Contaminants

Contaminants can be biological, chemical or physical. **Biological** contaminants include microorganisms, or microbes that can cause illness (these are called pathogens). They usually enter water via human or animal waste. **Chemical** contaminants include salts, metals, pesticides and more. They may come from natural sources or human activity. **Physical** contaminants include sediment and particles and are not generally a major health hazard in drinking water.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Health Risks and Harm

RFSAs recognize that safe water is essential for health and opportunity. Some parameters are contaminants, such as arsenic and fluoride, which can directly harm human health at sufficient levels. Other parameters such as turbdity and *Escherichia coli* are known as **indicators** and are measured because their presence indicates harmful contaminants may be in the water, although the indicators themselves may not be harmful. Parameters such as high electroconductivity (salinity) can also make water unpleasant to drink, and this may cause users to choose other, potentially unsafe sources.


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Collecting water from a borehole with a hand pump


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Filling a jerrycan from a shared piped source

Health hazards posed by water contamination generally depend on:

1. The types of contamination present (what is in the water)
2. The level or intensity of contamination (how much there is)

Most contaminants that can cause harm are also called **pollutants**.

CONTENTS

Example Parameters for Characterizing Water Quality

Salinity describes the salt content of a water source and is related to electroconductivity.

Turbidity is a measure of the cloudiness of water, usually caused by fine suspended particles (soil, sediment, algae, etc.). When turbidity is high, microbial contaminants are often present as well.

pH describes the acidity of water. pH 7 is a neutral value (neither acidic nor basic). Values lower than 7 indicate acidity. Values higher than 7 indicate water that is basic. The pH of drinking water should generally be between 6.5 and 8.5.

2. Why Is Water Quality Monitoring Important?

What Is Water Quality Monitoring (WQM)?

Water quality monitoring (WQM) is the ongoing sampling and analysis of water to determine contaminants and conditions. It is often done to make sure water is safe for use. Monitoring programs test the water sources people depend on and incorporate sanitary inspections, questionnaires, direct measurements and observations, and other site-specific parameters.

WQM protects human health and the environment.

Why Is Ongoing Monitoring Important?

A one-time test cannot capture the whole picture of water quality. Parameters can change across days or seasons due to weather, physical-chemical processes, human activity or other causes.

Even the best monitoring system cannot quantify all potential hazards in every water drop. Contaminants may be present at some times and absent at others, or may be missed by testing methods. **Repeated, periodic monitoring** using suitable methods is needed to ensure water safety.

What Do WQM Programs Measure and Report?

1. The **quality and functionality of water systems** (pipes, wells, pumps, etc.)
2. The **quality of water delivered** by water systems (measure of contamination)

Rope pump, Niger

Arsenic testing, coastal Gujarat, India

Additional WQM Program Details

Determining Water Safety

Water safety is compromised when a contaminant exceeds national or international standards, or when problems occur in a water system that make it vulnerable to contamination. Detection of either type of hazard may prompt action. The absence of such hazards in WQM does not necessarily guarantee that a water system is safe.

Hazard Identification

Well-designed monitoring programs allow analysis of hazards in water systems to enable their prevention, management or removal.

Decision-making

WQM programs can help inform decision-making throughout the construction, management, maintenance, operation and use of water systems and services. Over time, WQM data can help enhance the management of safe water service delivery and minimize exposure to waterborne hazards.

How Does Water Quality Affect Nutrition Outcomes? Why Include WQM in Multisectoral Food Security Activities?

Use and consumption of safe water improves nutritional outcomes. Some microorganisms in water are **pathogenic** — meaning they can cause infections. Such infections can result in malnutrition through:

- Loss of calories, water, iron, or electrolytes.
- Reduction of nutrients absorbed in the body.

One common symptom of pathogenic infections — diarrhea — can contribute to the risk of undernutrition, especially when repeated cases occur in childhood.

Preventing high levels of other hazards in drinking water can also help reduce adverse health effects. For example, arsenic, fluoride and lead can all interfere with healthy child development.

To improve nutritional outcomes and food security, it is important to monitor for microorganisms and other contaminants in water.

3. Water Sources, Storage and Points of Use

A **water source** is the location from which households obtain water, such as a tap or borehole. This can be surface water, a borehole, a well, a spring or piped water. Samples are collected at water sources to monitor the quality of the water that people are collecting and help with understanding how water supply systems are performing.

The **point of use** is the place where households use and consume water, usually the home. The quality of water consumed at the point of use may be very different from that at the source because water can become contaminated during transport, storage and use. Some WQM programs sample at the point of use

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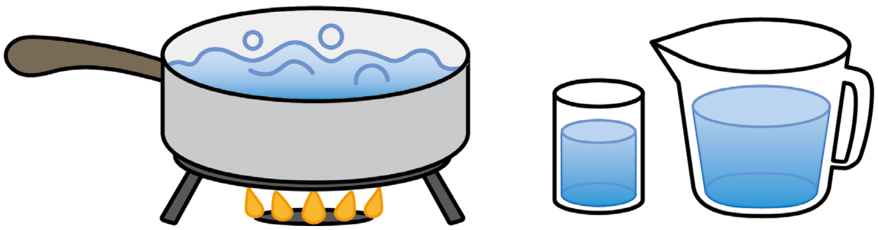
Collecting a sample from a water source



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Water being treated (boiled) at the point of use

in a few households in each community to help understand and improve the safety of the water people are using.

Water can be treated at a central location before it is collected, at the point of collection, or at the point of use. Water treatment that takes place at a water source is often called **point-of-collection treatment**. Water treatment that takes place at the point of use is called **point-of-use treatment**. This can improve the quality of water consumed.

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Stored water

4. Public Trust and Perceptions

Public Trust

Safe water helps protect human health and support economic development. Clear and transparent communication of WQM activities and results to the public can help build trust in these activities and also enable communities to better understand and manage issues that affect their water quality.

An important part of building trust is the open acknowledgment (either internally or publicly) of failures in monitoring or water quality. **Monitoring failures** are mistakes in data collection or planning. **Water quality failures** occur when potentially harmful water is supplied. Both types of failures should be analyzed and corrected to build trust.

When such failures occur, acknowledging them helps to:

- Create a culture of accountability. Team members can address problems within an organization or within the programs or projects.
- Build trust with community members by working alongside them to correct the failure and improve for the future.

Examples of Failures

Monitoring

- Recording inaccurate results
- Using a testing method that is not effective or accurate
- Lacking the infrastructure to monitor correctly
- Collecting data that are not useful
- Trying to monitor too many things

Water Quality

- Does not meet national standards
- Does not achieve targets set by your organization
- Does not improve with intervention

Perceptions and Experiences

Though you should use data fit for purpose to make decisions, community perceptions, experiences and stories can be helpful in the evaluation of a water system. Pursuing these sources of information may help provide context during decision-making or may make it easier to understand why a current problem exists.

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Ensure clear, appropriate communication when failures are acknowledged at the community level.

5. Basic Units of Measurement

Chemical Concentrations and Conversions

These units of measurement generally follow the same formula:

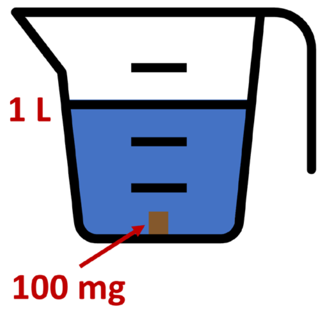
$$\frac{\text{Amount of substance}}{\text{Volume of sample water}} = \text{Concentration}$$

Some units are expressed in terms of mass or weight of a substance per liter of water:

µg/L = micrograms/Liter
mg/L = milligrams/Liter
Note: 1 mg/L = 1,000 µg/L

Note that two of the units above are equivalent to either parts per billion (ppb) or parts per million (ppm). These represent parts of substance per million parts of the surrounding volume (such as water):

ppb = parts per billion = **µg/L**
ppm = parts per million = **mg/L**
Note: 1 ppm = 1,000 ppb



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For example, if there is 100 mg of an unknown substance in 1 L of water, the concentration of the unknown substance is 100 mg/L or 100 ppm.

Other Measurements

NTU = nephelometric turbidity units (standard unit)
µS = microSiemens (standard unit of electroconductivity)

Priority Water Quality Parameters

1. Water Quality Parameters and Their Health Importance

USAID recommends/requires monitoring water sources for the following eight parameters: **electroconductivity**, **total dissolved solids** (TDS), **turbidity**, **pH**, **nitrate**, **arsenic**, **fluoride** and ***E. coli***. Brief introductions to these parameters and their health effects are provided below.

Depending on your program's resources and location, as well as your country's drinking water quality standards, you many want to monitor additional parameters.

CONTENTS

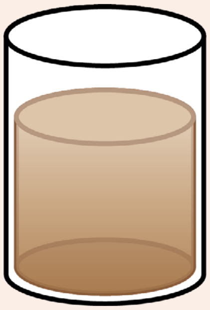
Physical and Aesthetic Parameters

Electroconductivity

- **The ability of water to pass an electrical current**, which depends on salts and inorganic chemicals present in the water. Varies with water temperature.
- **Changes in electroconductivity** mean that the concentration of salts and inorganic chemicals in the water have also changed. This may indicate the presence of new or additional contaminants in the water.
- High measurements may occur due to increased salt content and may give clues as to the underlying geology affecting drinking water.
- High salinity can lead users to abandon drinking water sources and sometimes switch to less safe sources.
- Drinking very salty water can cause serious long-term health problems.

Turbidity

- **A measure of the cloudiness of water**.
- Caused by suspended particles in the water (algae, dirt, minerals, proteins, oil, bacteria, etc.) that aren't individually visible but scatter light.
- **Does not directly affect human health**.
- High turbidity is often associated with the presence of microbial contamination in drinking water.
- High turbidity can limit the effectiveness of some water treatments including chlorination.
- Highly turbid water may be off-putting for consumption.



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Total Dissolved Solids (TDS)

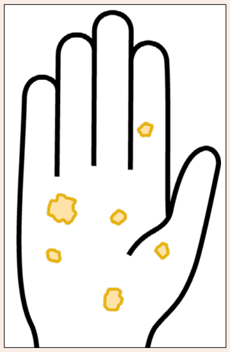
- The **inorganic salts and small fragments of organic matter in solution** in water.
- Similar to electroconductivity in occurrence and effect.
- Typically consist of calcium, magnesium, sodium and potassium cations and carbonate, bicarbonate, chloride, sulfate and nitrate anions.
- **Spikes or sudden changes in TDS may indicate a new source entering the water system**.
- High TDS may affect the taste of the water, which may cause people to choose other, less safe sources of water.

Chemical Parameters

pH

- Measures **how acidic (low pH) or basic (high pH) water is**.
- Typical pH levels (6.5-8.5) pose no threat to human health.
- **More extreme pH levels in drinking water can indirectly affect human health**. Highly acidic water in particular can corrode pipes and plumbing, contaminating water with metals present in pipes and fixtures, and can dissolve minerals in rocks and soil, leading to high concentrations of elements present in these materials. Where toxic elements are present, they can cause health problems.

Arsenic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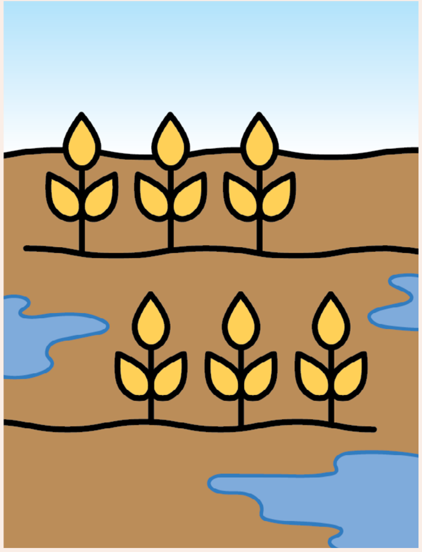
- **A chemical that naturally occurs in rocks.** It may also be generated by industrial activity.
- Can be absorbed into food crops such as rice. Detecting its presence in drinking and irrigation water is important.
- **Short-term exposure can cause acute poisoning**. Exposure can also have negative effects on fetal and infant health and development.
- **Long-term exposure can cause negative health impacts** such as cancer, skin lesions and poor cognitive development.

Fluoride


JUDE COBBING

- **A naturally occurring element that may be present in water** (typically groundwater) **as the result of contact with mineral deposits**.
- At lower levels, provides dental benefits for consumers by helping prevent cavities.
- At higher levels, excessive fluoride can bring about negative health effects such as dental fluorosis, which affects the appearance of teeth, and skeletal fluorosis, which contributes to chronic weakening of bones.

Additional chemical parameters may include lead, copper, mercury, phosphorus and ammonia.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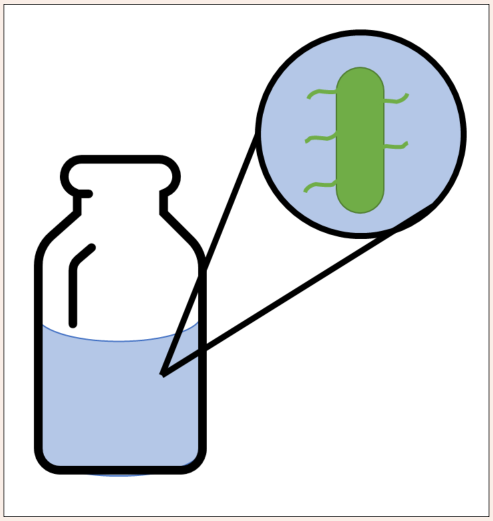
Nitrate

- A **chemical contaminant** typically originating from agricultural activity or from human and animal waste.
- Low-level consumption is rarely harmful.
- High-level **consumption may be associated with health problems** such as poor circulation or oxygenation of the blood.
- Exposure is harmful primarily for infants and in extreme cases can cause methemoglobinemia, a rare condition in which blood cannot properly oxygenate.
- Can indicate that agricultural runoff is present in the water, which also may include additional contaminants such as pesticides or fecal matter.

Microbiological Parameters

E. coli

- **Fecal indicator bacteria** commonly present in the feces of mammals. The presence of *E. coli* often indicates fecal contamination in water.
- Concentration is measured in coliform forming units (CFU) per 100 mL (CFU/100 mL).
- Most strains are nonpathogenic, meaning they do not cause disease, but some strains are pathogenic and can cause infection. Symptoms of infection include diarrhea, stomach cramps, nausea, vomiting and fever. Less commonly, more severe symptoms can include bloody diarrhea, blood problems, kidney infection or urinary tract infections.
- *E. coli* may not always cause an infection, but its presence means that other infectious fecal pathogens may also be present (see box below).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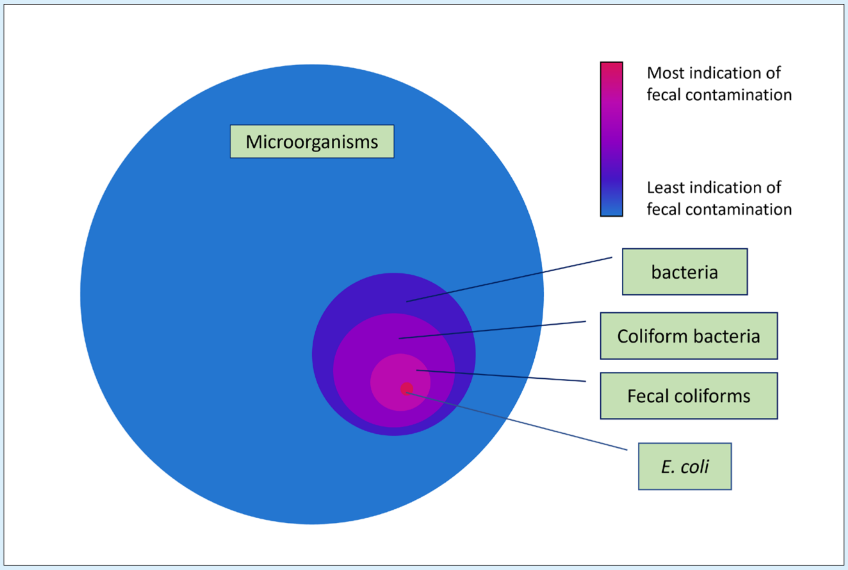
Why Do We Use *E. coli* as "Fecal Indicator Bacteria"?

Microbiological contaminants can enter water systems through the intrusion of water contaminated by feces (fecal contamination). Consuming this water can cause disease. Microorganisms that can cause infections are called **pathogens**. They can include bacteria, viruses, protozoa and helminths. Infections with these pathogens can cause diarrhea, malnutrition and a weakened immune system. The risk of infection depends on which pathogens are in water, their concentrations and the underlying health and immune status of the person drinking the water.

It isn't efficient or even possible to test for each type of microbiological pathogen that might be in a water system. Instead, we can test for **fecal indicator bacteria** that indicate the likelihood of fecal contamination. When fecal indicator bacteria are present, the risk that pathogens are also present is considered to be elevated. Fecal coliform bacteria are found in the environment and the digestive tracts of mammals. *E. coli* are a type of fecal coliform bacteria that are strongly associated with fecal contamination and therefore make good fecal indicator bacteria.



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The relationship between *E. coli* and other common microbiological parameters, as well as how strongly the presence of these can indicate fecal contamination.

Additional microbiological parameters may include total coliforms and fecal coliforms.

2. Guideline Values and Regulatory Limits

Guideline values and **regulatory limits** for water quality parameters are established to protect the health of water consumers. Countries set regulatory limits, and drinking water systems are required to meet them. The World Health Organization (WHO) publishes guideline values that are not enforceable but provide guidance that countries can consider when establishing national regulations. Partners should consult national regulations as well as limits recommended by specific programs, sponsors (such as USAID) and WHO as relevant. The table below includes standards for the eight USAID priority parameters.

Water Quality Standards

Make sure to consult your national standards. If values from two sets of standards conflict, follow the more restrictive.

Parameter	Units	U.S. Environmental Protection Agency Maximum Contaminant Levels	World Health Organization Guideline
Electroconductivity	µS/cm (microSiemens/cm, sometimes presented as micromhos/cm)	1,600 µS/cm	N/A
TDS	mg/L	500 mg/L	None
Turbidity	NTU (nephelometric turbidity units)	5 NTU	N/A*
pH	Values from 0 to 14 (does not have units of measurement)	6.5-8.5	None
Arsenic	µg/L (sometimes reported as ppb by test kits)	0.01 mg/L	0.01 mg/L
Fluoride	mg/L	4.0 mg/L	1.5 mg/L
Nitrate	mg/L N, or mg/L NO_3 (mg/L nitrate)**	10 mg/L as N	50 mg/L as NO_3
Fecal coliform, *E. coli*	CFU/mL (coliform forming units/mL)	0/100 mL	<1 CFU/100 mL

* No official guidelines found, but some WHO documents suggest <1 NTU as a target or 5 NTU for small suppliers in low-resource settings.
**Nitrate concentration can be reported "as N", or "as NO_3". 10 mg/L nitrate as N is equivalent to about 49 mg/L nitrate as NO_3. Similarly, 50 mg/L nitrate as NO_3 is equal to about 11 mg/L nitrate as N

Free Chlorine Residual

When chlorine, a common disinfectant, is added to water, it reacts with contaminants and organic material in the water. After these reactions, some chlorine may remain that is available to inactivate disease-causing organisms. This is referred to as free chlorine, or **free chlorine residual** (FCR).

The presence of adequate FCR suggests that the water sample had enough chlorine present to kill most harmful microorganisms and prevent recontamination during delivery and storage, and as a result the water is likely to be safe to drink.

If your system uses chlorine, your government may have guidelines for minimum FCR concentration that should be present. Typical values are 0.2–0.5 mg/L. Concentrations greater than >2 mg/L affect taste and may result in stakeholders choosing alternative water sources. Simple meters and test kits can enable you to test for FCR.

Quality Assurance / Quality Control

If results are somewhat outside of acceptable norms, this may indicate a **water quality problem**. However, if results are so far outside expected ranges that they are unlikely to be accurate, this can indicate an **error** (for example, nitrate concentrations of 10 mg/L may indicate a water quality problem, but concentrations of 10,000 mg/L are likely an error).

Learn more in the "Data Management and Analysis" section.

How Monitoring Improves Service Delivery

1. Ensuring Water Safety

The goal of your monitoring program is to ensure water safety by preventing contamination, managing risk and verifying that your actions are effective. Physical inspections are an important tool in this process. They can establish a baseline for water source functionality and identify potential problems early.

Prevention

Your first goal should be to prevent water from being contaminated. This can be done by improving infrastructure to protect sources or by adding water treatment to piped networks. Problems are cheaper to solve when they are identified early.

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Prevent infrastructure failures with early maintenance as issues arise.

Management

When you find a problem, address it with remediation (improvements). This may mean using outside sources to help select the correct improvement.

Verification

Once you have managed a problem, use your **Water Quality Assurance Plan** (**WQAP**, see next section) or monitoring plan to test water quality and confirm the new water is safe.

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This handpump may be loose at its base (the area inside the orange magnifying glass). The flange plates above the base may be missing a bolt that holds the connection together to prevent intrusion of contamination during extreme weather events. A missing bolt could also contribute to leaks that could wash fecal contamination into the borehole. When using a WQAP to monitor frequently, you can identify and correct these problems before they have harmful effects on communities.

How Does My Organization Ensure Water Safety Practically?

Your organization can work toward water safety if it takes intentional, proactive measures to protect water quality. This can be done using a WQAP (described in the next section) or other frameworks such as a Water Safety Plan to monitor and evaluate the quality of your water and the effectiveness of improvements.

This may mean that you need to:

- Add evaluation elements to your WQAP or monitoring plan.
- Sample more frequently to track progress to water safety goals.
- Evaluate water at more points than the minimum required (new) infrastructure locations.

2. Sanitary Inspections

What Is a Sanitary Inspection?

A **sanitary site inspection** is a physical inspection that identifies the ways that a water source is vulnerable to contamination. Answering yes/no questions about what you observe at the site helps determine the risk factors for a drinking-water supply system and identify what needs to be done to protect public health.

Conducting a Perimeter Walk

What Is a Perimeter Walk?

In a sanitary inspection, a **perimeter walk** allows you to systematically scan the area around a water point for potential sources of contamination. Most contaminants (e.g., *E. coli*) are not visible, but sources such as latrines or open sewers should be.

How to Do a Perimeter Walk

1. In the office, **measure** how many paces equals 10 m.
2. In the field, **walk 10 m** from source.
3. **Make a loop** around the source, staying 10 m away.
4. Look toward the source as you walk, **noting any excreta/contaminants** inside the circle.
5. Make a **second loop**, looking for excreta/contaminants outside the circle (within 30 m of the source).

Questions to Ask During a Perimeter Walk

- ❑ Are there any **latrines** within 10 m of the water point?
- ❑ If a latrine is present, is it on **higher ground** than the water point?
- ❑ Is there **human excreta** on the ground within 10 m?
- ❑ Is there **animal excreta** on the ground within 10 m?
- ❑ Is there a **sewer or gutter receiving sewage** within 10 m of the water point?
- ❑ Are there **other types of contamination** within 10 m?

Be sure to watch out for snakes, animals and other harmful objects while conducting a perimeter walk.

Questions Encountered During Sanitary Inspection

The form you fill out during a sanitary inspection may look similar to this. The questions below are real questions you should ask and answer during an inspection. The questions asked during sanitary inspections can be adapted to your context and water source type. More examples of questions can be found on the next page.

Are the above-ground parts of the water source hardware loose at the point of attachment to the base (which could permit water to enter the casing)?	❑ Yes ❑ No	Comments:
Are there signs of leaks in the main pipes feeding the system? Are pipes exposed within 10 m of the water point?	❑ Yes ❑ No	Comments:

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Is there adequate fencing around the water point to keep animals out?

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Does the water point have a full cement apron?

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Are there visible cracks on the cement floor?

MIKE FISHER

Do the walls/sides of the concrete pad go below the ground at all points?

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Does the water point have cement walls? Are there any cracks in the walls?

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Is the base of the water point adequately sealed so that outside water can't enter?

MIKE FISHER

Does the water point have a drainage channel? Is the drainage channel broken, cracked or in need of cleaning? Is it full of still water?

MIKE FISHER

Does the water point have a cement floor? Is there any ponding of still water within 2 m of the floor?

3. How a Water Quality Assurance Plan (WQAP) Can Help

What Is a WQAP?

A **Water Quality Assurance Plan** (WQAP) is a tool used by USAID partners to monitor and improve water quality. It is designed to improve water quality and service through standardized, robust monitoring. A WQAP helps to improve and maintain water quality by:

- **Identifying potential water quality issues**.
- **Preventing harmful impacts to water** by using early and practical measures.
- **Responding to water quality issues** when they are identified through monitoring.

Is a WQAP a Permanent Plan?

A WQAP is a document that helps your organization build toward a comprehensive, permanent plan. This means the WQAP will change over time as your organization's capacity grows.

A WQAP should:

- **Act as a starting point** for water quality monitoring when there is no existing plan.
- **Add additional monitoring tools and analysis** as needed.
- **Build toward a permanent, risk-based monitoring program** such as a Water Safety Plan (WSP).

Should My Organization Use a WQAP?

The WQAP is one of many tools that can be used to improve water service delivery. An organization **should use a WQAP** if it:

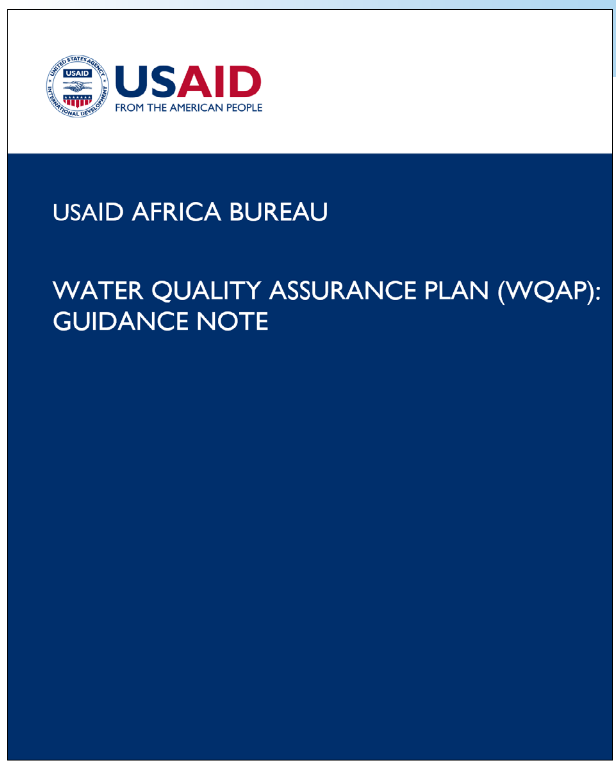
- Operates a small water system.
- Operates a rural water system such as a single borehole.
- Operates a water system that was developed in partnership with a USAID project.
- Has completed an Initial Environmental Examination.
- Has new water system infrastructure or improvements.
- Has no existing water quality monitoring plan in place.

Ready to Fill Out a WQAP?

Your WQAP will be **unique to your organization's monitoring needs**. This guide is meant to help you contextualize and understand the WQAP, but to write a WQAP, please use **USAID-specific resources**. When filling out your WQAP, you should:

1. Scan this code to visit the USAID site that features the **WQAP template**.
2. **Conduct the research needed** to complete each section (that is, identify your resources and what needs to be monitored). The following page includes a description of each section.
3. Complete the document according to the **guide rules**.

https://www.usaid.gov/environmental-procedures/environmental-compliance-esdm-program-cycle/special-compliance-topics/water



USAID

Ensuring a Strong Monitoring Program

Regardless of the framework used to build it, the strongest WQM programs are:

Proactive
Your organization monitors for problems before they occur. With good data analysis, you can identify where contamination may reach your water and fix those problems early. The opposite practice is reactive, which means responding to problems only when they are already harming health.

Data-focused
Solid data are the one tool you can rely on in monitoring. Build up your data analysis capacity. Plan how you will use data. Collecting data without using it is a waste of time and resources.

Forward-thinking
Your organization's work has a significant impact on the community. The program must recognize that some remediation practices, such as closing down failing water points, may result in the use of worse, unmonitored sources of water or threaten availability. Avoid closing water sources whenever possible. Plan into your program how you will ensure the continued safety and availability of water before making decisions.

How Does a WQAP Work?

Establishing a WQAP will guide you to think through many aspects of your community's water quality and water-delivery infrastructure, including the following:

INTRODUCTION

Provides context for making decisions about your monitoring plan and helps identify issues that may arise

- The region and population you are working with.
- Existing water system characteristics, vulnerabilities and future improvements.
- Barriers to success and how to overcome them. Barriers include access to laboratories, level of training, budget limitations and more.

REGULATORY ASSESSMENT

Helps identify what parameters to include in a monitoring scheme, including site-specific parameters

- The laws and regulations on water quality that set safety standards and drive water quality monitoring.
- Historical water quality issues, trends and land-use-related contaminants to include in a monitoring program.
- Your organization's capacity (financial, human resources, logistical and access to external laboratories).

RESOURCES AND METHODS

Solidifies your collection and analysis methods and determines which parameters will be tested using field methods.

- The methods, tools and techniques used to collect and analyze water samples.
- The field-based and/or laboratory water quality testing capacity available for sample analysis.
- The capacities and quality assurance / quality control practices of third-party laboratories.

SUSTAINABILITY

Identifies how you will maintain monitoring when your program reaches its conclusion

- The capacity of local organizations to take over monitoring and analysis responsibilities after the conclusion of the program.
- How professionals, committee members and/or community members members will be trained to carry out monitoring.

REMEDIATION

Identifies who is responsible for improving water quality when problems are found

- How information from monitoring will affect decision-making on water points.
- Who will be responsible for repairing, rehabilitating, or (as a last resort) closing or replacing water points when water quality problems arise.

4. How Water Quality Monitoring Supports WQAP Implementation

Your water quality monitoring (WQM) program will support the WQAP process by providing data in these three major areas:

- **Which parameters** you monitor.
- **How often** you monitor.
- **Where** you monitor.

How Else Does Monitoring Help?

A WQAP should be used to see if infrastructure or interventions are improving water quality. Monitoring helps determine whether solutions were effective or if additional work is needed.

Which Parameters You Monitor

WQAP Parameters Tested
TDS
Electroconductivity
Turbidity
pH
Arsenic
Fluoride
Nitrate
E. coli
Cyanide
Phosphate
Lead

The USAID eight major parameters will be included as well as site-specific parameters, such as cyanide, phosphate and lead.

Your WQAP will generally require that you monitor for the eight parameters indicated by USAID in addition to other site-specific parameters.

If you are monitoring parameters beyond the USAID eight, explain why you are including each one in the regulatory assessment section of your WQAP. Reasons could include knowing or suspecting a contaminant to be in an area at levels of health concern, or the contaminant being monitored as a part of a different monitoring program.

How Often You Monitor

Each parameter should generally be monitored at least annually in water systems, with *E. coli* and turbidity monitored more frequently if feasible to capture seasonal variability. More frequent monitoring for *E. coli* is recommended by the WHO for systems serving large numbers of people. Furthermore, additional sampling and measurement should be done when:

- An infrastructure project is about to begin.
- Infrastructure is about to be commissioned or opened.

The following are highly recommended as good practice:

- Infrastructure has had repairs or damage (cracks, leaks) has been observed.
- A major rain or drought event, including floods, has occurred.

Where You Monitor

A WQAP typically requires monitoring water at **newly constructed** water points or infrastructure as well as on an ongoing, regular basis throughout the system.

The goal of monitoring is to protect and improve human health, so it is important to monitor at the locations where water is consumed. This may mean adding monitoring at other pumps, wells and piped networks, as well as household monitoring in more robust monitoring programs.

KAIDA LIANG

5. Using a WQAP to Improve Water Quality

A WQAP can be a useful tool when an organization uses it to improve data collection and then uses the findings to improve water quality. It is most useful for creating **a plan that can identify areas of concern about water quality and guide partners toward helpful solutions**. An organization should be willing to rely on the data generated by WQAP-related water quality monitoring for answers and guidance. This will allow for responsible decision-making from high-quality data.

Your WQAP can be most useful to help:

- **Generate data**. Use the WQAP to identify systems, contaminants and areas of concern for the community's health related to water safety and services and conduct additional testing as needed to track progress.
- **Identify problems**. Invest time and effort in good data analysis, including summary statistics disaggregated by source type and season, as well as geospatial analysis. These tools can help you find and address emerging problems in the community's water.
- **Cautiously remediate water quality issues**. Your goal is to improve water safety and availability. Preventing problems is best. Remediating problems once they occur is next best. Closing water systems is usually a last resort since water quantity as well as quality is vital for communities.

If your solution includes closing water points, make sure sufficient alternative water points are available, working and have water of equal or greater quality.

JUDE COBBING

1. What Data to Collect

If you are using paper-based data collection, check off each of these items in your data collection process. If you are using a mobile survey tool (MST), make sure the survey includes each of these data points.

Basic Information

- ❑ Name of Collector
- ❑ Employee ID
- ❑ Project ID
- ❑ Date
- ❑ Time

Environmental Data

- ❑ Air temperature
- ❑ Water temperature
- ❑ Sanitary inspection
- ❑ Recent rainfall events
- ❑ Flow rate (if applicable)
- ❑ Water level (if applicable)

Parameter Data

- ❑ Kit used
- ❑ Measurement results
- ❑ Where parameter is measured (in the field or in a lab
- ❑ Laboratory code, if used

Community Data

- ❑ Community code
- ❑ Coordinates
- ❑ Source type
- ❑ Timing of draw
- ❑ Sample preservation

https://www.usaid.gov/documents/1860/wqap-annex-7-standard-operating-procedures-field-measurements-and-sample-collection

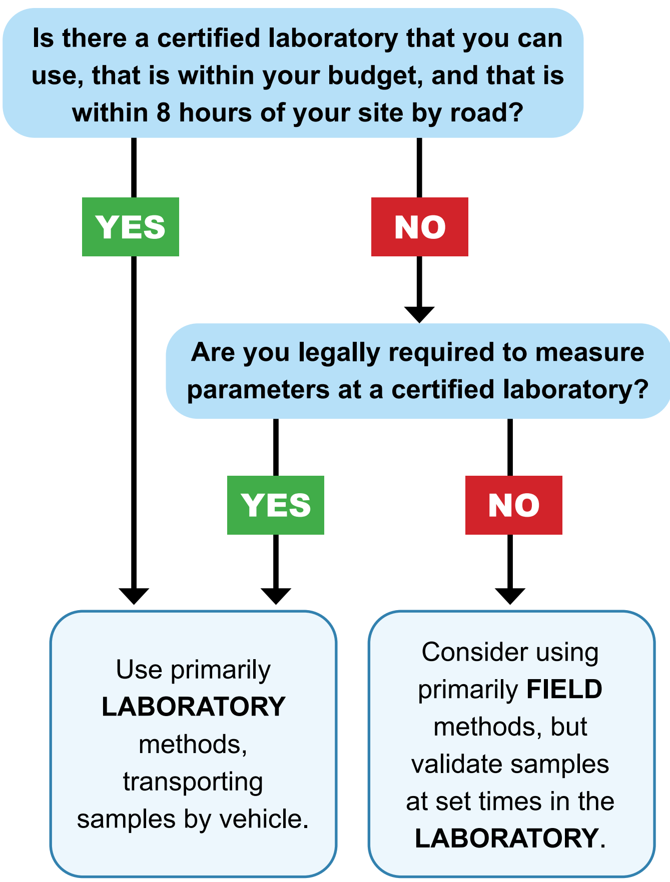
CONTENTS

Data Collection Tip

You should **standardize how you record data** across your organization. For example, your organization should make a decision on recording parameters in ppb, standardizing spellings of chemicals and standardizing codes.

2. Laboratory vs. Field Measurement

You may use different methods depending on the parameter being tested. If using a laboratory, ensure that it is able to measure for each intended method. A mix of laboratory and field kit measurements often can be useful. The flow chart below can help you decide which method would be the best fit for your monitoring program.



Laboratory Capacity Tip

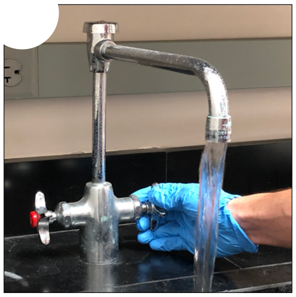
If you are sampling far from accessible certified laboratories, consider requesting permission to use university laboratories or field-based methods, or to increase sample hold times up to 18 hours on ice, if needed and if permissible. Over time, supporting development of certified laboratory capacity where needed may be explored if appropriate and feasible.

In the Field: pH and FCR

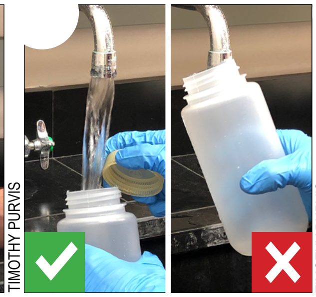
You'll need to sample for pH and potentially free chlorine residual (FCR) in the field regardless of laboratory use!

3. Collecting Samples

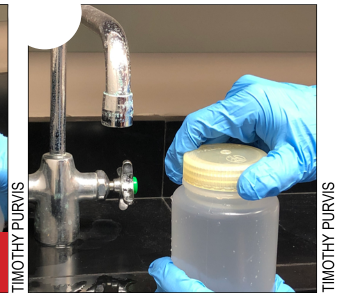
Piped Water



Open tap fully.



Put container under the flow, not touching tap.



Turn off tap and seal container.

Pumped Ground Water

Pump water.

Put container under the flow, not touching tap.

Measure flow rate while sample is collected.

Best Practices: Sampling

1. To avoid contaminating a water sample, **put the cap on** as soon as the sample is collected.
2. **Do not let the cap touch** the ground, soil, or surfaces that may introduce new contaminants.
3. If you are sampling in uncovered wells or open water, you may want to **hold the sample container with a stick** or other device so that you don't need to lean over and risk falling into the water.
4. The analysis method or laboratory will usually specify the size of the sample that needs to be taken, but if not then a sample size of at least 500ml is recommended.

Collecting Useful Data

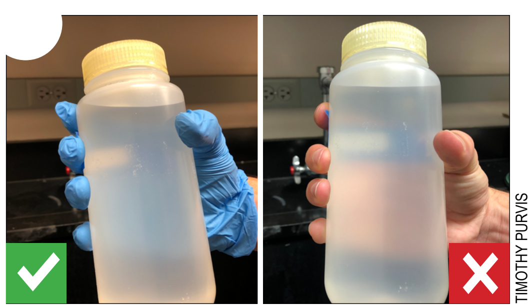
- Collect a sample the same way a **regular user** would.
- Keep the sample **sterile**, with no outside contamination.

Sterile Technique

Use containers and lids that are unused or bought for sampling.

Clean sample containers thoroughly, following standard practice.

Never touch the inside of the container or the cap to any surface once sterilized. Do not leave samples uncapped.



Always use gloves when sampling. If a sample gets contaminated, resample with a backup sample container.

Tap Sterilization Tip

You can use a **flame** or an **alcohol wipe** to **sterilize a water tap** or other water supply hardware. This is only necessary if you are monitoring the quality of water at the source, not the quality of water that people are drinking.

4. Sample Preparation for Analysis, Storage, and Transportation

Preparing for Transport

When you **transport samples** to a laboratory or a second field location keep the containers upright and tightly closed inside a secondary container such as a clean plastic bag that is sealed or loosely tied. That will help minimize contamination of the samples if they leak.

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Sample as above and measure for pH and free chlorine residual (FCR) immediately.

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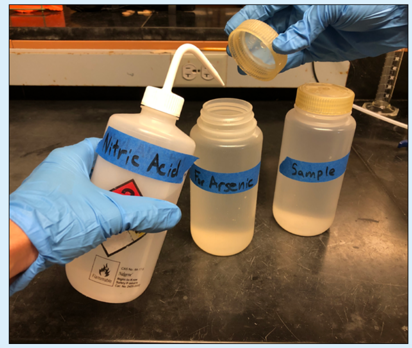
Store samples in a cooler with ice, labeled with barcodes.

Note on Arsenic Samples

If you will be testing for arsenic in a lab, **separate** and **acidify** any samples for arsenic (or by laboratory recommendation).



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Parameter Storage Times and Conditions

pH, **free chlorine residual (FCR)**	Must be tested in the field immediately after the sample is taken. Preservation may skew results.
Total dissolved solids (TDS), **electroconductivity**, **nitrate**, **fluoride**	Must be stored at 4°C. Can be processed within 7 days of sampling.
Arsenic	Must be stored at 4°C. Should be stored separately from other parameters and acidified with nitric acid. Can be stored for up to 6 months.
E. coli, **other microbial parameters**	Must be stored at 4°C. Begin processing within 8 hours. In remote locations where travel times to field sites are more than 8 hours, partners may store samples at 4°C for up to 18 hours if the results will not be used for regulatory compliance purposes.

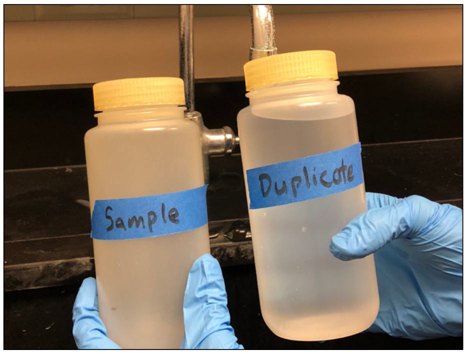
Sample Preservation Tips

- Bring a **cooler** AND **ice**.
- If you are collecting more than one sample, put all the empty sampling containers in the cooler with ice ahead of time to make sure you will have **enough space** for them.
- Don't use handwritten labels. They'll fade or wash off. If possible, **write on stickers** or better still, use **printed barcodes**.
- Plan ahead for **travel** by moto, car, bus, or train, and make sure you will be able to fit your samples in the vehicle safely.

5. Field Quality Assurance / Quality Control

Duplicates

A field **duplicate** is a second identical sample collected right after the first sample an stored, transported, and tested in the same way. Comparing test results for the two identical samples helps determine whether sampling and testing procedures are working properly.



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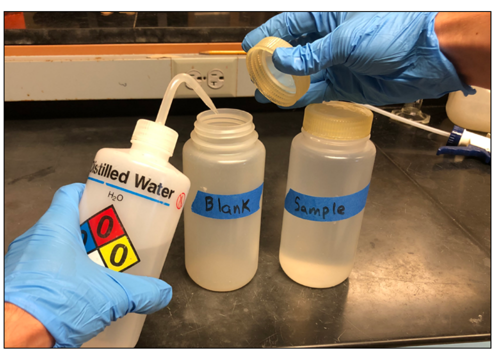
Collecting a duplicate

After collecting a duplicate, measure it the same way you measured the first sample For some parameters you canno collect a true duplicate because first-draw samples may hav different concentrations than later ones. Even so, collecting duplicates is still important. When differences in duplicate samples regularly exceed listed tolerances, sampling methods should be reviewed and improved.

Blanks

A field **blank** is very pure water with known water quality measurements (such as sterile distilled water or bottled water from a trusted brand) that is taken to the field, poured into sample containers, and stored, transported, and tested just like any other fiel sample. Comparing the test results to expected values can help determine whether sampling and testing procedures are working properly.



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Collecting a blank

After collecting a blank, measure it the same way you would normally. If you need to acidify your sample, please collect an extra blank to acidify as well.

When to Collect Blanks and Duplicates

- Collect blanks and duplicates **every 10 sites or samples**.
- If sampling at multiple sites on the same day, take blanks and duplicates at the **first site or sample location**.

Best Practices: Calibration

1 Calibrate methods **weekly** before sampling. Store methods not in use as recommended by the manufacturer. Suitable calibration standards should be purchased for each test kit.

https://blog.hannainst.com/guide-to-environmental-water-quality-testing

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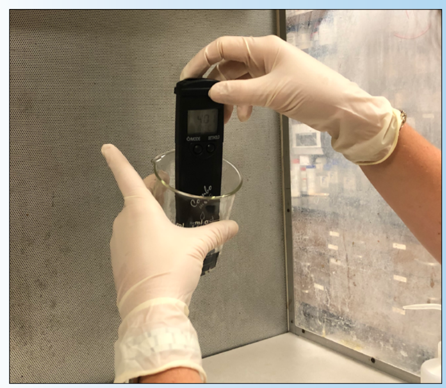

BERKLEY WOOD

In a **controlled setting**, follow manufacturer calibration methods.

3

BERKLEY WOOD

Store all reagents in a **climate-controlled** location away from light.

6. Using Field Kits

Electroconductivity, Total Dissolved Solids and pH

Most field tests for electroconductivity and pH will use a meter such as th electroconductivity/TDS/pH tester shown below as an example. There are several reputable brands of meters available.

> **Note on Total Dissolved Solids**
>
> Electroconductivity is measured as a proxy for **total dissolved solids (TDS)**. TDS can be calculated from conductivity readings if temperature is also recorded.

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Electroconductivity / TDS / pH Tester

1. Uncap the probe.
2. Turn on the meter and set to pH by pressing the "Power/mode" button. An indication of the parameter or parameter units should appear on the screen to show what you are measuring. Press "set/hold" to navigate between parameters and units (e.g., electroconductivity, TDS, pH) if needed.
3. Place the probe (the end that was capped) underwater.
4. Slowly and gently stir the probe.
5. Continue stirring until the reading on the meter does not change for 10 seconds.
6. Record the reading and temperature shown.
7. Recap the probe, making sure to keep it wet.

Turbidity

There are two main ways to measure turbidity in the field: a portable turbidimeter or a turbidity tube

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Turbidimeter

1. Fill the cuvette with sample water, clean the cuvette off, and insert it into the meter.
2. Turn the meter on and run it to get a precise reading.

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Turbidity Tube

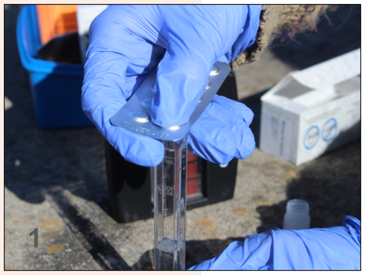
1. Fill the tube with sample water.
2. Slowly drain the water until the marks at the bottom of the tube can be seen.

Nitrate

Nitrate kits can use colorimetry-based methods. Instructions for all colorimetry-based nitrate kits will be similar to those for the kit shown below, but you should consult the instructions of your specific kit

Example: Using a Nitrate Nitrogen Tablet Kit

1. Add 5 mL of sample water to the test tube. Then add 1 Nitrate #1 tablet. Cap and mix until the tablet dissolves.
2. Add 1 Nitrate #2 tablet. Insert the test tube into the protective sleeve. Cap and mix for 2 min. Allow to sit in the protective sleeve for 5 min.
3. Remove from the sleeve and put into the holder. Compare the color of the post-reaction sample to the color chart and record as ppm nitrate nitrogen. (Holding a white sheet of paper behind the color comparator can make the difference in colors easier to see.) Then, multiply the results by 4.4 and record this number as ppm nitrate.



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Chemical Field Kits

In field kits that use **colorimetry**, chemical reagents are mixed with sample water to cause reactions that change the color of the water. This color change is caused by the amount of the pollutant in the water. Colorimetry can be used to obtain concentrations of **nitrate**, **arsenic**, **fluoride**, and other parameters.

Data Recording Tips

Record exactly the result your field kit returns. For example, if it returns <2 ppb, record <2 ppb, NOT 0 ppb.

Make sure to record the units your field kit uses. This could be ppb, ppm, μS, μg/L, mg/L as NO3, or mg/L as N.

Creating a Field Measurement Station

When setting up to test water samples in the field

1. Choose a **well-ventilated** location with a **flat surface** (indoors or outdoors).
2. Clear off any **debris**.
3. Set up field kits carefully to **prevent spills**.
4. Prevent **papers from blowing away** by setting heavier objects on them.
5. **Pack away** each field kit once you have finished using i

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Example of a field measurement station in use. Field kits not in use are packed away. Papers are held down with an object.

Arsenic

Arsenic kits can use colorimetry-based methods and can be aided by the use of a meter. Instructions for two colorimetry-based arsenic kits are provided below, but you should consult the instructions of your specific kit

Make sure you are in a well-ventilated location when using arsenic field kits. Arsine gas produced by the kits can be hazardous.

Example: Using the Arsenic Quick™ II

1. Fill the clear sample holder with sample water up to the etched line.

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2. Add 2 scoops of the firs reagent, cap, and shake for 15 seconds. Add 2 scoops of the second reagent, cap, and shake for 15 seconds. Let it sit for 2 minutes. **Check your kit's instructions** on adding reagent and how long to shake and sit.


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3. Prepare the turret cap by lifting the close mechanism. Open a test strip at the visible perforations. **Do not touch the other end of the strip.** Place the paper end between the closing mechanism and the hole in the cap and close fully.


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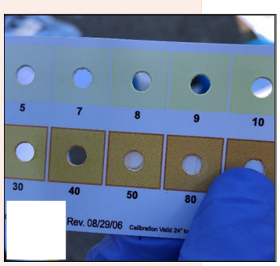
4. Add 2 scoops of the third reagent. Recap the container and shake vigorously for 5 seconds.
5. Remove the black cap and add the turret cap. Seal tightly.



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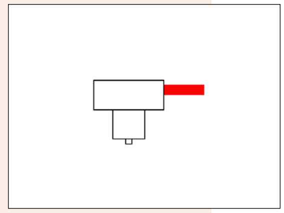
6. After sitting, compare the results with the color chart provided in your field kit, such as seen in th picture on the right.
7. Dispose of the paper strip in the kit's waste bag.

Example: Using the Palintest Digital Arsenic Test Kit (Arsenator)

1. Add the respective filte papers to the bung device, black slide, and red slide. Insert the red slide into the bung device.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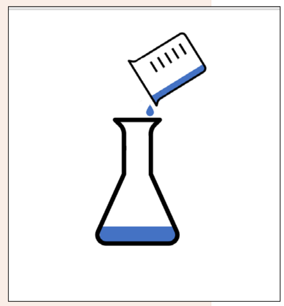
2. Turn on the DigiPAsS and insert the black slide to calibrate it.
3. Insert the black slide into the bung device.
4. Add 50 mL of sample water to the flask. Add the contents of the A1 sachet to the flask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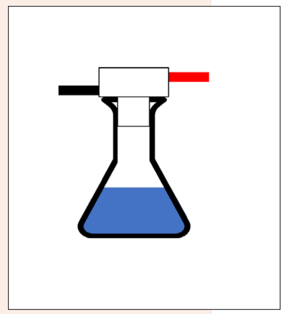
5. Add the contents of the A2 sachet to the flas and immediately push the bung device onto the flask. Let sit for 20 min (Use DigiPAsS to time).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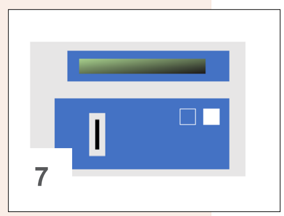
6. Remove the black slide and compare the color on the paper to the chart.



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7. If the result is <100 ppb, insert the black slide into the DigiPAsS and record the result.

Fluoride

Fluoride kits can use colorimetry-based methods, photometers, or other types of meters. Sample instructions for using a fluoride meter and a colorimetric kit are provided belo .

Example: Using the ExStik Fluoride Meter

1. Fill the vial with sample water to the 20 mL mark.
2. Add one reagent tablet to the vial. Cap the vial and shake until the reagent dissolves.
3. Uncap the meter. Put the electrode end of the meter into the water in the vial.
4. Turn on the meter.
5. Gently stir the water with the meter until the screen displays "HOLD".
6. Record the results.
7. Put the cap back on the electrode, making sure to keep the electrode wet.
8. Dispose of waste and clean the vial.

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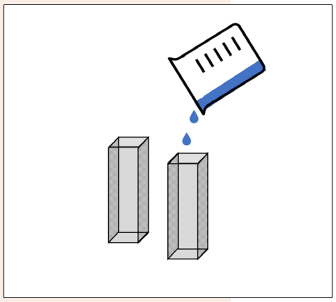
Example: Using the Palintest Photometer 7500

1. Turn on meter and select Fluoride Test.
2. Fill 2 cuvettes with 10 mL of sample water.
3. When the meter requests a blank, place the light cap over the cuvette, insert one cuvette into the meter and press OK to run.
4. In the other cuvette, add Fluoride #1 tablet and mix until dissolved.
5. In the same cuvette, add Fluoride #2 table and mix until dissolved.
6. Let sit for 5 minutes.
7. Remove blank from meter, placing the light cap over it, and insert the second cuvette.
8. Press OK to run and record results.



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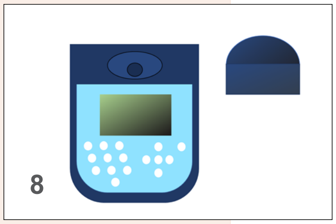

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Microbial Contaminants

Example: Compartment Bag Test

These can be used to find the most probable number of *E. coli* or total coliforms in a sample.

1. In the field, pour 100 m of sample into the *Thio* bag.

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2. Add media to the bag, fold the top over three times, and close using the attached wire ties. Turn upside down several times to mix, and let stand until media dissolve.
3. Open the compartment bag, making sure each compartment is open so that the mixture can enter.

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4. Pour mixture into the compartment bag.
5. Adjust the mixture in the bag until all compartments are full.
6. Incubate for 24 hours at 35°C. The compartments will change color based on the presence of *E. coli*. Where electricity is unavailable and average temperatures are above 25°C, you can leave the tests in a closed container in a warm space (not air conditioned) for 24-48 hours (48 recommended if average temperatures below 30°C).

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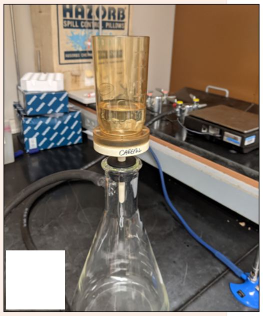
CLARK APPLING

7. Compare the bag to the chart in the kit to calculate the most probable number of *E. coli* in the sample. To calculate total coliforms, compare the bag to the chart under UV light.

Example: Membrane Filtration

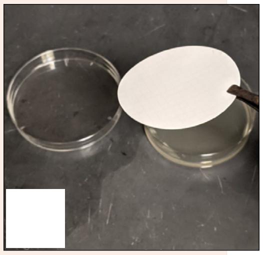
This can be used to obtain the most probable number of total coliforms, fecal coliforms, or *E. coli*, depending on the specific field ki

1. Prepare agar according to manufacturer instructions using sterile technique, then pour into sterile petri dishes and allow to solidify. Use immediately or store at 4°C for up to a week.



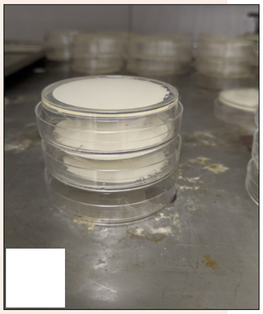
MIKE FISHER

2. Use a vacuum element to pull 100 mL samples through filte paper.



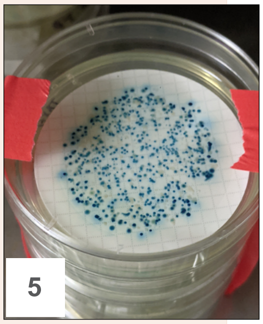
MIKE FISHER

3. Using sterile forceps/tweezers, pick up the used filter pape and lay it on a prepared agar plate. Do not fold the paper. The side that was facing up in the filter assembly and was i contact with the sample should face up. Sterilize the forceps with a flame between samples



MIKE FISHER

4. Incubate plated samples at the right temperature for the method and media you are using (often 37°C) for 24 hours. Store plates upside down with the agar surface on top. This prevents condensation from affecting microbial growth.



MIKE FISHER

5. After 24 hours, remove the plates and count the number of colonies on each one. If you used an undiluted 100 mL sample in step 1, record units of CFU/100 mL. Otherwise, conversion factors may be needed.

8. Selecting Field Kits

Characteristics to Consider

You should always select your field kit based on how simple and reliable its use will be. A well-performing kit that is impossible to purchase is not useful in the long-term. Find the best-performing kit that is accessible for your monitoring. Performance results can be found in scientific studies or manufacturer information. When possible, use published studies to identify characteristics of different field kits.

Some companies may sell multiple parameters in one kit. If not all of the parameters needed are not present in the kit you purchase, you may need to buy individual parameter kits.

Performance

- Limit of detection
- Time to result
- Precision
- Accuracy
- False positive rate
- False negative rate

Logistics

- Expense, including one-time capital costs as well as costs for maintenance and consumables
- Ability to source kit components
- Shipping time for parts or kits
- Size/portability

More Kits Available

The partial list of available kits below is not a comprehensive list of all acceptable tests. More information can be found by scanning this code.

https://www.fsnnetwork.org/sites/default/files/2022-01/PRO-WASH_Test_Kit_Lists.pdf

Partial List of Available Kits

pH, TDS/EC

- Thermo Scientific™ Elite PCTS pH / Conductivity / TDS / Salinity Pocket Testers
- Hanna Instruments Low Range pH/Conductivity/TDS Tester (HI 98129)

Turbidity

- Carolina Turbidity Tube
- 60 or 120 cm turbidity tube
- Hanna Instruments Turbidity Meter (HI 98703)
- Oakton Turbidimeter (meter)

E. coli

- Membrane filtration
- Compartment bag test (CBT)
- Colilert
- Compact dry plates

Arsenic

- ITS Quick II Arsenic Test Kit
- LaMotte Arsenic Test Kit
- Merck Arsenic Test Kit
- Palintest Digital Arsenic Test Kit (Arsenator)

Fluoride

- Extech Waterproof ExStik Fluoride Meter
- LaMotte Fluoride Tracer PockeTester
- Hanna Instruments Fluoride Portable Meter (HI 98402)
- Palintest Photometer 7500

Nitrate

- LaMotte Nitrate Test Kit
- Hach Nitrate Test Kit

9. Selecting a Laboratory

Steps for selecting laboratories:

1. Identify all laboratories that samples can be transported to and tested at within eight hours of sample collection (if using laboratory for microbial methods).

2. Identify for each laboratory the following:
   - Certification status
   - Storage and handling procedure used by laboratory
   - Storage capacity
   - Processing time for newly-delivered samples
   - Equipment to process samples
     - Method used by lab for each parameter
   - Disposal procedure for hazardous materials
   - Number of staff and qualifications
   - Laboratory method for reporting the following:
     - Uncertainty in measurements
     - Quality assurance and quality control measures
     - Compliance with policies

3. If a laboratory does not meet the logistic and data quality requirements above, remove them from the list
   Select the most economical laboratory from the list of remaining, qualified laboratories

4. If no laboratories remain, identify for which laboratory it would be easiest to build up capacity and data quality. Work with this laboratory to improve procedures.

5. Not all laboratories with required equipment and methods are able to perform those methods adequately to achieve accurate results. Once you have identified a potentially suitable laboratory, work with its staff to analyze a set of field samples, field blanks, duplicates and standards (preferably where the concentration of the standard is known to you but not to the laboratory) to ensure that the laboratory is capable of obtaining accurate results. Request copies of all calibrations and standard curves, in addition to WQ test results, from the laboratory. If the laboratory fails the initial demonstration of capability (IDC), you can work with them to improve and strengthen capacity, then repeat the IDC, if you wish. In some cases it may be necessary to use field test kits to measure parameters which the laboratory is not yet able to measure.

Laboratory Certification

Certified labs:

- Have **standard (and advanced) equipment**.
- Have **sufficient staff** to properly analyze samples.
- Have a **certified QA/QC process**.
- Should be used.
- Are often the only laboratories **allowed by law**.

Noncertified labs may not be reliable. They should only be used when approved by the local government or by the partner organization.

Types of Laboratory Equipment

1 **ICP-MS:** uses high energy to break apart samples into its individual ions and elements. It then measures how much of each type of element is present based on its mass. ICP-MS is used for measuring chemical parameters only.

2 **Incubator:** used to keep samples around/above 35°C. This allows for microbial parameters to grow colonies and be measured by conventional methods.

10. Safety and Planning

It is important to remain safe during monitoring activities. You will know the best ways to stay safe in your location. Some useful tips include:

- Wear personal protective equipment.
- Practice good hygiene.
- Bring a first-aid kit.
- Wear seatbelts and helmets for appropriate motor vehicles.
- Avoid travel and sampling at night.
- Don't work alone – rather work in teams.
- Bring a flashlight.
- Know where you are.
- Make sure others know where you are and when you will return.
- Have cash available for emergencies.
- Have a cellphone charged with enough credit to make emergency calls.

11. Common Sampling Problems

Common challenges that can arise during water quality sample collection, transport and analysis include:

Accessing community or water system

- Difficulty locating or accessing a community
- Water system difficult to access
- Water systems in community very far apart

Collecting water sample, system details

- Water system nonfunctional at time of visit
- Water systems in constant use, making it difficult to sample without interrupting use
- Difficulty locating community member who knows details about water system
- Flow rate too low to collect water in a timely way

Avoiding contamination

- Field blanks contaminated
- Duplicates show high variability
- Water quality results outside likely values

Logistical challenges

- Network connectivity not available
- Ice not available for preserving samples
- Vehicles unavailable for travel

Many issues can be addressed through advance planning; coordination among teams, members and communities; piloting WQM before implementing at scale; and providing adequate initial and refresher training, supervision, and support as needed.

12. Other Recommendations for Field Sampling and Monitoring

Sanitary Inspections

Sanitary inspections, described more in section 3, are short inspections of a water source to identify the ways that a water source could be, or is currently being, contaminated. What you observe at the site can help determine risk factors for a drinking-water supply system and identify what needs to be done to protect public health.

More Info Available

Scan this code for detailed instructions on conducting sanitary inspections.

https://www.epa.gov/dwreginfo/sanitary-survey-guidance-manuals

Mobile Survey Tools Vs. Paper Data Collection

Data can be collected using paper forms, which require no upfront costs, or MSTs, which run on cell phones and tablets and can easily integrate multimedia such as photos and GPS coordinates. MSTs also allow for easy data entry when conducting QA/QC and data analysis. They are highly recommended, and the final choice will depend partly on budget, available devices and software, and staff training.

More info on Mobile Survey Tools

Mobile survey tools (MSTs) is an expanding and changing field, and the final choice of a MST will depend on the project requirements and available resources. Commonly used MSTs include Open Data Kit (https://www.opendatakit.org/) or mWater (https://www.mwater.co/) but there are several others available. Remember that MSTs need adequate institutional support, training, and quality control – otherwise they may only help us to collect poor data faster!

13. Checklist for Field Sampling and Monitoring

Sample Collection and Preservation

- ❑ Sterilized sample containers for collection of all planned samples, blanks, and duplicates
- ❑ 2 sterilized sample containers for storage
- ❑ Waste container (with lid)
- ❑ Deionized/clean water container
- ❑ Cooler
- ❑ Gloves
- ❑ Ice packs/ice
- ❑ Nitric acid (if transporting water samples to lab for arsenic testing)

Parameter Test Kits (if using field methods)

- ❑ Electroconductivity test kit
- ❑ Turbidity meter OR turbidity tube
- ❑ pH test kit
- ❑ Nitrate test kit
- ❑ Arsenic test kit
- ❑ Fluoride test kit
- ❑ Compartment bag test OR membrane filtration test ki

Double Check Your Kits

Make sure **all components** of test kits are present before you go out to collect samples.

Make sure your kits have enough **reagents** for all planned samples, blanks, and duplicates.

Helpful Items for Field Testing

- ❑ Permanent marker
- ❑ Cup
- ❑ Labeling tape
- ❑ Barcode tape
- ❑ Scissors
- ❑ Squeegee or other cleaning method
- ❑ Phone or device with GPS
- ❑ Identification card, or other form of identificati
- ❑ Letter of entry/purpose
- ❑ Offline map of the regio
- ❑ First aid kit
- ❑ Pen
- ❑ Hand sanitizer
- ❑ Notebook/data collection form
- ❑ Trash bag (including for potentially hazardous materials such as arsenic test strips)
- ❑ Forceps/tweezers
- ❑ Flashlight

Additional Test Kits (optional)

- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________

Data Management and Analysis

1. Data Summaries

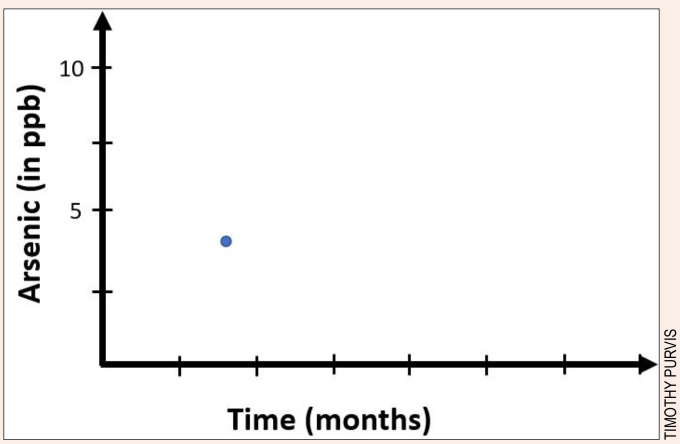
CONTENTS

The Goals of Data Analysis

Data analysis can help you better understand and evaluate the quality of the data you collect. It can tell you what you can expect to find in the water, whether an individual measurement represents the actual conditions and whether contaminant levels are increasing or decreasing, among other things.

The Foundation of Data

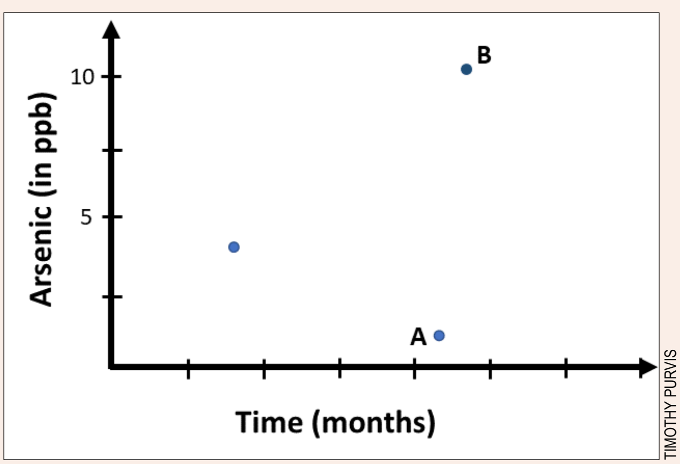
Individual measurements give you a specific value at a specific time under a specific set of conditions. Many of the characteristics of water can vary widely depending on the conditions at the time the measurement was taken. By comparing these repeated measurements (data analysis) you can get a better sense of whether any individual measurement is consistent with what you should expect or is an indicator of a potential problem. The more data you have (i.e., the more measurements you make) the better your understanding of the system's behavior will be.



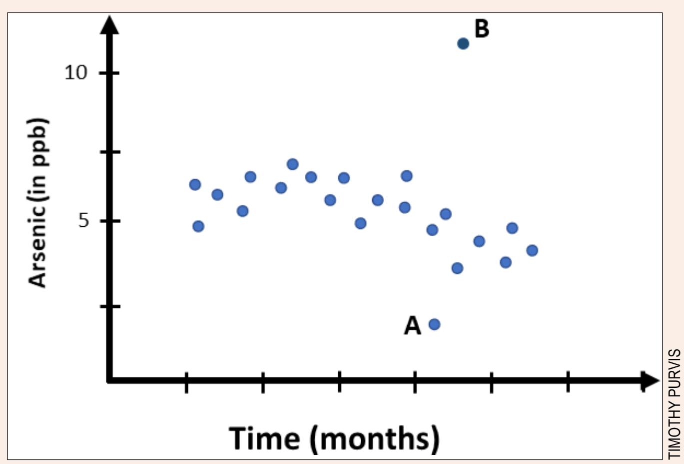
A single data point may not be useful for data analysis.

Looking at the image at bottom left, is measurement *A* valid? Is measurement *B* valid? Do they represent the typical water quality at that location? You can't tell if you only have a few data points. By comparing those points with a larger data set, such as the one in the bottom right image, you can better understand whether *A* is a valid data point or an error.

In this case, *A* may be an outlier and not an accurate representation of current conditions, or may show a true change in the water quality.It is important to retest the conditions when such an "outlier" is found.



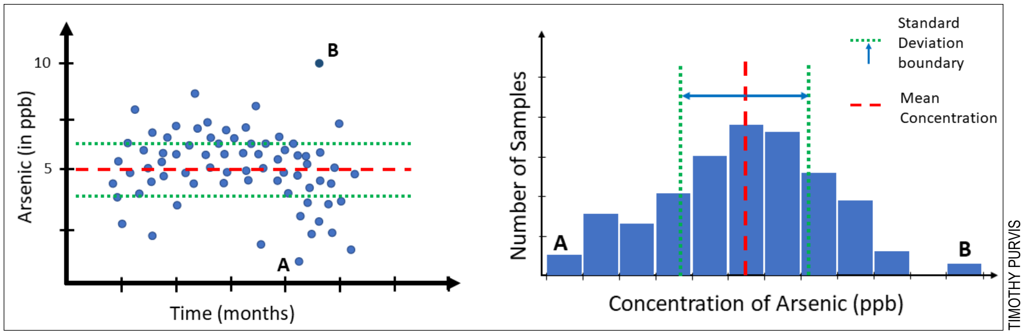
Having only a few data points still doesn't give context to water quality.



As more data are collected, it is easier to understand how new data points compare with past ones.

Ways to Represent Data

When many data points are collected from one location, the resulting data set provides a better idea of the normal, expected measurement for that location. The images at the right show two common, different ways of looking at the same data: measurement value vs. time and frequency vs. the measurement value.



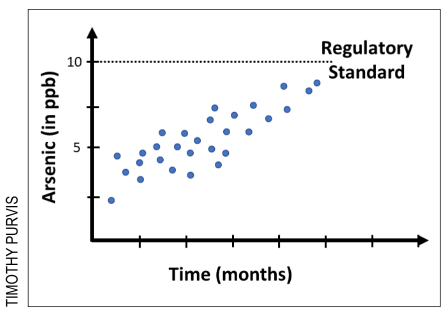
Two visual representations of the same data set. Measurement value vs. time (left) and frequency vs. measurement value (right). *Frequency* means the number of times a specific value was measured.

The Normal Distribution

Data for each parameter are typically represented in at least one of the following ways:

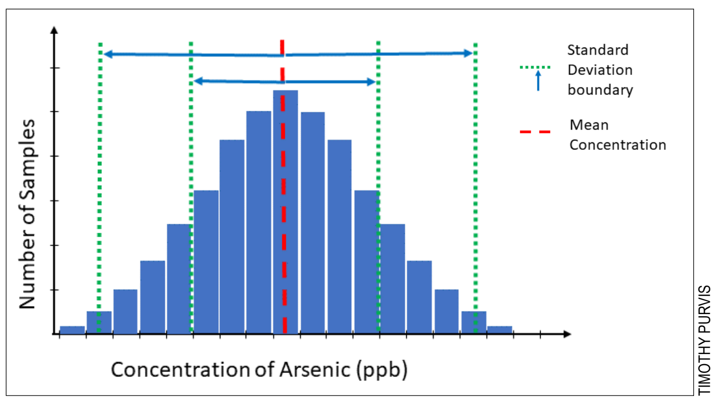
1. A chart showing frequency of measurement vs. measurement, such as the normal distribution frequency chart seen to the right.
2. **Summary statistics**, which include:
   a. Minimum value
   b. Maximum value
   c. **Median** value (the middle value in an ordered set)
   d. **Mean** value, or numerical average (the sum of all measurements divided by the number of measurements)

   Summary statistics provide a quick overview of the data before further analysis begins.
3. A **graph of measurement vs. time**.



Measurement vs. time plots are useful for identifying and comparing recent measurements.

If data are grouped by frequency of observation, the measurements produce characteristic patterns, or **distributions**, that help us interpret WQM data and predict expected ranges. The figure below depicts one common pattern, the **normal distribution**, which is important in data analysis. The center of the normal distribution has the highest frequency of occurrence, with measurements towards the far left and right edges being less frequent. Values near the middle of the distribution are more likely to be observed. Many patterns in nature and water quality follow a normal distribution: temperature, rainfall, etc.



Data distribution tells you:

- What the typical value is for the measured parameter (the center of the normal distribution, for example).
- How different new measurements are compared with past ones (by seeing where data fall in the normal distribution).

More Information

Scan this code for more details on the normal distribution.

https://www.mathsisfun.com/data/standard-normal-distribution.html

What does it mean for a measurement to be away from the center of the normal distribution? It could mean that:

- A change has happened in the system (the intervention is working or there is new pollution).
- The measurement is an error.
- More data are needed to fully characterize the distribution of data.

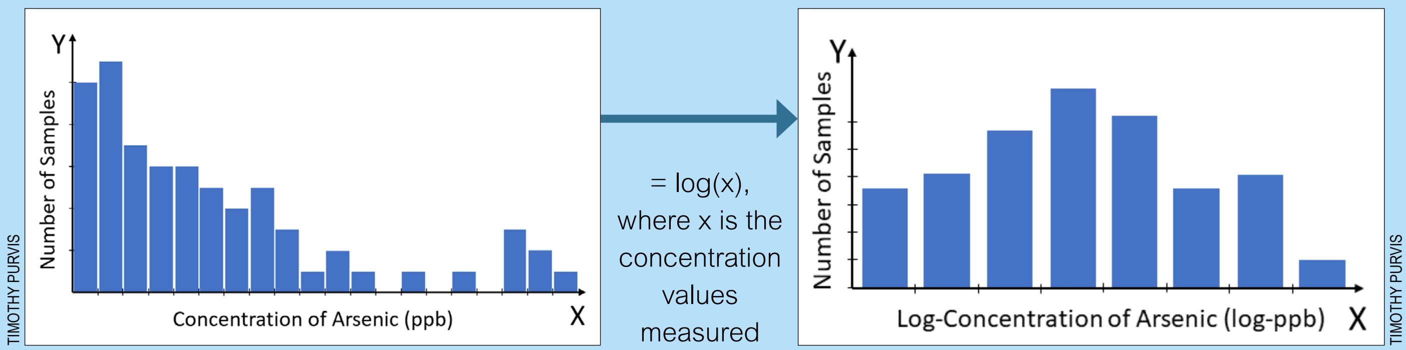
Recording a value away from the center of the normal distribution means that something different is happening. You should take more measurements to determine whether water quality is actually changing.

Standard Deviation

The standard deviation describes how spread out from the mean your data are as a whole. In a normal distribution, 68% of your data will be within one standard deviation from the mean and 95% of your data will be within two standard deviations.

Log-normalizing Data

Because concentrations of contaminants for water quality parameters can never be less than 0, your data may be skewed. A large portion may be near 0 with a long tail extending to the right. You may be able to correct this by taking the log(x) of values to help the data look more like a normal distribution, which is needed for more advanced analysis. When data look normally distributed after log-normalization, the same analysis like standard deviations can be used.



Remember to convert log values back to their true value when interpreting results.

Log-normalizing helps this data look like a normal distribution.

2. Data Quality

Characteristics of High Quality Data

USAID has developed a set of characteristics to describe high quality data and limitations to data quality, described in this document. Note that the language used below was created by USAID.

Your data should show:

1. **Timeliness**
2. **Validity/Accuracy**
3. **Reliability**
4. **Precision**
5. **Integrity**

Timeliness

Data are only useful if they are analyzed, interpreted and reported in time to inform decisions. If your data are **timely**, you get useful answers from them soon after you sample. Data that aren't reported in a timely manner may be true and accurate but not relevant for current issues.

Potential issues with data quality related to timeliness include late delivery, out-of-date information and too infrequent collection.

Validity/Accuracy

The data generated by your measurements should be **valid**. This means the data are produced in a way that can be trusted. This includes high-quality methods and a consistent, error-free process.

Potential issues with data quality related to validity/accuracy include:

- Poorly structured instruments
- Reliance on proxy measures
- Inconsistencies in data collection process
- Instruments not always completed
- Transcription errors
- Small or possibly biased sample/not representative
- Under-skilled or under-supervised data collectors

Integrity

Integrity is a measure of how faithfully the reported data represent what was actually observed and measured in the field at the time of monitoring. Integrity can be improved when incentives and systems minimize errors, avoid intentional misreporting of data and quickly detect problems if they occur.

Potential issues with data quality related to integrity include:

- Incentives in the data delivery system
- Incentives in the partner performance arrangements
- Uncertainty about data quality from secondary source

The descriptions of issues with data quality for each characteristic were produced by USAID and are housed on the Data Quality and Limitations page.

Reliability

The data have high **reliability** when their collection method is defined, repeatable and consistent over time

Potential issues with data quality related to reliability include:

- Unstructured data collection technique
- No operational definitions for terms
- Lack of proper calibration of instruments

Precision

Precision indicates how much margin of error or how much uncertainty is associated with a measurement.

Potential issues with data quality related to precision include:

- Response categories not sufficiently fine grain
- Rounding at too high a level
- Unacceptable margin of error

Why Do You Need High-Quality Data?

Having high-quality data will help you:

1 **Recognize potential improvement to your program.**
- Draw informed, reliable conclusions.
- Make recommendations for future projects.
- Learn from past failures.
- Understand water quality and performance.

2 **Describe the behavior of one or more parameters.**
- Identify clusters or groupings.
- Compare two or more locations or time periods.
- Examine relationships between variables.

3 **Discover how and where data collection may be failing.**
- Identify gaps in data collection plans by location or date.
- Locate parameters that are outside regulatory limits.

4 **Add context to results.**
- Understand how your data compares to past measurements.
- Identify trends in water quality.
- Understand which locations need improvements.

3. Data Management and Access

Common Errors in Data Entry / Management

- Entering data in inconsistent formats over time
- Inconsistent use of text or numeric entries for a particular variable
- Inconsistent formats used to report items such as dates, units of measurement, etc.

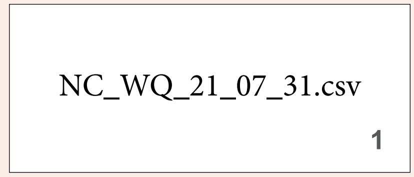
Anonymizing Data

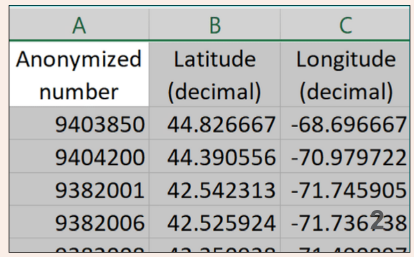
The first requirement for managing data is to **prevent the identification of individuals and/ or households** from data collected about them. If any data are collected on individuals or households, even household GPS coordinates, these should be anonymized as described in the adjacent “Managing Data” section. Otherwise, individuals may be less willing to have their water sampled or they may fear community or government pressure based on their data.

Managing Data

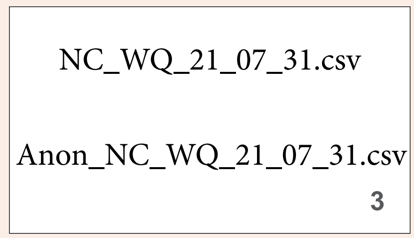
Managing data includes entering, uploading, storing and accessing it. The goal of managing data is to maintain it as originally recorded in a way that is easy to use and protects data privacy and integrity. Follow these steps:

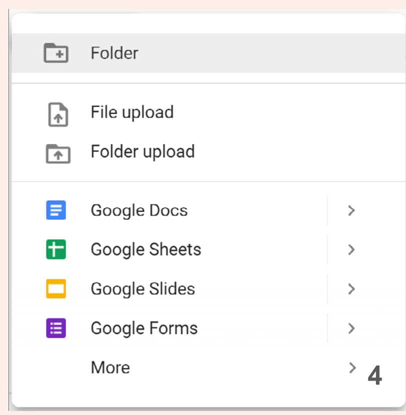
1. **Convert recorded data and measurements to a usable file format** (such as a Microsoft Excel or .csv file, a Tableau workbook file, etc.). MSTs may do this automatically (see box). If entering data manually, save data files with a name that indicates when the data were collected.
2. **Anonymize data** by using a randomly generated ID number to represent each sample location. Any identifiable data items should be stripped out and stored separately using the sample ID to link to the file. GPS coordinates can be removed or anonymized by stripping digits to reduce precision to ≥1 km. Some MSTs can easily anonymize data sets and GPS coordinates.
3. **Save the anonymized file** of sample data for future analysis, with the year and month of data collection and the word *anonymized* or *anon* in the file name.
4. **Back up the files** and save them in a secure location where they are less likely to be lost or accessed by unauthorized persons. Partners may wish to upload anonymized data to a secure cloud-based storage platform such as OneDrive or equivalent. Laws or organizational policies may require that data be stored in a specific, secure location or server, or may require that data be submitted for use in government information systems. Speak with program coordinators to determine best practices for your program.





A	B	C
Anonymized number	Latitude (decimal)	Longitude (decimal)
9403850	44.826667	-68.696667
9404200	44.390556	-70.979722
9382001	42.542313	-71.745905
9382006	42.525924	-71.736738





Mobile Survey Tools (MSTs) vs. Manual Data Entry

Manual data entry can be time-consuming and burdensome, and it tends to introduce errors. Consider using mobile data collection tools, also known as **mobile survey tools** (MSTs).
MSTs typically avoid data entry errors and should be used instead of paper forms whenever possible.

If paper forms are used, consider using **double entry** to minimize errors. This is when two different people enter the same paper form into an electronic format and compare results. Only results that match are used. Any mismatches are checked against the form to reduce errors.

Accessing Current Data

If you are using an MST (see box above) or other electronic data collection tool, you will have the opportunity to export data to a useful format for your analysis, such as a .csv file.

Data may need to be **cleaned** prior to analysis. Data cleaning prepares data for analysis by correcting misspellings and formatting. No recorded values should be edited except for anonymizing data. It is a good idea to **never modify the raw data**. Instead, make a copy for cleaning, or do all cleaning separately in a software package after importing the raw data. Cleaning should be done only by a trained data manager.

If you need to edit a file that other members of your organization may need to use, make sure to **make a copy** of the unedited file first. In some cases, you may edit shared files, in which case **version control** is important to avoid confusion.

Accessing Older Data Files

Your organization may have older types of data files that are different from what you currently use or that have not been anonymized. Follow these steps when you need to access these files:

1. **Make a copy** of the original file. Work with the copy so that you don't accidentally damage the original.
2. **Convert the copied file** to the file type your organization uses (for example, from a .txt text file to a .xlsx Microsoft Excel workbook file).
3. **Anonymize the data** as described earlier in this section.
4. **Save the new file** with the naming system your organization uses.
5. **Upload the new file** to the system your organization uses so that it can be analyzed.

Data Security Tips

After you have anonymized your data, make sure your data storage method is **secure and inaccessible** to people outside your organization.

If you are using an online service, make sure it is protected. If you are storing data on hard drives, consider adding security.

Some additional data security tips include:

1. Data access must be protected by a **username and password** that meets complexity and change requirements for your organization (e.g., includes uppercase and lowercase characters, changes yearly, etc.)
2. Data must be **accessed from within a secure network** (Microsoft OneDrive meets this requirement). Computers storing data must have **antivirus software**.
3. Study data must be **encrypted** when possible (enable Microsoft BitLocker).
4. Computers used to store study data regularly must be **scanned for vulnerabilities**.
5. Users should be given the lowest necessary level of access to data.
6. Make sure that your computer regularly receives **Microsoft Windows updates**. BitLocker will protect sensitive data in the event of laptop theft/loss. If you store data on an external drive, make sure that drive has **BitLocker enabled**.

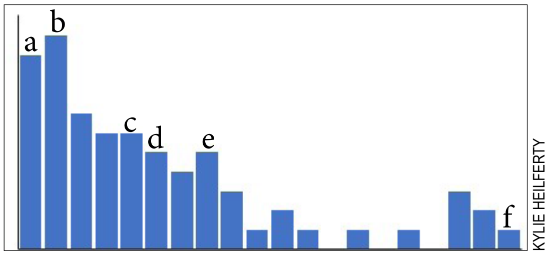
4. Data Analysis

Basic Analysis

Use summary statistics to provide a quick understanding of water quality in an area. Software such as Microsoft Excel or Tableau can help generate these. To visualize results, highlight the parameter and select the plot you want to generate from the list of options.

Summary Statistics

- Minimum value (a)
- 1st quartile (b)
- Median value (c)
- Mean value (d)
- 3rd quartile (e)
- Maximum value (f)



Data represented by histogram

Intermediate Analysis

Trend analysis: Use trend analysis to see how data trends change over time. You can visually inspect this on a time-based plot in Microsoft Excel or an equivalent software, but more rigorous analysis can be done in statistical software like R. As R is open-source, use existing documentation to do trend analysis, or Tableau's resources for time series analyses.

Hypothesis testing (means comparison)**:** Use hypothesis testing to compare water quality between two or more different communities or groups (strata). This is useful for determining whether one water type or community has significantly different water quality. Hypothesis testing should be done in software like R. A good resource for hypothesis testing is Khan Academy's guide to significance tests.

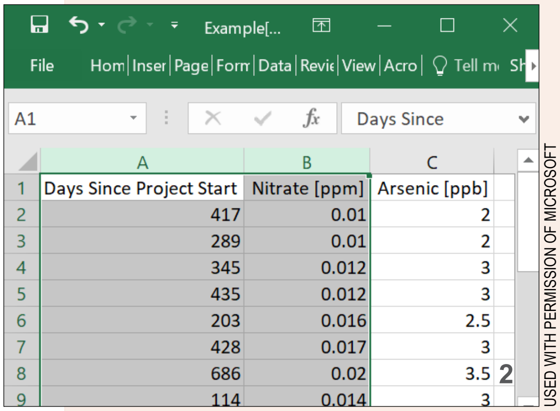
Visual distribution analysis: Use a visualized distribution to manually inspect data to look for trends. This should be done by plotting data against the sample date and also by plotting one parameter against another (such as plotting nitrate against pH). This can be performed in Microsoft Excel or in statistical software.

Advanced Analysis

Geostatistical analysis: Use geostatistical analysis to understand how a parameter varies spatially. This may be beneficial for identifying and mapping out measurement problems associated with the testing methods or environmental risks that may impact multiple drinking water

Visualizing Data in Microsoft Excel

1. Open dataset and clean as needed. If importing as a .csv file, select the appropriate delimiters to import your data.
2. Select column(s) of relevant data, typically by highlighting and using Ctrl+click to select multiple columns.
3. Click on type of chart wanted under Insert > Charts. Typical chart types may be scatter plots or histograms.



	A	B	C
1	Days Since Project Start	Nitrate [ppm]	Arsenic [ppb]
2	417	0.01	2
3	289	0.01	2
4	345	0.012	3
5	435	0.012	3
6	203	0.016	2.5
7	428	0.017	3
8	686	0.02	3.5
9	114	0.014	3

2

More Information Available

Scan this code for more details on using Microsoft Excel.

https://support.microsoft.com/en-us/excel sources. Geostatistical analysis requires the use of GIS or advanced software such as BMEGUI, Matlab. MEASURE Evaluation has useful tools on using geostatistical analysis in public health applications.

Data validation: Use data validation to determine whether data have been falsified. Data are reviewed with a number of statistical analyses to determine whether values are true. These analyses require software like R or Matlab.

Additional resources and links on statistics are available in the Common Challenges section of this guide.

More Information

Scan these codes for more details on data analysis using Matlab, QGIS and R.

https://www.mathworks.com/products/matlab.html

https://www.qgis.org/en/site/

https://www.r-project.org/

4. Using Data to Make Informed Decisions

Compare your results with the health-based WQ standards your project is using. If the WQ at one of your water sources exceeds these standards, you will need to notify appropriate authorities, inform the community and take corrective action to improve the water source. If the WQ at a water source exceeds health-based standards by a very large amount, you may need to take **immediate, drastic action**, though do so only with community involvement. The flow chart below takes you through the process of using WQM for decision making.

PROBLEM	WQ problem identified.
ENGAGE LOCAL COMMUNITY	Meet with and discuss problem with local community. Identify who knows, is responsible for and interested in WQ. Discuss, build trust and identify all possible pertinent factors that influence WQ in the area.
HISTORY	Search for and collate all available historical data. If there is none, look for similar data from neighboring areas. To make best guess, estimate for local conditions.
SAMPLE	Sample water and gather GPS and associated pertinent data from each sampling location, preferably using mobile technology. Data should be high quality.
DATA SECURITY	Ensure all data gathered are stored and shared using data protection and security standards.
TEST WQ	Follow project standards and use the most appropriate methods available when testing WQ.
ANALYZE	Statistically analyze sampled, cleaned data and compare with historical data. Specifically look for trends and identify apparent outlier data.
SIGNIFICANT DATA OUTLIERS	Actions to address poor WQ often are outside the direct influence of the water technician. It is best practice to identify all influencing factors that might affect success of WQM intervention. All attempts must be made to ensure data integrity has informed the technical recommendations. More samples may be needed to confirm results.
REPORT	Prepare full scientific report, including technical recommendations using best evidence. Share and discuss results and recommendations with your managers. Create an action plan for your next steps for monitoring.
ACTION PLAN	Discuss and agree with manager and with local community the course of action for future WQM and testing, as well as actions required to address the specific technical action points in the report.

ANGELA BRAMMER

Prioritizing Improvements

Data analysis results will help determine which parameters, systems and settings may be most in need of urgent attention. Improvements and corrective actions should be prioritized based on considerations for protecting public health. If multiple systems require action, responses may be prioritized in some cases to ensure the greatest impact in terms of preventing harm to populations. Factors to consider in such cases include:

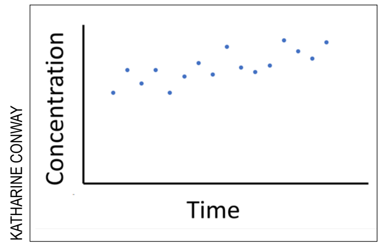
- **Health risk**. It may be useful to prioritize actions based on the likelihood of success and the magnitude of benefits of those actions (or the severity and likelihood of adverse consequences if action is delayed), as described in risk prioritization schemes in WHO's Guidelines for Drinking-Water Quality.
- **Equity**. Improvements should not be targeted on the basis of community or individual characteristics such as wealth; ethnic, tribal or other affiliation; status or influence; or other demographic factors.

Managing Trends

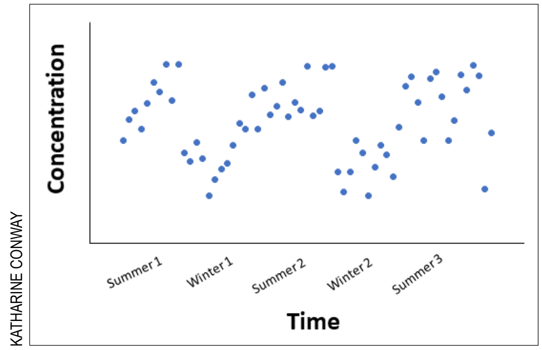
Data analysis may reveal trends in water quality such as:

- The concentration of a contaminant exceeds guideline values in one season but meets them in the next.
- The concentration of a contaminant increases over time but has not yet exceeded guideline values, so preventive action may be needed soon to avoid a future exceedance.
- The concentration of a contaminant is currently over guideline values but is decreasing over time.

Identifying these trends is important for long term planning. You may need to plan different treatment processes in different seasons or alter your programming to determine why the concentration of a contaminant is increasing and how to plan for future corrections.



Trend of increasing concentration over time



Seasonal trend of contaminant

Improving Your Process

Data analysis also can help you improve your water monitoring process. Data validation allows you to analyze how well data is being collected and can help pinpoint where more training is needed — for example, additional training on the arsenic test method — or where a data collection tool may be confusing for enumerators.

A few frameworks exist for using data to improve your program, including USAID's Water Quality Assurance Plan (WQAP), discussed earlier in this document. You may wish to implement one of these as part of your WQAP:

- **Continuous quality improvement** (CQI) is a method of iterative steps to target and improve specific processes, used by industry for decades. It has recently been adapted for use in water systems.
- **Water safety plans** (WSP), promoted by the World Health Organization, use risk assessment and management to ensure the safety of a drinking-water system. These are most appropriate for larger or long-term monitoring needs.

More Information Available

Scan these codes for more details on CQI and WSPs.

https://www.who.int/publications/i/item/9789241562638

https://www.fsnnetwork.org/sites/default/files/2022-01/PRO-WASH_Additional_information_on_Continuous_Quality_Improvement.pdf

Engaging with Stakeholders

1. Why Stakeholder Engagement Matters

Stakeholders are any of the individuals, groups and organizations who have a stake in or are affected by water systems. Each water program has different stakeholders depending on context. Stakeholders may include **communities**, **nongovernmental organizations**, the **government** or **private sector partners**.

Engaging with stakeholders is crucial to planning and sustaining a monitoring project, plus using results to improve programs and outcomes. Good stakeholder engagement improves the chances of your monitoring program successfully providing safe water to its users. Engagement with stakeholders is recommended throughout a program.

CONTENTS

2. Best Practices in Stakeholder Engagement

The best methods for stakeholder engagement will vary by location and community and you will know best how to engage your stakeholders. Consider these tips when planning stakeholder engagement.

Community Membership

The community consists of all local, nonprivate partners and stakeholders, such as:

- Local leaders
- Local water committees
- Regular citizens

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Ethics and Principles

Build Trust

The most important factor that determines success in a multistakeholder setting is the level of trust between its members. Do not underestimate the resources (time, money and social capital) required to do this, and budget accordingly.

Open-Source Data

Ideally all deidentified data gathered should be public record and easily available via the internet for independent verification, use and iterations.

Feedback

Build in and fund a stakeholder feedback mechanism through which fresh data and the consequences of actions can be updated to create new recommendations. Do not underestimate the time, money and staff hours that will be required for actions that are planned to occur beyond the funded duration of a project.

Data Quantity

The more data generated, the better the results and analysis (as long as data are high quality).

Data Quality

Investigate original data sources: how recent are the data, how and when were they updated, how comprehensive and detailed is the focus of monitoring, do the data from the same sources or location change over time, etc.

Data Driven

Any recommendations that require action must be driven by data, ideally with publicly accessible data.

Gender Equality

At every level, gender equality and female empowerment should be encouraged and promoted.

Communities and Nongovernmental Organizations

Identify Key Individuals

Who is responsible? Who is interested and motivated? How can these individuals be supported to implement WQM? Motivate volunteers to help and to gain experience practicing water quality monitoring.

Outreach

Speak with as many different stakeholders as possible. Talk with those who truly know the issues, including practitioners and and lower-income community members. Take into account possible language and reading ability barriers.

Open Meetings

Consider regular face-to-face meeting with stakeholders to discuss issues and review latest information. You should host additional meetings when results from monitoring are being shared and when recommendations are being made.

Community Entry

Inform community leaders and members of when you will arrive to sample in their community, where you will sample, and what you will measure. Greet community members and ask before sampling water points.

Governments

Identify Key Individuals and Entities

Which individuals and ministries are responsible for WQM?

Government Buy-in (National, Subnational and Local Levels)

Gain formal buy-in (agreement of the importance of water quality and monitoring) and endorsements from at least two national ministries and relevant local-level ministries, through memorandums or letters of understanding.

Professional Behavior Tips for Enumerators

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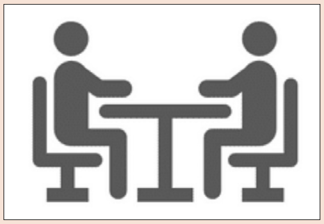
Dress professionally, not formally.



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Address interview subjects politely, neutrally and in a friendly manner.

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Show formal identification and documentation on request. Be prepared to describe your water quality monitoring activities.

Sustainability

Engaging with stakeholders including communities and governments can aid long-term WQM program success.

Note that in the long run, **oversight and operation of WQM programs should be transitioned** to stakeholders such as local leaders, government, organizations or water committees. It is important to take into account staffing, capacity and resources of stakeholder organizations when planning this transition.

Private Sector Partners

Identify Motivating Factors

Leverage in-depth knowledge of each stakeholder group to determine best interests for each group. Beneficial questions to ask are: Why is the private sector interested? Where is profit available in WQM? How important is corporate social responsibility to the partners?

Buy-in

Get buy-in (agreement of the importance of water quality and monitoring) from senior managers/directors.

Invite Key Actors to the Field Sites

Hands-on direct shared experience of field level WQM is important.

Future Sustainability

Identify long-term stakeholders from current and potential future list of private sector actors.

Localization

When planning for the future of the program, increase local support for monitoring by identifying local, private companies who can sustain monitoring through sourcing materials, making repairs, and benefit economically through increased water quality.

USAID on Private Sector Partners

USAID has previously identified the potential impacts of different types of private sector partners and has made recommendations on how to engage with private partners for water security. Scan the code to learn more.

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https://www.usaid.gov/work-usaid/private-sector-engagement/pse-at-usaid

Informed Consent and Participant Confidentiality

Scan this code for additional information.

https://www.fsnnetwork.org/sites/default/files/2022-01/PRO-WASH_Additional_Information_on_Informed_Consent.pdf

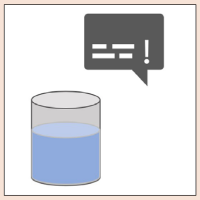
3. Responsible Communication of Sampling Results

Communicating with stakeholders is important if you want your WQM program to lead to improvements. **The best method of communication depends on the audience.**

Written reports are a common way to communicate water quality data. Results will most likely be reported this way to superiors, sponsors, government agencies and aid agencies. Reports may include:

- Current status of water sources and systems.
- Methods used during monitoring, such as sampling, testing, data recording and data analysis procedures.
- Data analysis results.
- Interpretation of data analysis and recommendations.

Communication about potentially **unsafe water sources** is especially important.



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Results should be communicated in a **clear, understandable** way. All stakeholders should have access to the information. But, while water users should have access to the above reports, formal written documents may not be the most effective way to communicate. Local organizations (town council, community-based organizations, religious groups, schools) can help organize better ways to communicate information.

Community meetings often can be helpful. They should be well planned and have well-defined purposes. They should not be overly frequent and should not be used to recite raw data or monitoring results. Instead, they should focus on explaining what results mean, what actions may be warranted based on the data and more in-depth information about water quality issues and priorities. This can empower communities to use WQM results to improve water safety.

Language and Low-Literacy Communication

- **Consider the audience** when selecting the words you will use.
- For an audience with **low literacy rates**, communicate with visuals or verbally address them.
- Use **clear and understandable language**.
- **Avoid jargon**.
- Determine whether you need to **translate results into another language**. Partners may have policies on this. Documents for an international audience should be in English. The official language or lingua franca will likely be appropriate for national government or scientific audiences.

4. Communicating Uncertainty

What Is Uncertainty?

Uncertainty and accuracy are important concepts in the measurement of data. **Accuracy** is how close the measured result is to the actual value being measured. A highly accurate test method will provide a true value of the parameter being measured. **Uncertainty** is a quantitative measure of the error in the measured result. Scientific data always contains some uncertainty — even the best instruments and methods cannot yield "perfect" results. Some uncertainty comes from systematic errors that affect all the data; some errors are random and highly variable.

Anything that can impact the accuracy of a test method and is not accounted for can increase the uncertainty of results. This could include human error, environmental conditions, lack of calibration (for instruments that require regular calibration) or other factors. All WQ measurements and subsequent analyses have varying amounts of uncertainty or error. The standard deviation of a data set about a mean value (described in the Data Management and Analysis section) is a common measure of uncertainty. A larger standard deviation indicates greater uncertainty and a greater chance that any single measurement is far away from the true value.

Why Is Uncertainty Associated with WQM Data?

The goal of a WQ measurement is to assess the true value of the characteristic being measured. Since the exact true value can never be known, it is important to communicate how close the measured value is likely to be to the true value. The smaller the uncertainty in the data, the greater the confidence that measured data are close to their true values. If the uncertainty is large, then the measured values are likely to be further away from the true values.

For this reason, all data should be reported along with its corresponding uncertainty. When the uncertainty of the data is not known, that should be made clear.

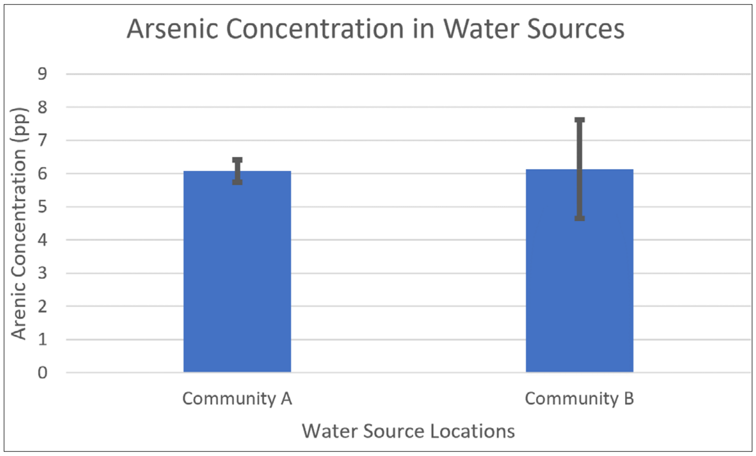
Communicating uncertainty in WQM data is about faithfully reporting the limitations of measured WQM data and the expected difference between reported results and their true values. This information is critically important in determining how to interpret WQM data and how best to use them to decide if, when and how to take remediation actions. Failure to clearly communicate uncertainty may be interpreted as a failure to fully disclose the limitations of the measured WQM data, which can erode trust and confidence in the WQM process.

How to Communicate Uncertainty

The three main ways to communicate uncertainty are:

- Visually, using charts or graphics
- Numerical representations
- Verbal descriptions

Visual representations of uncertainty such as error bars are often useful and intuitive for audiences. If visuals cannot be used, numerical representations or verbal descriptions may be helpful. Numerical representations may be expected when communicating to more technical audiences.



KATHARINE CONWAY

Error bars convey uncertainty in this chart.

When communicating uncertainty, consider factors that could change a strategy's effectiveness, including:

- **The audience.** Communicating uncertainty should be tailored to the audience to promote their understanding. Consider what your audience knows about data (such as sample size or analysis methods) as well.
- **Practicality.** What method will be practical for you to use? How fast can the information be shared using this method? How easily can the information be updated using this method?
- **The risk.** What are the potential effects of uncertainty in your type of results? Do the results pose a threat to the community? Do you need to communicate quickly?

More Information Available

Scan this code for additional resources on communicating risk and uncertainty.

https://royalsocietypublishing.org/doi/10.1098/rsos.181870

Tips on Communicating Uncertainty

- Avoid using words such as *likely* or *very unlikely* when possible (e.g., avoid saying "10% of water systems are likely contaminated with arsenic in XYZ setting"). **Interpretations of these words can vary** from person to person.
- Avoid using words such as *around* or *estimated* by themselves. Used alone, they are **inadequate** for conveying uncertainty. For example, avoid saying, "an estimated 10% of systems exceed standards."
- **Incorporate additional pieces** to your data's story. Your communication is strengthened by including information such as the margin of error, sample size, confidence interval and other data items. For example, stating, "The mean concentration of arsenic in tested water systems is 7 ppb, with a standard deviation of 5 ppb."
- Report results to an appropriate number of **decimal places** for the uncertainty associated with your measurements.

Resource Management

1. Equipment and Transport

Overview

WQM programs require several types of inputs, consumables and logistical resources to function. Key categories of equipment include:

- **Sample collection, preservation, and transport**.
- **Data collection** (paper-based or mobile) and sample labeling (barcode or manual).
- **Safety**.
- **Data entry, verification and analysis**.
- **Staff transportation** to and from field sites, field offices and/or laboratories, and other essential locations.

Equipment is also needed for sample analysis. This is described earlier in the "How to Test Water Quality" section.

Sample Collection, Preservation and Transport

Supplies for this generally include clean, sterile, water-tight sample collection containers. Depending on your parameters and methods, these may be:

- **Presterilized** to prevent microbial contamination.
- **Acid-washed** in trace-metal grade acid to prevent chemical contamination.
- **Purchased from a reputable supplier** and used as received, if known to be (or tested and found to be) free from chemical and microbial contamination.

If samples are to be tested for chemical parameters somewhere other than at the point of collection, preservation may be needed, in which case needed supplies may include **a strong trace-metal grade acid** (often nitric or hydrochloric), along with a method of dosing the acid and proper **personal protective equipment**.

In almost all cases, **a method of keeping samples cold** (such as a cooler or refrigerated container) is needed to ensure samples are kept at or near 4°C until they can be analyzed.

Data Collection

Before WQM data can be used they must be entered into a computerized database. **Smartphones** are the preferred data collection equipment for WQM when available because they enable data to be digitized at the time of collection, and they integrate **GPS, camera and timekeeping** features. When paper data collection is necessary, teams will need **paper data collection sheets** and pens, as well as standalone GPS, camera and timekeeping equipment. In addition, supplies and staff will be needed to **digitize paper forms**. In all cases, **consent forms** may be needed.

CONTENTS

Sample collection and preservation

Data collection

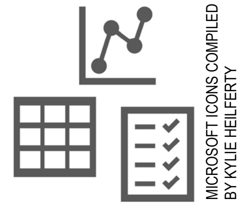
Safety

Teams should have **first aid kits** and training, **flashlights**, **power banks** for communications and other **basic safety equipment** when traveling to the field.

Safety

Data Entry, Verification and Analysis

A description of the needed **data analysis software** can be found in the "Data Management and Access" section of this document. Other needs include a **computer** capable of running the software and personnel to perform the tasks.



Data entry, verification and analysis

Transportation

Reliable transportation to and from water systems, sample points and communities will be needed. Consider these factors when determining your transportation needs:

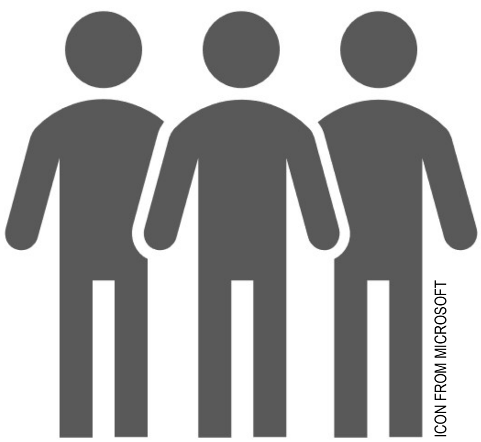
- The **number of communities and systems**.
- **How often** they will be monitored.
- The **distances** between them and your base of operations.
- The **number of staff** and **amount of equipment to be transported**.
- **Road quality** and seasonality.

2. Personnel

Most WQM programs will require support in at least four critical areas:

- **Field-level sampling and data collection.**
- **WQM operational planning, management and supervision.**
- **Data analysis and interpretation.**
- **Program management and sponsorship.**

In some cases staff members may be able to perform multiple roles or may perform other roles in addition to one of more of these. Make sure your WQM program has all these capacities available to support it, with adequate effort allocated to WQM activities.



Field-level Sampling and Data Collection

Enumerators should be fluent in relevant local languages as well as the main business language used by the partner (e.g., English, French, etc.) and should have strong mathematics skills (e.g., at a level adequate to enter university). They should be familiar with smartphone usage if mobile data collection is used. Enumerators should be comfortable spending long hours in the field and working in the heat and rain.

Capacity and Effort

WQM programs generally require **dedicated effort** to function. If existing staff are asked to "help out" with WQM without a **significant amount of their time set aside** for WQM activities, they cannot be relied upon to achieve results.

WQM Operational Planning and Supervision

This is often conducted by supervisors or coordinators with prior management experience. They must be able to ensure enumerators are effective and can collect high-quality WQM data. Some technical background is helpful. Supervisors may also support procurement of supplies and other essential functions for WQM. They may collaborate with data analysis staff to determine sampling schedules and locations.

Data Analysis and Interpretation

This is often conducted by a statistician or other staff member with statistical expertise. This person may also assist with interpreting results, preparing reports and communications, and facilitating discussions of WQM data to generate recommendations and next actions for improvement.

Program Management and Sponsorship

This position is typically filled by a high-level staff member who takes ownership of the WQM program and can authorize staff effort, budget allocation, vehicle use and procurement of supplies and equipment needed for a WQM program to function.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In-house Staff, Collaborators and Consultants

In some cases partners may have all required staff capabilities in their organizations and may have available capacity to take on these roles. In other cases new staff must be hired and trained. If this is not feasible or desired, partners may contract with external consultants to perform some WQM activities and functions, and/or partner with local government agencies, universities, nonprofits or other collaborators to conduct WQM activities together.

3. Budgeting

WQM programs require a budget. The budget required will vary from project to project. Many factors will impact the budget such as: the size of the project, distance between sampling sites, distance to laboratories, cost of laboratory services, cost of procuring equipment and consumables in-country, staff etc. Costs often include:

- **Staff**, including time needed for data collection, analysis, dissemination and use.
- **Travel**, including vehicle use, maintenance and fuel.
- **Equipment and consumables**, which are materials that have to be replaced when used up.
- **Management**.

When budgets are too small to implement WQM at scale, partners may train staff and pilot WQM activities to build capacity for when resources are available.

Common Challenges

1. Strategies for Common Problems

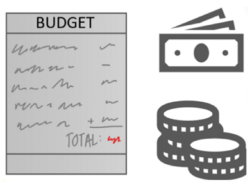
Please see suggested solutions for frequently encountered problems below.

CONTENTS

Common Problem	Potential Solution

No WQM Budget

Inadequate budget for WQM activities means resources are not available for WQ testing, transportation or staff effort. WQM requires a budget.



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WQM requires committing resources. If funds are not allocated to WQM, partners can still conduct limited training, piloting and planning while they work to secure a sufficient budget for WQM at scale. If funding is scarce, consider phased implementation with pilot WQM activities in a subset of systems, eventually scaling to all systems.

Sites Inaccessible

Communities or systems to be monitored are so far away or roads are so bad that access is difficult and WQM falls behind schedule.

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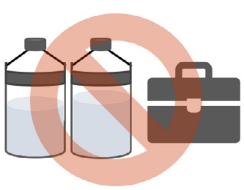
Where many systems or communities are far from a base of operations but close together, consider stringing multiple sites together and sending teams to monitor over the course of a week or longer. A local base of operations may be needed, such as a hotel or local partner's offices. If road are are not accessible by four-wheeled vehicles, consider whether teams can use motorbikes for WQM activities.

Supplies Unavailable

It can be challenging to procure WQM supplies, test kits, reagents or other needed items due to import restrictions, lack of suppliers or other factors.



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To keep WQM activities on track, it is essential to be able to procure supplies, reagents and materials of suitable quality that meet specifications. Consider partnering with importers or suppliers (who may already import similar items), placing larger orders further in advance or reaching out to other stakeholders such as government agencies, large NGOs/CSOs, universities, or others with similar needs.

Labs Unsuitable

Laboratory testing of water samples may be desired or even required by regulation, but suitable labs may not be available.

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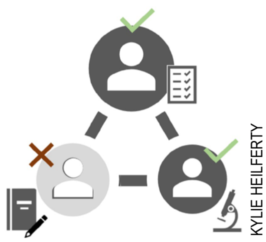
Laboratory capacity tends to be best in large or capital cities. If a partner has many labs to choose from, assess each in terms of the instruments and methods available, and then select among those with the equipment needed to perform desired tests. Ensure that adequate calibration and quality assurance procedures are in place. If not, building lab capacity may be an option. More details are available in the section on laboratory selection.

Common Problem	Potential Solution

Capacity Unavailable

WQM requires staff with capacities for robust field work, management and data analysis. If they are not available, WQM is difficult.



Where critical capacities are missing, consider hiring new staff, providing additional training for existing staff, partnering with other stakeholders such as government or local universities or hiring consultants. These solutions can help partners extend their WQM capacity in the short term. In the long term, they may be able to build additional WQM capacity in-house as needed.

Data Quality Poor

WQM programs should regularly check data quality using quality assurance and quality control tools. If problems are found, corrective action can be taken.

Where data quality issues are detected, it can be useful to examine the problems to determine if they occur most frequently for a particular team, a particular type of data or parameter, a particular season, etc. Once a pattern is identified, targeted retraining may address the issue. If not, managers can closely observe the problem data being collected to identify and address challenges.

2. Where to Find Additional Help and Advice

These additional text and web-based resources, listed by topic, may be useful in planning or implementing your water quality monitoring program.

General

Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum by the WHO provides overview of water quality, including information water quality impacts on health, on water quality monitoring and potential parameters of interest. It can be found at https://www.who.int/publications/i/item/9789241549950

Bartram, J., & Ballance, R. (Eds.). (1996). Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. Taylor & Francis Group.

Behmel, S., Damour, M., Ludwig, R., & Rodriguez, M. J. (2016). Water quality monitoring strategies - A review and future perspectives. The Science of the Total Environment, 571, 1312–1329. doi:10.1016/j.scitotenv.2016.06.235

World Health Organization. (2012). Rapid assessment of drinking-water quality: a handbook for implementation. World Health Organization. This can be found at https://apps.who.int/iris/handle/10665/331485

WQM Frameworks

The USAID website has addition resources on the WQAP resources, found at https://www.usaid.gov/environmental-procedures/environmental-compliance-esdm-program-cycle/special-compliance-topics/water

The WHO and International Water Association run a web portal which has tools and resources for developing Water Safety Plans which can be found at https://wsportal.org/.

The Water Institute has guide for using Continuous Quality Improvement in WaSH settings, which can be found at https://waterinstitute.unc.edu/wp-content/uploads/sites/3640/2014/10/CQI-manual-1.31.2017-d.pdf

The USEPA has a guide for volunteer water quality monitoring programs, which helps to develop a monitoring plan when none exists. It can be found at https://www.epa.gov/sites/default/files/2015-06/documents/vol_qapp.pdf

Site Selection and Sampling

Some information on site selection and sampling for water quality assessments can be found in the WHO 2012 book introduced above.

Water Quality Parameters

The WHO's drinking water guidelines, introduced above, provides an overview of many parameters.

Water Quality Testing

USAID has some guidance available at https://www.usaid.gov/documents/1860/wqap-annex-7-standard-operating-procedures-field-measurements-and-sample-collection

Data Analysis

For those with no prior study of statistics:

Crash Course Statistics on YouTube provides a conceptual overview of major topics, especially these summary statistics and basic applications for the analyses below. It can be found at: https://www.youtube.com/watch?v=sxQaBpKfDRk

The University of Amsterdam's "Basic Statistics" Coursera course gives a rapid overview of methods. It can be found at https://www.coursera.org/learn/basic-statistics?specialization=social-science

For those with some familiarity with statistics and needing to apply statistics:

Duke University's "Introduction to Probability and Data with R" Coursera course covers initial data summary statistics and distributions with the software R, a very useful platform for subsequent data analysis. It can be found at https://www.coursera.org/learn/probability-intro?specialization=statistics

University of Michigan's "Understanding and Visualizing Data with Python" Coursera course (and the subsequent courses for advanced topics) covers initial summary statistics, basic interpretation, and more advanced methods. It can be found at https://www.coursera.org/learn/understanding-visualization-data

To understand advanced analyses and the data needed for them, practitioners should read the Canadian Guidance Manual for Optimizing Water Quality Monitoring Programs: https://ccme.ca/en/res/guidancemanualforoptimizingwaterqualitymonitoringprogramdesign_1.0_e.pdf

Stakeholder Engagement

MEASURE evaluation has a tool for stakeholder engagement which can be found at https://www.measureevaluation.org/publications/ms-11-46-e.html

Winrock International and USAID produced a guidance on private sector engagement for water security, which gives a good overview of the private sectors impact on water issues

https://www.swpwater.org/wp-content/uploads/2017/10/Private-Sector-Engagement-in-the-Water-Security-Improvement-Process.pdf

Remediation

Remediation techniques are particular to specific locations and parameters so there is no single guide that can be applied. However, USAID documents the approach one should take when remediating water quality problems found at https://www.usaid.gov/documents/1860/wqap-annex-3-approach-resolution-water-quality-contamination

The Water Institute at UNC

The Water Institute has additional resources on water quality monitoring programs. You can find them online at https://waterinstitute.unc.edu/

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Annex of Checklists

Sanitary Inspection and Perimeter Walk

The form you fill out during a sanitary inspection may look similar to this. The questions asked during sanitary inspections can be adapted to your context and water source type.

Are the above-ground parts of the water source hardware loose at the point of attachment to the base (which could permit water to enter the casing)?	❑ Yes ❑ No	Comments:
Are there signs of leaks in the main pipes feeding the system? Are pipes exposed within 10 m of the water point?	❑ Yes ❑ No	Comments:
Is there adequate fencing around the water point to keep animals out?	❑ Yes ❑ No	Comments:
Are there visible cracks on the cement floor?	❑ Yes ❑ No	Comments:
Does the water point have a full cement apron?	❑ Yes ❑ No	Comments:
Does the water point have cement walls? Are there any cracks in the walls?	❑ Yes ❑ No	Comments:
Do the walls/sides of the concrete pad go below the ground at all points?	❑ Yes ❑ No	Comments:
Does the water point have a drainage channel? Is the drainage channel broken, cracked or in need of cleaning? Is it full of still water?	❑ Yes ❑ No	Comments:
Is the base of the water point adequately sealed so that outside water can't enter?	❑ Yes ❑ No	Comments:
Does the water point have a cement floor? Is there any ponding of still water within 2 m of the floor?	❑ Yes ❑ No	Comments:

How to Do a Perimeter Walk

1. In the office, measure how many paces = 10 m.
2. In the field, **walk 10 m** from source.
3. **Make a loop** around the source, staying 10 m away.
4. Look toward the source as you walk, **noting any excreta/contaminants** inside the circle.
5. Make a **second loop**, looking for excreta/contaminants outside the circle (within 30 m of the source).

Be wary of snakes, animals and harmful objects while conducting a perimeter walk.

While performing a perimeter walk, answer these:

- ❑ Are there any **latrines** within 10 m of the water point?
- ❑ If a latrine is present, is it on **higher ground** than the water point?
- ❑ Is there **human excreta** on the ground within 10 m?
- ❑ Is there **animal excreta** on the ground within 10 m?
- ❑ Is there a **sewer** or gutter receiving sewage within 10 m of the water point?
- ❑ Are there other **types of contamination** within 10 m?

What Data to Collect

If you are using paper-based data collection, check off each of these items in your data collection process. If you are using a mobile survey tool (MST), make sure the survey includes each of these data points.

Basic Information

- ❑ Name of Collector
- ❑ Employee ID
- ❑ Project ID
- ❑ Date
- ❑ Time

Environmental Data

- ❑ Air temperature
- ❑ Water temperature
- ❑ Sanitary inspection
- ❑ Recent rainfall events
- ❑ Flow rate (if applicable)
- ❑ Water level (if applicable)

Parameter Data

- ❑ Kit used
- ❑ Measurement results
- ❑ Where parameter is measured (in the field or in a lab
- ❑ Laboratory code, if used

Community Data

- ❑ Community code
- ❑ Coordinates
- ❑ Source type
- ❑ Timing of draw
- ❑ Sample preservation

Checklist for Field Sampling and Monitoring

Sample Collection and Preservation

- ❑ Sterilized sample containers for collection of all planned samples, blanks, and duplicates
- ❑ 2 sterilized sample containers for storage
- ❑ Waste container (with lid)
- ❑ Deionized/clean water container
- ❑ Cooler
- ❑ Gloves
- ❑ Ice packs/ice
- ❑ Nitric acid (if transporting water samples to lab for arsenic testing)

Parameter Test Kits (if using field methods)

- ❑ Electroconductivity test kit
- ❑ Turbidity meter OR turbidity tube
- ❑ pH test kit
- ❑ Nitrate test kit
- ❑ Arsenic test kit
- ❑ Fluoride test kit
- ❑ Compartment bag test OR membrane filtration test ki

Double Check Your Kits

Make sure **all components** of test kits are present before you go out to collect samples.

Make sure your kits have enough **reagents** for all planned samples, blanks, and duplicates.

Helpful Items for Field Testing

- ❑ Permanent marker
- ❑ Cup
- ❑ Labeling tape
- ❑ Barcode tape
- ❑ Scissors
- ❑ Squeegee or other cleaning method
- ❑ Phone or device with GPS
- ❑ Identification card, or other form of identificati
- ❑ Letter of entry/purpose
- ❑ Offline map of the regio
- ❑ First aid kit
- ❑ Pen
- ❑ Hand sanitizer
- ❑ Notebook/data collection form
- ❑ Trash bag (including for potentially hazardous materials such as arsenic test strips)
- ❑ Forceps/tweezers
- ❑ Flashlight

Additional Test Kits (optional)

- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________
- ❑ ________________________________