February 2023

Montana Bureau of Mines and Geology Open-File Report 758

STANDARD PROCEDURES AND GUIDELINES FOR FIELD ACTIVITIES, MONTANA BUREAU OF MINES AND GEOLOGY

Montana Bureau of Mines and Geology

Version 2.0

Cover photo: Amanda Rossi, MBMG: night scene of Butte, Montana.

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January 2023

Edited by Madeline B. Gotkowitz

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MBMG
Montana Bureau of Mines and Geology

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

The Montana Bureau of Mines and Geology (MBMG) serves Montana by collecting and publishing information on the State's geologic and water resources. Data collection and interpretation by MBMG scientists must be of the highest integrity, starting with consistent measurement techniques that follow well-documented, standardized procedures.

1.2 Purpose and Scope

This report presents recommended and standard procedures for routine field activities related to soil, rock, surface water, and groundwater monitoring and sampling in MBMG investigations. These procedures establish guidance for fieldwork, standardize routine tasks, support training of staff, and aid in maintaining quality and consistency in field-based data collection efforts.

Compiling these procedures establishes a standard of practice and provides a basis for quality control for these activities across various MBMG program areas and office locations. Standardizing routine activities supports the collection of high-quality data by providing agreed-to protocols in a written format. Among other benefits, standard procedures support adequate and consistent training of personnel new to certain activities, personnel new to the MBMG, and students hired on an *ad hoc* basis.

These guidelines include procedures for visits to field sites such as wells or springs, measuring groundwater levels with a variety of techniques, calibration of meters used in the field, sampling groundwater and surface water, measuring streamflow, conducting aquifer tests, using a portable x-ray fluorescence analyzer, and sampling rock and sediment.

This report, which is both easily cited and publicly accessible, provides a reference for methods used in MBMG investigations. Periodic reviews, updates, and reissuing will ensure that the document is relevant to evolving procedures and equipment. Version 2.0, this version, provides updates to conducting and reporting on aquifer tests (Chapter 11) and includes guidelines for field sampling of rocks and sediment (Chapter 13).

Although these guidelines provide standard and recommended techniques for MBMG investigations, they do not preclude the use of modified procedures or alternative methods by MBMG personnel. On the contrary, well-documented deviations from standard procedures are often needed to support project- or program-specific scientific objectives. Each chapter in this report provides MBMG staff with a complete and detailed description of how to conduct a routine set of activities, and each chapter can serve as a starting point from which to develop and document alternative methods. Many other field techniques meet specific project needs, and these methods should be documented in related data reports.

1.3 Acknowledgments

The information presented in this report was based on standard procedures and guidance written and revised over the past several decades by MBMG staff members. In 2020, a team of MBMG compiled existing procedural documents and guidelines for review and revision. Staff involved in this effort and the revisions completed in 2023 included C. Elliott, G. Icopini, J. Madison, S. McGrath, E. Meredith, M. Richter, D. Snyder, J. Timmer, J. Dohman and C. Thomson.

Many MBMG staff members contributed to writing and reviewing various sections of this report: G. Abdo, J. Berglund, S. Bierbach, A. Bobst, C. Carstarphen, K. Chandler, J. Foley, A. Huft, S. Korzeb, S. Kuzara, J. LaFave, D. Mason, T. Myse, J. Reiten, K. Scarberry, C. Thompson, J. Wheaton, M. Wolfram, K. McDonald, A. Van Rythoven, J. Mosolf, Y. Gavillot, and T. Duaime.

Special acknowledgment is due to Dean Snyder and Mike Richter. Their expertise and experience in field methods, and their willingness to help, improved the rigor and practicality of these procedures.

Additional thanks are offered to S. Barth and S. Smith, MBMG staff who provided editorial and production support.

2.0 FIELD VISITS TO WELLS AND SPRINGS

2.1 Purpose

This document provides standard procedures for documenting field visits and collecting data from wells and springs.

2.2 Background and Definitions

MBMG staff routinely visit wells and springs located on private and public lands. A site inventory is a thorough data collection and documentation process that occurs at the first visit to a site. Site inventory data include a Groundwater Information Center (GWIC) ID, owner information, location, site details, project code, aquifer code, measuring point, site notes, a site sketch map, and field visit data.

Subsequent visits to the same site after the site inventory are field visits (however, both the site inventory and subsequent field visits are referred to as “field visits” on the public-facing GWIC website, https://mbmggwic.mtech.edu/). A field visit includes water levels or flow measurements; water-quality purging parameters; pumping water level (at wells); notes; and sampling details if samples are taken.

Inventory and field visit information are recorded on the Site Inventory/Field Visit Sheet (SIFVS; appendix 2.22.1), and subsequently entered into the GWIC database. The paper SIFVS is scanned into the GWIC library and digitally attached to the GWIC ID in the database to remain easily accessible. The SIFVS is the original record of the field visit. Clearly documenting all procedures and measurements in the field on the SIFVS can prevent future confusion and uncertainty.

2.3 Equipment and Supplies

- Site list generated from GWIC for area of interest
- Site Inventory/Field Visit Sheets (appendix 2.22.1)
- Landowner Information Sheet (appendix 2.22.2)
- Business cards and/or project summary sheets
- Toolkit [crescent wrenches, socket set, hex (allen) wrench set, screwdrivers, hammer, needle-nosed pliers, pipe wrenches, measuring tape in tenths/hundredths of feet, lubricant, wire brush, permanent markers, Teflon tape, etc.]
- Replacement plugs, bolts/nuts for access ports and well caps (for lost or missing fittings; typical bolt diameters: 1/4, 5/16, 3/8, 7/16, 1/2)
- GPS, typically a handheld unit
- Water-level indicator (electrical tape, also referred to as “e-tape” or “sounder”)
- Steel surveyors’ tape, of appropriate length, graduated in 0.01-ft increments, and chalk
- Pressure gage for flowing wells
- Sonic (acoustic) sounder (optional)
- Bleach solution and/or disinfecting wipes
- Garden hose (discharge hose)
- Five-gallon bucket
- Y-valve discharge splitter (garden hose diverter)
- Watch/timer
- Digital camera
- Digital meters, probes, and flow-through cell for purging parameters
- Calibration solutions and cups for calibration
- Fill solutions for probes (pH and redox) if needed
- Nitrate test strips (Hach or equivalent)
- Extra batteries for water-level indicator and meters
- Deionized water (DI water)
- Optional materials:
    - ▫ 7.5-min topographic map of site
    - ▫ Township, range, and tract template
    - ▫ Portable small-diameter pump with car charger or portable battery (optional)
    - ▫ Small-diameter bailer
    - ▫ Threaded and rubber pipe couplings of various sizes
    - ▫ Flexible copper tubing (9 ft long for retrieving water-level indicators wedged on pitless adapters)

Additional materials specific to springs:

- Velocity meter with Top Setting Wading Rod: SonTek® FlowTracker®, Hach® Marsh-McBirney®
- 100-ft Fiberglass tape (graduated in feet/tens/hundredths)
- Kevlar tagline: for wider spring channels and windy conditions

- Chaining pins or stakes to anchor tape or tagline
- Wire brush or other cleaning device for staff gage and/or flume
- Waders and/or wading boots
- Flume to measure flow in smaller springs

2.4 Preparing to Visit Wells and Springs

Personnel conducting a site inventory will primarily interact with private well owners and to a lesser extent county, state, and federal agencies when gaining access to a site for site inventory and field visits. This typically includes making contacts in person and by telephone. Identify potential sites to visit before going into the field. Always obtain landowner permission before collecting data from private land.

Select wells from the GWIC database on the basis of well construction and lithology criteria. Identify the current site owner, which may differ from the owner listed in GWIC. The current site owner may be determined from information in GWIC, land ownership maps, or online using Montana Cadastral Mapping (http://cadastral.mt.gov/). Contact the site owner in person, by telephone, or by mail or email. Introduce yourself as an employee of the Montana Bureau of Mines and Geology. Briefly describe the project and how and why their site was selected. Verify that the well or spring (the site) exists on their property by describing the information about the site to them and verify the type of use (domestic, stock, monitoring, etc.). Ask permission for access to their property to visit the site. Describe what data will be collected and how that data will be used. Briefly verify directions to the site. Determine if any special instructions are needed to get to the site or at the site. Thank the landowner for their cooperation even if they do not allow access to their site.

Before visiting a site for the first time, check the GWIC database for previous visits by the MBMG or other agency(s). If the site is a well, it is very important to identify the site's GWIC ID and associated well log. Without the ID, well log, and other information, the field visit data and any samples collected are not as useful and can become counterproductive in future database applications.

If the GWIC ID for a site cannot be found (due to an out-of-date owner name, no well log turned in, mislocated, etc.), consider finding a different site to visit. Alternatively, gather as much information about the well as possible from the owner and continue searching for the well log in GWIC and DNRC databases. The well owner may have a well log that you could copy or photograph.

2.5 Accessing a Site and Landowner Information

Record the site owner's name, address, phone, and email and, if different, the name, address, phone, and email of the resident or site user. Permission must be granted by the landowner at rental properties. If the site owner was contacted by telephone and the site is near the owner's residence, stop briefly at the owner's house to introduce yourself when making the field visit. When finished give the owner a completed landowner information sheet (appendix 2.22.2). If the owner is not present, leave the owner information sheet and your business card in a predetermined location.

When visiting a site, leave open gates that are open; close all gates that are closed after driving or walking through them. Clean and sterilize all equipment before putting it into a well. Replace well caps to their original condition. Always be alert for dogs or other animals that could inflict bodily harm. Complete the SIFVS during the visit. This form has been designed to record all necessary information and to match data entry screens. Before leaving the site, check that the SIFVS is completely filled out.

2.6 Location

Place your handheld GPS unit on top of the well cap, close to the well head on the ground, or next to the head of the spring and wait for good satellite coverage. Record latitude, longitude, datum, and "geomethod" (in this case, "nav-gps"). Many MBMG staff use NAD83 datum and NAVD88 elevation datum. If satellite coverage is poor or GPS unavailable, plot the site on a topographic map or digital mapping program such as Montana State Library Digital Atlas, Google Earth, or Google Maps (geomethod: "digital map"). Check and record township, range, and section (TRS) and use plastic tract overlay or the "LL2TRS" function in the datagwic tools section (the TRS can be identified after the field visit on a computer). Estimate and record the elevation of ground surface using topographic or digital maps. Record all location details on the SIFVS.

2.7 Site Details

At wells, record the well use, casing inner diameter, total depth and method used to measure it, measuring point (MP) height (positive above ground, negative below ground), MP description, sampling point (closest to well) description, well condition, land use, and pressure tank/water treatment details on the SIFVS. See section 2.11 for spring sites. Dedicated pumps, discharge pipe, and electrical service can interfere with measuring the total well depth; in some cases field staff may need to rely on well construction records to determine total depth.

2.8 Static Water Level

Procedures and protocols for measuring static water levels in wells are provided in chapter 3. Record method, time, time zone, depth to water from the MP, psi if flowing artesian well, steel tape hold and cut if a steel tape is used, and remarks on the SIFVS.

2.9 Well Purging Parameters

Review chapters 5 and 6 of this report for detailed procedures and protocols related to collecting water-quality measurements and samples from wells.

Identify the sampling point closest to the well head (a faucet, hand pump, hydrant, etc.). Attach a y-valve (splitter), flow cell, and discharge hose. Direct the discharge into a place that will not cause a problem (away from buildings, foundations, etc.). Open the valve, diverting about 1 gallon per minute (gpm) to the flow cell with probes and meter, and direct the remainder of flow through the discharge hose. Record the time water was turned on. Record purging parameter times (actual or elapsed), temperature in Celsius, specific conductance in µS/cm, pH, redox in mv, dissolved oxygen in mg/L, and any notes in the purging parameters table on the SIFVS. Repeat measurements every 5 min or as needed until parameters stabilize. Calculate discharge in gpm by recording fill time in a 5-gal bucket (for example: 300 s to fill a 5-gal bucket = 1 gpm) while the flow is shut off to the flow cell at the y-valve (all flow goes to the discharge hose). Note whether the pump is cycling on/off or running continuously (running continuously is preferred). Typical purge time for a well visit is 30 min unless a shorter or longer purge time is appropriate based on well owner recommendation, well construction, well performance, or the purging parameters themselves. Beware of over-pumping, which can result in well turbidity, cavitation (air in the pump), fine sediments entering the well screen. These can damage the well or pump (section 2.11). Record the last, stable measurements in the "Final" row of the Purging Parameters table on the SIFVS; these values will be entered into the GWIC database. If appropriate for specific project, conduct and record results of a field nitrate test (Hach or equivalent) following manufacturer instructions.

2.10 Pumping Water Level

Be aware that deep pumping water levels (PWLs) pose a greater risk of tangling the water-level indicator or causing turbidity in the well [sonic (acoustic) sounders can be used to avoid these problems]. Monitor the PWL during the visit and record the value at 30 min or, if the pump is cycling on/off, at the end of a pump cycle. Note if the PWL is steady or dropping in the PWL remarks. If a PWL is dropping quickly, adjust the discharge rate at the sampling point or y-valve, or shorten the test, to avoid over-pumping the well.

2.11 Springs

Spring settings vary widely; some discharge from a discrete point on an outcrop of a known aquifer while others discharge from a diffuse location, or from a point where bedrock is overlain by unconsolidated material. Some springs have been modified with collection systems, storage tanks, or spring boxes. Some configurations consolidate flow into a pipe. There are many ways to capture spring water and deliver it to a point of use; some springs have been developed in ways that prevent access prior to storage in a reservoir or other container. In these cases, note that field data were collected post-storage.

Collect location, field water-quality information, and samples from as close to the spring source ("head of spring") as possible. Record time (actual or elapsed), temperature in Celsius, specific conductance in µS/cm, pH, redox in mv, dissolved oxygen in mg/L, and any notes in the purging parameters table on the SIFVS. Repeat measurements every 5 min or as needed until parameters and instruments stabilize. Record stable water-quality parameters in the "Final" row of the purging parameters table on the SIFVS. Measure flow using a 5-gal bucket, flume, or velocity meter (see chapter 9). If unable to measure flow, derive and estimate based on width, depth, and velocity of discharge, recording the method of measurement as "Estimated."

2.12 Site Notes

Record directions to the site, beginning at the nearest main road and continuing to the site using an odometer or map to report distances in miles. Describe relationship and distance of well or spring to houses, structures, and any other wells. Mention anything that makes the site difficult to access or find. Describe the location of power shut off (breaker box) to the pump, if accessible.

2.13 Site Sketch Map

Show the site's relationship to landmarks (roads, homes, bridges, lakes, streams, etc.). Include distances from main roads and parking area. Show the location of the sampling point in relation to the well or spring and other notable features at the site (be sure to show and label other nearby wells). Plotting the site's location on a digital mapping application with base layer options can be useful.

2.14 Field Visit Notes

Document any important aspects of the field visit on the SIFVS. Examples include any equipment malfunctions, special circumstances, or complications and observations related to water levels or purging parameters. Record the water condition as clear, turbid, warm, turbid after 20 min pumping, etc.

2.15 Sample Details

If collected, note type of sample (complete, nitrate only, radon, etc.), bottle types filled, filtration, and preservation. Record the bottle number (ideally GWIC ID# for site) and if a duplicate or field blank was collected. Record sample condition (clear, turbid, etc.) and collection method (pumped, grab, etc.) in the space provided. Record type of sample in the space provided on the top right, front page of SIFVS.

2.16 Alkalinity Titration

Use the table provided on the SIFVS to record details from the alkalinity titration, if applicable.

2.17 Well Volume Table

Use the table provided on the SIFVS to calculate gallons of water stored in the well casing, which, when divided by discharge rate, gives purge time in minutes per well volume.

2.18 Name and Agency

Record the name(s) of employee(s) conducting the visit along with agency affiliations.

2.19 Aquifer

The Data GWIC database includes a dropdown list of aquifer codes with all MBMG-mapped geologic units, from youngest to oldest. Aquifer codes assign three numbers corresponding to the age of the unit and four letters corresponding the unit name or material.

Select the geologic material the well is completed in from the list of aquifer codes. These can be determined and recorded in the office, following the site inventory. Use the well log, well completion details, location on a geologic map, and water-quality parameters to pick the applicable code or codes.

2.20 Landowner Information Sheet

Fill out the Landowner Information Sheet (appendix 2.22.2) and leave it with the owner upon completion of the inventory and/or field visit.

2.21 Data Management

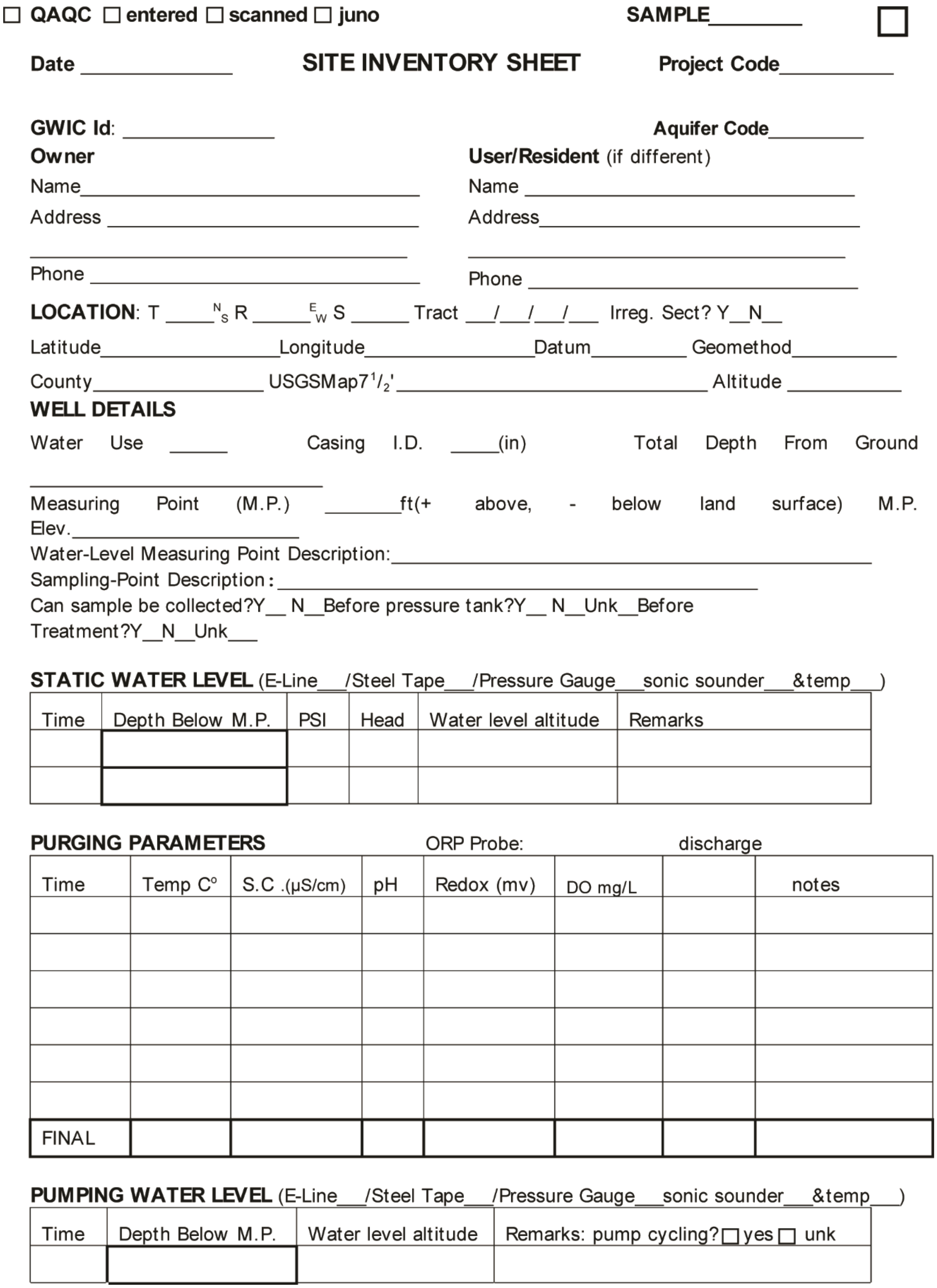
The SIFVS should be checked for completeness and accuracy by co-workers before entering data and submitting it to the GWIC office for scanning. The SIFVS is the original record of the field visit. The paper SIFVS is scanned into the GWIC library and digitally attached to the GWIC ID in the database; this ensures that it remains easily accessible.

See the GWIC Manual (available from the GWIC office) for detailed data entry instructions. GWIC relies on several data entry forms (Sites, Owner, Measuring Point, Project, Aquifer, and Inventory) for a complete Site Inventory. For a field visit at a previously established monitoring site, the "Inventory Viewer" screen is used to enter data.

Clearly documenting all procedures and measurements in the field can prevent future confusion and uncertainty. If a water sample is collected, the inventory screen must be filled out in addition to the sample submission screen, since the sample submission table does not include all inventory or field visit data. Enter an inventory or field visit into data GWIC before submitting water samples to the MBMG Analytical Laboratory, then select that visit in the sample submission process. Make sure the date and times match to create a single, complete record of your visit in the database. Failure to do so will result in duplicate or incomplete records, and these become problematic in database applications.

2.22 Appendixes

Appendix 2.22.1 Site Inventory/Field Visit Sheet



☐ **QAQC** ☐ **entered** ☐ **scanned** ☐ **juno** **SAMPLE**________ ☐

Date _____________ **SITE INVENTORY SHEET** **Project Code**__________

GWIC Id: ______________ **Aquifer Code**_________

Owner
Name_________________________________
Address _______________________________
____
Phone ________________________________

User/Resident (if different)
Name ________________________________
Address_______________________________
____
Phone ________________________________

LOCATION: T _____$^{N}_{S}$ R ______$^{E}_{W}$ S ______ Tract ___/___/___/___ Irreg. Sect? Y__N__

Latitude_________________Longitude________________Datum_________ Geomethod__________

County________________ USGSMap7$^{1}/_{2}$'______________________________ Altitude ___________

WELL DETAILS

Water Use ______ Casing I.D. _____(in) Total Depth From Ground ____________________________

Measuring Point (M.P.) _______ft(+ above, - below land surface) M.P. Elev._____________________

Water-Level Measuring Point Description:____

Sampling-Point Description:____

Can sample be collected?Y__ N__Before pressure tank?Y__ N__Unk__Before Treatment?Y__N__Unk___

STATIC WATER LEVEL (E-Line___/Steel Tape___/Pressure Gauge___sonic sounder___&temp___)

Time	Depth Below M.P.	PSI	Head	Water level altitude	Remarks

PURGING PARAMETERS ORP Probe: discharge

Time	Temp C°	S.C .(μS/cm)	pH	Redox (mv)	DO mg/L		notes
FINAL							

PUMPING WATER LEVEL (E-Line___/Steel Tape___/Pressure Gauge___sonic sounder___&temp___)

Time	Depth Below M.P.	Water level altitude	Remarks: pump cycling?☐ yes ☐ unk

SITE NOTES:

____

____

____

____

_____

SITE SKETCH MAP
Show location of well and sampling point. If necessary show site location in relation to roads.
^ North

INVENTORY NOTES:____

____

____

____

General condition of well and surface seal (Good ___ Fair ___ Poor __)

Condition of water: Clear ___ Turbid ___ Other__________________________________

SAMPLE: Standard (250ml **FU**, 500ml **FA**{HNO_3},500ml **RU,** 10ml **FU** 2H&O18) ☐

Other (nitrate only, tritium, etc.) ____

ALKALINITY TITRATION **Bottle Number**_______________

Vol. Of Sample	Total Vol. Titrated	Acid Conc.	Original pH	Digits to Reach 8.3 pH	Actual Endpoint	Digits to Reach 4.5 pH	Actual Endpoint	Total Digits

Alkalinity Concentration ☐ (mg/L as CaCO3)______________________________

FEET OF WATER	gal/ft by casing diameter	total gal	/DISCHARGE RATE	MINUTES PER WELL VOLUME
	(2"x.163),(4"x.65),(6"x1.47),(8"x2.61),(10"x4.08),(24"x23.5)			

Name___________________________ **Agency** ____________________

Appendix 2.22.2 Landowner Information Sheet

Thank you for participating

Your well was visited on ___________________by____________________________________
of the Montana Bureau of Mines and Geology GWIC ID____________ Total Depth_________

The following parameters were measured:

Depth to groundwater ________**feet below casing**

Groundwater temperature ________**F** ________**C**

Specific conductance* ________**micromhos**

________**estimated TDS**

pH** ________

Nitrate*** ________**mg/L**

Pumping water level ________ **feet** ________**gallons/minute discharge rate**

***Specific Conductance** is a measure of how easily water conducts electricity and provides an indication of the amount of minerals in the water. When minerals dissolve in water they form ions that can conduct electricity. The more minerals dissolved in water, the greater the conductance. The total dissolved solids (TDS), in parts per million, can be estimated by multiplying the Specific Conductance by 0.6.

****pH** is a measure of how acidic or basic the water is. Water with a pH of 7 is neutral; less than 7 is acidic, and greater than 7 is basic. Low values of pH, particularly below pH 4, indicate a highly corrosive water. High values, particularly above pH 8.5, indicate alkaline water. Most groundwater has a pH between 6.5 and 9.0.

*****nitrate mg/L** is a field measurement of the nitrate concentration from your well. This field measurement is made using a colorimetric method and is less accurate than a lab test, but is useful as a reference. Source of nitrates in groundwater can range from the geologic deposits that form the aquifer, to infiltration from septic tank seepage, fertilizers, or animal wastes. The national drinking water standard for nitrate is 10 mg/L; natural background levels are less than 2 mg/L.
For more information about your well or wells in your area visit the Ground Water Information Center (GWIC) on the web: www.mbmggwic.mtech.edu. Internet search: gwic

For more information contact:
John I. LaFave
Groundwater Characterization Program
Montana Bureau of Mines and Geology
Montana Tech of the University of Montana
1300 West Park Street
(406) 496–4306

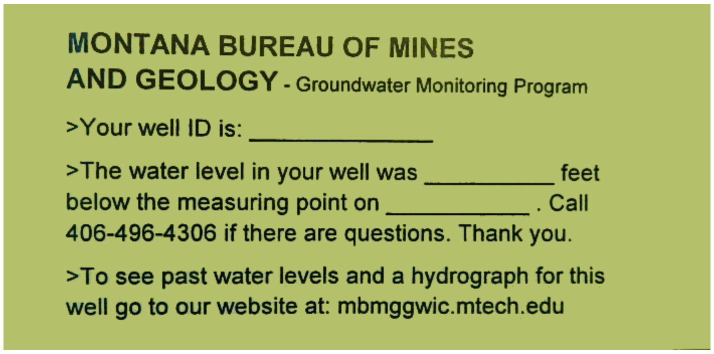
3.0 STATIC WATER-LEVEL MEASUREMENTS IN WELLS

3.1 Purpose

This document presents standard procedures for measuring the depth to water or pressure in a well under non-pumping conditions using a water-level indicator, graduated steel tape, sonic (acoustic) sounder, or pressure gage. Procedures cover wells under non-flowing and flowing ("artesian") conditions.

3.2 Equipment and Supplies

- Water-level indicator (electrical tape, also referred to as "e-tape" or "sounder"), e.g. Solinst, Sinco, or equivalent
- Steel surveyor's tape, of appropriate length, graduated in 0.01-ft increments.
- Carpenter's chalk
- Some method of cleaning the tape (10% bleach and water in a spray bottle, a container of disinfecting wipes, paper towel or cloth)
- Extra batteries for the water-level indicator
- Pressure gage and series of graduated metal attachments, hose clamps
- Sonic sounder with well cover or cardboard cover
- Mirror and/or flashlight
- Site Inventory Sheet (appendix 2.2.1)
- Route Sheet
- Landowner Water-Level Cards (fig. 3.1)
- Toolkit [plumber's tape, crescent wrenches, hex (allen) wrench set, hammer, needle-nosed pliers, pipe wrenches, engineer scale graduated metal tape, WD-40, wire brush, small, medium, and large screwdrivers, socket wrench and socket set, permanent markers, etc.]
- Keys to access the well, if locked


MONTANA BUREAU OF MINES
AND GEOLOGY - Groundwater Monitoring Program

>Your well ID is: ______________

>The water level in your well was __________ feet below the measuring point on ___________ . Call 406-496-4306 if there are questions. Thank you.

>To see past water levels and a hydrograph for this well go to our website at: mbmggwic.mtech.edu

Figure 3.1. Landowner water-level cards may be used to inform a property owner about results of a field visit.

3.3 Establishing a Site and Measuring Point

If this is the first visit to the well by MBMG staff, follow procedures in chapter 2.

Many of the sites visited by MBMG staff are privately owned. Always obtain landowner permission before collecting data from private land. As described in chapter 2, check the Ground Water Information Center (GWIC) database for previous visits by the MBMG or other agency(s) before visiting a site for the first time. It is very important to identify the site's GWIC ID with attached well log. Without the ID, well log, and other information, the water-level data are not as useful and may become counterproductive in future database applications. If the GWIC ID for a site cannot be found (old owner name, no well log turned in, mislocated, etc.), find a different site to visit or gather as much information about the well as possible from the owner and continue searching for the well log in the GWIC and DNRC databases.

The measuring point (MP) is the point at which a depth to water is measured from. The MP is typically established at the top of a well casing or an access port in the well cap. The MP should be clearly marked. If the MP has not already been established, clearly describe the measuring point on an MBMG Site Inventory/Field Visit Sheet (appendix 2.22.1) and document the distance between the land surface and the measuring point. If the MP isn't marked, a common method is to establish it on the north side of the casing, marking it with an oil paint marker.

The MP for a flowing well should be placed as close to the outlet as possible. Follow MP data entry procedures as outlined in the GWIC Manual, which is available from the GWIC office. The MP is needed so that a hydrograph can be generated from the GWIC database.

3.4 Procedures

Static water-level measurements must be made under non-pumping conditions. If the well contains a pump, turn off the pump if possible, preferably by shutting off power to the pump at the breaker box. If necessary, talk to the well owner regarding turning off the pump before proceeding further. If the well has a drop pipe installed, the measurement is taken within this pipe to avoid tangling the water-level indicator. Remove well cap by loosening and/or removing nuts and bolts or access plug carefully, using caution to avoid disturbing wiring inside the well casing.

Use of a water-level indicator is the preferred method. If it will not fit through an access port or if it hangs up when lowered into the well casing, attempt measurement with a steel tape. If neither a water-level indicator nor steel tape can be lowered to the water level, attempt to measure the depth to water with a sonic sounder.

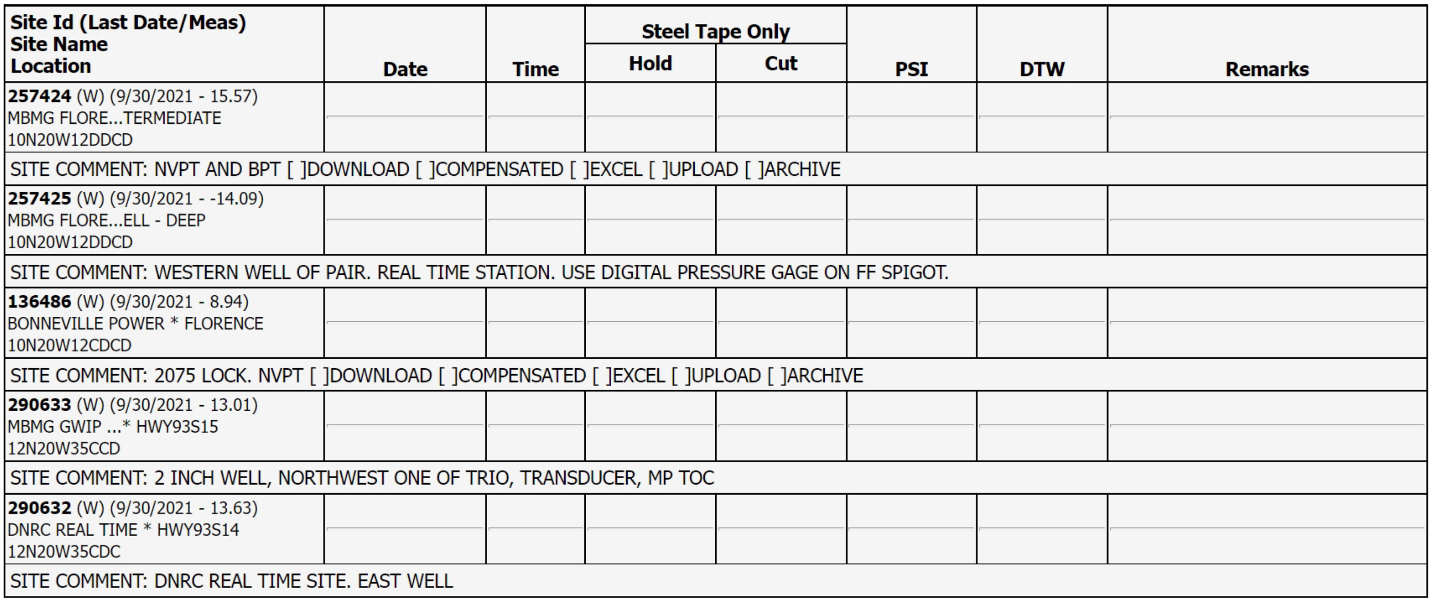
When measurements are complete, replace cap, nuts and bolts, and/or plug, without overtightening. Turn power back on if it was shut off.

3.4.1 Water-Level Indicator Measurements

1. Test the water-level indicator by dipping it in water and observing the indicator or by activating the “test” switch.
2. Lower the water-level indicator slowly into the well until contact with the water surface is indicated by sound and/or the indicator light.
3. Read the depth at the measuring point while the probe is just touching the water surface, and record the distance to water.
4. Repeat the measurement and record on the route or inventory sheet, or field notebook. If two measurements of static water level made within 1 min do not agree within 0.02 ft, repeat the measurements until a reason for the lack of agreement is determined, the results are shown to be reliable, or until it is determined that a more precise measurement is not possible. In cases of a recovering water level, remain for a reasonable time until consecutive water-level measurements agree. Otherwise record both measurements on the inventory or route sheet (fig. 3.2) and note that they are “non-static.” Record the date and time.
5. After completing the water-level measurement, disinfect, rinse, and dry the portion of the tape that was submerged or became soiled during the measurement.

3.4.2 Steel Tape Measurements

1. Apply chalk to the first few feet of the tape by pulling the tape across a piece of carpenter’s chalk. A smooth coating of chalk on the tape should result.
2. Lower the tape into the well from the measuring point until a short length of the tape is submerged (estimate from previous measurements if available).
3. When the tape is submerged, hold the tape at the measuring point and read the value; record this “hold” value on the field form, inventory sheet, or in field notes.
4. Retrieve the tape from the well and note the



Site Id (Last Date/Meas) Site Name Location	Date	Time	Steel Tape Only		PSI	DTW	Remarks
			Hold	Cut			
257424 (W) (9/30/2021 - 15.57) MBMG FLORE...TERMEDIATE 10N20W12DDCD							
SITE COMMENT: NVPT AND BPT [ ]DOWNLOAD [ ]COMPENSATED [ ]EXCEL [ ]UPLOAD [ ]ARCHIVE							
257425 (W) (9/30/2021 - -14.09) MBMG FLORE...ELL - DEEP 10N20W12DDCD							
SITE COMMENT: WESTERN WELL OF PAIR. REAL TIME STATION. USE DIGITAL PRESSURE GAGE ON FF SPIGOT.							
136486 (W) (9/30/2021 - 8.94) BONNEVILLE POWER * FLORENCE 10N20W12CDCD							
SITE COMMENT: 2075 LOCK. NVPT [ ]DOWNLOAD [ ]COMPENSATED [ ]EXCEL [ ]UPLOAD [ ]ARCHIVE							
290633 (W) (9/30/2021 - 13.01) MBMG GWIP ...* HWY93S15 12N20W35CCD							
SITE COMMENT: 2 INCH WELL, NORTHWEST ONE OF TRIO, TRANSDUCER, MP TOC							
290632 (W) (9/30/2021 - 13.63) DNRC REAL TIME * HWY93S14 12N20W35CDC							
SITE COMMENT: DNRC REAL TIME SITE. EAST WELL							

Figure 3.2. A static water-level field sheet can be generated with the ‘My Routes’ tool in data GWIC. Field notebooks may be used in place of field sheets or inventories but are more difficult to scan and archive.

water mark, or "cut" mark, on the chalked part of the tape. Record the "cut" mark.

5. Subtract the "cut" reading from the "hold" reading to determine the distance to water below the measuring point. Record the resulting distance to water value. Record the date and time.
6. Repeat the measurement by lowering the tape into the well a second time and "holding" at a point on the tape 1 ft greater than the initial "hold" point. Subtract the new "cut" mark and determine a second distance-to-water value for the well. Record the measurements on the inventory or route sheet. If two measurements made within a few minutes do not agree within 0.02 ft (in wells having a depth-to-water less than 300 ft), repeat measurements until a reason for the lack of agreement is determined, the results are shown to be reliable, or until it is determined that a more precise measurement is not possible. For depths greater than 300 ft, measurements should agree to within ±0.1 ft. Record measurements on a field form or inventory sheet (fig. 3.2).
7. After completing the water-level measurement, disinfect, rinse, and dry the portion of the tape that was submerged or became soiled during the measurement.

3.4.3 Pressure Gage Measurements

1. Note the position of the valve controlling flow from the well when open; turn off (close) this valve.
2. Carefully wire brush the threads on the pipe extending from the well. Put Teflon tape around the threads. If the pipe is cross-threaded or if there is any uncertainty about the integrity of the well casing and piping on a discharging well, do not attempt to measure pressure.
3. Carefully attach the necessary fittings to reduce to the diameter of the fitting on the pressure gage. Attach the pressure gage.
4. Slowly open the valve controlling flow from the well until fully open.
5. Give the pressure gage adequate time to respond; 15 min is a general recommendation, but this varies with well and pressure gage.
6. Read the pressure gage twice, several minutes apart. If two measurements of pressure level made within a few minutes do not agree within 0.05 psi, repeat the measurements until a reason for the lack of agreement is determined or until the results are shown to be reliable or until it is determined that a more precise measurement is not possible.
7. Record date and times and both measurements on the inventory or route sheet.

3.4.4 Sonic Sounder (Acoustic) Measurements

1. Variability in well construction and pump installation can limit the accuracy and effectiveness of acoustic sounders. However, this method may work in wells where a steel tape or e-tape (water-level indicator) will not.
2. Follow manufacturer instructions for temperature setting based on provided regional map or temperature tables. In areas with known geothermal or other anomalous conditions, measure the water temperature and adjust device accordingly.
3. Set the device on top of the well casing with the well cover or into the access port and initiate the measurement.
4. Repeat the measurement and record with date and times on the route or inventory sheet. If two measurements of static water level made within 1 min do not agree within 0.02 ft, repeat the measurements until a reason for the lack of agreement is determined, the results are shown to be reliable, or until it is determined that a more precise measurement is not possible. In cases of a recovering water level, remain for a reasonable time until consecutive water-level measurements agree. Otherwise record both measurements and date and times on the inventory or route sheet and note that they are "non-static."

3.5 Quality Control

Quality control will be maintained by collecting two consecutive water-level measurements within acceptable agreement for the procedure used. If agreement is not achieved, note the lack of agreement on the field form or inventory sheet in the remarks column.

3.6 Documentation

Many MBMG projects include providing a record of each site visit to the property owner. The landowner water-level card (fig. 3.1) may be used for this purpose.

Standard documentation procedures include clearly recording all measurements and noteworthy remarks on the field form or inventory sheet, followed by scanning the paper copy of the form or sheet into the GWIC library. This procedure prevents confusion and uncertainty about measurements when the data are used in the future. Field notebooks may be used in place of the field form or inventory sheet but are more difficult to scan and archive.

Date, time, and time zone (MDT or MST) are also clearly recorded under the appropriate heading. Important details that may have affected the measurement are noted in the remarks column. If not already established, the well location and MP are documented on the Site Inventory/Field Visit Sheet (appendix 2.22.1) including a map of the site, directions, and notes about any special circumstances or locations of additional wells (chapter 2).

3.7 Data Entry and Archive

Follow SWL data entry instructions as outlined in the GWIC Manual, which is available from the MBMG GWIC office. Submit completed field form or Site Inventory/Field Visit Sheet to the GWIC office for a quality control check and scanning into the GWIC library. After scanning, file the paper copy in appropriate program storage file. MBMG staff should ensure that water levels are entered into the GWIC database within 1 mo of measurement.

3.8 Additional Information

Cunningham, W.L., and Schalk, C.W., compilers, 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 p., available only online at https://pubs.usgs.gov/tm/1a1/ [Accessed October 2021].

Garber, M. S., and Koopman, F.C., 1968, Methods of measuring water levels in deep wells, techniques of water-resource investigations of the U.S. Geological Survey, Book 8, chap. A1, 23 p.

U.S. Geological Survey, 2013, National Ground Water Monitoring framework report, available at http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf [Accessed October 2021].

U.S. Geological Survey, 1980, National handbook of recommended methods for water-data acquisition, chap. 2, Ground Water, 149 p.

4.0 MEASURING WATER LEVELS AND TEMPERATURE WITH RECORDING PRESSURE TRANSDUCERS

4.1 Purpose

This document provides standard procedures for the use of pressure transducers (PTs) and data loggers to collect and record water levels and temperatures in wells. PTs are typically suspended inside well casings and stilling wells on a length of non-stretch cord or direct read (data transmission) cable available from the instrument manufacturer.

4.2 Equipment and Supplies

- Non-vented (absolute) pressure transducer (NVPT)
- Vented (gaged) pressure transducer (VPT)
- Barometric pressure transducer (BPT)
- Communications cable from manufacturer
- Field computer or other data storage and programming device
- Non-stretch cord (1.7-mm 400-lb Kevlar, dyneema, etc.); 1/16–1/8 in 7 x 7 plastic/vinyl-coated galvanized or stainless steel aircraft cable/rope, or manufacturer’s direct read cable
- Attachment system, typically consisting of stainless steel wire, eye bolt with extra nuts, well collar with attachment point, large-diameter hose clamps with stainless steel key rings
- Small carabiner clips
- Cordless drill
- Logger retrieval spool
- Water-level indicator (also referred to as an e-tape or sounder)
- Toolbox
- Disinfecting wipes or bleach solution

4.3 Procedures

Obtain well owner permission before taking measurements or installing equipment. Shut off any power sources to the well (typically at a breaker box) before equipment installation and turn power back on after installation is complete. Most well caps are vented, but if the well has a sanitary seal cap it may need to be vented by drilling a small hole in the access port plug. Venting allows for changes in atmospheric pressure to affect the well bore.

4.4 Pressure Transducer Type, Range, and Length of Cord or Cable

PTs are available as non-vented (NVPT, section 4.4.1), vented (VPT, section 4.4.2), or barometric (BPT, section 4.4.3). NVPT and VPT types are available in several pressure ranges that allow submergence below the water level from 5 to 200 m. Estimated maximum and minimum water levels determine the length of cord or cable to ensure the PT remains submerged at all times, without exceeding the pressure range (section 4.6). Subjecting the PT sensor to out-of-range pressures may damage the sensor and diminish accuracy (see manufacturer recommendations).

4.4.1 Non-Vented (Absolute) Pressure Transducers

NVPTs are sealed, allowing for simple and cost-effective suspended cord (4.6.1) or direct read cable (4.6.2) installation. Following data retrieval, data recorded from NVPTs must be compensated for the changes in barometric pressure that occurred during deployment of the NVPT in the well. NVPT data are referenced to a manual static water level (SWL; section 4.8.2).

4.4.2 Vented (Gaged) Pressure Transducers

VPTs use a manufacturer-supplied cable to communicate and vent the sensor to the atmosphere, and this makes barometric compensation unnecessary. Air desiccation systems that keep moisture from entering the VPT vent tube are supplied by the manufacturer. The vent tube must stay open to the atmosphere, and care should be taken to avoid pinching or crimping the vent tube during installation. The cost of these cables and properly maintaining the desiccant can make VPTs less desirable for use in wells. VPTs can be most effective when used in shallow wells or stilling wells at staff gages or flumes because these require shorter vented cables. They are also very useful for real-time applications because barometric compensation is unnecessary. Other than barometric compensation, the same procedures generally apply for VPTs and NVPTs. VPT data are referenced to a manual SWL measured at the beginning of the record.

4.4.3 Barometric Pressure Transducers

BPTs are used to record atmospheric pressure during NVPT deployment. They are non-vented and have a low pressure range. The barometric pressure data are subsequently used to compensate NVPT data for atmospheric pressure changes. One BPT can be used for all NVPTs within about a 20-mi radius and 1,000 ft of elevation change (see manufacturer recommendations). BPTs are typically installed in wells at a depth above the high water level (to ensure they are never submerged), but below frost line (to avoid large temperature fluctuations that can affect accuracy).

4.5 Programming with Manufacturer Software

Download the latest version of the manufacturer's PT software onto a laptop or desktop computer. Find the user manual and instructions within this software, typically under "Help." Communication cables that transmit data from the PT to a computer are specific to each type of PT and are typically provided by the PT manufacturer. USB drivers for the communications cable may need to be installed manually or may automatically install when the communications cable is plugged into a computer USB port. Test the communication cable's functionality on your specific device while within range of an internet connection. This will enable the user to obtain software, driver, or firmware updates from the internet that might not be available otherwise. Check for any PT firmware updates and perform update if needed. Follow equipment manufacturer instructions to program PTs using a computer connected to the device with communications cable from manufacturer.

4.5.1 Units

PTs have multiple options for measurement unit settings. Typically set units on NVPTs and VPTs to "Feet" and degrees "Celsius," consistent with data display in the GWIC database. Set units on BPTs to "Feet" or "PSI" and degrees "Celsius." Adjust to different units as appropriate to meet project-specific needs.

Although manufacturer-dependent, some software provides options to record and process water levels as a depth to water or as a height of the water column. Setting PTs to display data in "Depth to Water" is recommended to match the format of the GWIC database, SWL depth. Adjust to a specific setting as appropriate to meet program-area or project-specific needs.

4.5.2 Naming the PT

Each PT is assigned a unique name during programming, prior to deployment. The name is recorded in the "Location," "Site," or other field, according to manufacturer software design. MBMG convention calls for the PT name to include the site type (well, spring, stream, etc.), the site GWIC ID, and the type of PT (LevelNVPT or LevelVPT or BaroPT). Including "Level" or "Baro" in the file name is helpful when processing data. Including the GWIC site name is optional (because site names may change over time) but can be helpful in post-processing. Some example file names include:

- well 123456 levelNVPT
- well 123456 levelVPT
- well 123456 baroPT
- well 123456McGovern levelNVPT

4.5.3 Logging Interval and Clock

PTs are often set to measure and record every hour (60-min intervals) at the top of the hour unless more or less frequent data are needed. Care should be taken if using shorter time intervals so that the PT data storage capacity is not exceeded between downloads. Sync the PT clock time to computer time during programming and downloading to minimize PT clock drift. Best practice is to use Mountain Standard Time (MST) year-round to avoid complications when clocks change at daylight savings.

4.5.4 Delayed Start or Future Start

The "delayed" or "future start" function can be used to start PTs on the next top of the hour, ensuring that NVPTs and BPTs collect readings at the same time. This increases accuracy during barometric compensations and creates uniformity across datasets, programs, and agencies. If a site exhibits rapid water-level fluctuations, minimize the period of time between collecting a manual SWL and the PT measurement by taking the manual SWL measurement at the top of the hour. Alternatively, change the PT start time to match the manual measurement time. Direct read cable installations can be started immediately or at the top of the hour since the PT is submerged to full depth while connected to a programming device. If the hydrogeologic setting is dominated by low-conductivity formations, collect a manual SWL prior to deploying the PT because the PT can act like a miniature slug, raising the water level a measureable amount in low-conductivity environments.

4.5.5 Data File Name and Data Directory Settings

File name and data directory settings are found under "Configuration" or "Preferences" in manufacturer software. Best practice for naming PT data files includes the location (name) of PT and download date (date file created). Other information, such as serial number and start date, are optional. The location name (site type GWIC ID levelNVPT/levelVPT/baroPT) and date of download format allows individual files to be easily organized and found by GWIC ID, site name, or date of download. Data directory settings allow the user to specify a directory to automatically save to when downloading data files from PTs (section 4.7).

4.6 Installation

Determine the depth of installation by estimating the maximum and minimum depth to water expected in the well. Select a length of cord or cable that falls within the range expected, to ensure the PT remains submerged at all times, without exceeding the pressure range of the transducer (section 4.4). Cables ordered from the manufacturer are available in custom lengths. Measure your own suspension cord or cable using a tape measure of some type. Sterilize the PT and the material that will be used to suspend it with a bleach solution or disinfecting wipes.

4.6.1 Deploying the PT

Non-stretch Kevlar or Dyneema cord, 1/16–1/8 in 7 x 7 plastic/vinyl-coated galvanized or stainless steel aircraft cable/rope, or other non-stretch material is preferred to support data accuracy. If the cord stretches or is moved while the transducer is deployed in a well, this causes a change in the depth of the PT, reducing the accuracy of the water-level record. Some non-Kevlar cables may retain kinks or bends that can prevent the PT from reaching the depth of a prior deployment.

Connect the cord or cable to the PT at one end and the carabiner or well head attachment point at the other, using a bowline, other suitable knot, or aluminum crimps. If using a carabiner, connect it to the top of the well casing using a loop of stainless-steel wire, eye bolt, well collar with attachment point, large diameter hose clamps with stainless steel key rings, or other robust system. These various options are illustrated in figures 4.1, 4.2, and 4.3 (next page).

Lower the PT slowly down through the well; PTs can be damaged by sudden changes in pressure. Do not allow the PT to "freefall" down to the static water level. Pay special attention if the well diameter varies with depth (for example, if the well has a small-diameter inner PVC casing or liner).

Beware of sharp metal edges that are often present along the top of well casings (fig. 4.1), as these may fray suspension cords. If livestock are present at the site, they can damage or detach well caps.

PTs can be pre-programmed with the "delay" or "future start" programming options (section 4.5.4) to ensure they are submerged to full depth before the first reading.

After the PT is deployed, collect and record a manual SWL measurement (chapter 3); this is the "level reference" or "field zero" (section 4.8.2). Be aware that in low-permeability aquifer environments, and particularly in small-diameter monitoring wells, the PT can act as a small slug that displaces water and temporarily increases the water level. In such cases, record a manual SWL prior to deploying the PT.

Use a field form or field book to record the brand, range, serial number, battery status, length of cord or cable (depth of install), and attachment system. Upon return to the office or remote work station, these field notes can be entered into the GWIC SWL table (details under "remarks") and into the GWIC metadata table for the site. Data entry procedures are outlined in the GWIC Manual, which is available from the MBMG GWIC office.

4.6.2 Direct Read Cable

Manufacturer's direct read cables allow the PT to be programmed and downloaded without retrieving the PT from the well. The cable is attached to the well cap or top of casing using one of the methods described in section 4.6.1, illustrated in figure 4.4, or according to manufacturer instructions. A field computer or downloading device is connected to the top end of the direct read cable with the manufacturer's communications cable.

Figure 4.1. Suspended cord installation with eye bolt, carabiner clip, and Kevlar cord. The bolt-on well cover is removed from the well in this photo. Note sharp metal edge along the top of the casing.

Figure 4.2. Suspended cord installation using well collar with attachment point. The bolt-on well cover is removed from the well in this photo.

Figure 4.3. Suspended cord installation using a small drilled hole and stainless-steel wire loop. The bolt-on well cover is removed from the well in this photo.

Figure 4.4. Direct read cables from a barometric pressure transducer and a non-vented pressure transducer are affixed to eye bolts. The bolt-on well cover is removed from the well in this photo.

4.6.3 Domestic, Stock, or Other Wells with Pumps

At wells with dedicated pumps, contract with a licensed driller or pump technician to install a drop-pipe in the well casing to the full depth of the planned PT installation. PTs are suspended inside the drop-pipe to avoid tangling the PT cord or cable during deployment or retrieval. If a drop-pipe cannot be installed, a direct read cable may be used to allow data downloads without removing the PT from the well. This lessens the chance of tangling. Although direct read cables and PT batteries will eventually require replacement, retrieval will be infrequent compared to use of a suspension cord.

4.7 Retrieving and Downloading the PT and BPT

Following the period of data recording, prior to retrieving the PT, collect and record a manual measurement of the SWL. This measurement will be used to check pressure transducer records for accuracy (drift) and as a "level reference" or "field zero" during the barometric compensation.

Retrieve the NVPT and/or BPT manually by carefully disconnecting the carabiner from the wellhead attachment point, connecting the carabiner to a retrieval spool, and withdrawing the PT from the well (fig. 4.5). Connect the PT or BPT to the laptop or downloading device. In cases where a direct read cable is used, connect the downloading device to the cable at a mounting location near the top of the well casing. Follow manufacturer instructions, as methods for downloading will vary. If the PT is stopped while downloading, it must be restarted after downloading, prior to redeploying in the well.

Figure 4.5. Retrieval spool (a repurposed water-level indicator) used to pull and replace a pressure transducer installed with the suspended cord method. Use the spool to slowly lower the pressure transducer down the well casing, avoiding tangling the cord in vegetation or snowpack.

It is good practice to perform a "dry run" through software programming and downloading to ensure files are named properly and saved to the appropriate folder before installing the PT (section 4.5.5). After downloading, check the appropriate folder on the computer or download device to ensure the data file has been properly saved. Back up the data file on a thumb drive or other type of removable media. Indicate that the PT has been downloaded on the route sheet or field book. Lower the PT slowly back down the well, and carefully reattach carabiner to attachment point if using a retrieval spool (suspended cord method). Under most conditions, the BPT that will be used to compensate NVPTs in a given area should be downloaded after the NVPTs, ideally within several hours. This avoids advanced records processing by ensuring a barometric record for each level record. Projects that include many transducers deployed within a study area should adjust as necessary to achieve overall efficiency in data management.

4.8 Data Management

The large amount of data and number of files related to recording pressure transducers require special attention to data management and file storage. At least three file types are archived on designated drives on the MBMG computer network:

1. Raw data files downloaded from the PT and/or BPT
2. Compensated and/or referenced data files that have been baro-compensated and/or field referenced
3. Excel data files prepared for GWIC upload

Standard practice includes completing data processing and GWIC uploads within 1 mo of download. Timeliness is critical because GWIC data are used widely by MBMG staff, other government agencies, watershed groups, consultants, and the public.

4.8.1 Archiving Raw Data Files

The "raw" (uncompensated and uncorrected) data file is copied and saved into the appropriate folder on the MBMG network. This archives the raw data file and should be completed as soon as possible after download, preferably within 1 week. Indicate on the route sheet or field book that the raw file is archived.

Examples of raw data file names automatically saved to a computer by downloading with manufacturer software, ready for archiving at the MBMG:

- Solinst:
  - _well 123456 levelNVPT_2020_01_15
  - 2101234 _well 123456McGovern BaroPT_2020_01_15
- In-Situ:
  - well 123456 2020-01-15 levelNVPT
  - well 123456 2020-01-15 BaroPT

4.8.2 Barometric Compensation and Level Reference

As described above, manufacturer's software may support water-level processing as a depth to water or as a height of the water column. Use of "Depth to Water" is recommended to match the format of the GWIC database, SWL depth. However, determining an alternative approach to standardize for a specific program area or a project may support efficient data management.

Follow the manufacturer's instructions and use the software provided, as methods vary with brands of transducers. Most software procedures include two steps in the barometric compensation process. The first step includes selecting the appropriate BPT file to use with one or more NVPT files and then running the barometric compensation program. The second step includes entering a manual SWL as a "field zero" or "level reference." If more than one manual SWL exists from the period of record, they can be entered to minimize data drift.

Barometric compensations can also be performed in an Excel spreadsheet and, although rarely used, most software provides instructions for this process. Using manufacturer-provided software programs to perform barometric compensations is preferred because it reduces the opportunity for human error.

4.8.3 Archiving and Exporting Barometric Compensated and/or Referenced File

The compensated and/or referenced data file is saved in the appropriate folder in the MBMG network. The file is then exported to Excel for an accuracy check and reformatting to facilitate uploading into GWIC. Indicate on the route sheet or field book that the compensated data file has been archived. Archiving this file is completed as soon as possible after compensation and/or reference is complete, within 1 mo of downloading.

Examples of a level referenced, compensated file name as automatically saved to a computer after compensation with manufacturer's software, ready for archiving at the MBMG:

- Solinst:
  - well 123456 levelNVPT_2020_01_15Compensated
  - 2101234_well 123456 levelVPT_2020_01_15Referenced
- In-Situ:
  - well 123456 2020-01-15 levelNVPT Compensated
  - well 123456 2020-01-15 levelVPT Referenced

4.8.4 Data Accuracy/Drift Assessment

Data that have been referenced to a manual SWL and barometrically compensated should be assessed for accuracy. Graphing functions built into the software or graphing in Excel are helpful for this analysis. Examine the beginning and end of the record for data recorded while the PT was not yet submerged, and to determine if barometric data fully cover the period of record. Invalid data should be deleted from the Excel file before proceeding further. Compare the final value from the compensated and/or referenced file to the SWL measured at the time of data download to assess drift. If drift is greater than the accuracy listed by the manufacturer (note the accuracy varies with the pressure range of the PT), there may be a problem with the installation, the SWL, or the PT, and the data may be inaccurate.

Some technicians apply a "level reference" correction during the barometric compensation process, which adjusts recorded data to manual measurements to correct for instrument drift. In some circumstances, such as deploying the transducer over long time periods, this can disguise progressive failure of the PT. An alternative practice consists of applying a barometric compensation without use of a level reference, and graphing the compensated data along with manual SWL measurements to assess for drift.

4.8.5 Data from Wells Pumped for Water Supply

Transducer data from wells that are pumped routinely (for example, a stock or domestic well) typically include water levels that reflect pumping and non-pumping periods. Scientists may choose to filter data to display hydrographs that include only data from non-pumping periods, depending on specific project needs. This can be accomplished by selecting water levels from a nighttime hour when the pump is typically off and using a spreadsheet or similar method to annotate data collected during pumping as “non-static.” This can be used to prevent GWIC from including data from pumping periods on hydrographs while retaining all recorded data for download.

4.8.6 Preparation for GWIC Upload: Excel Processing

Excel templates for wells, springs, and streams are available at datagwic.mtech.edu under the “Tools” heading. The “Data Loader IDs” are available under “More Tools.” In data GWIC, PT data are classified as “Digital Logger” under “Method” in templates. Copy and paste the prepared Excel sheet into a new worksheet and rename the worksheet tab “LOAD.” Save this Excel workbook with GWIC appended to the end of the file name. Copy the workbook into the appropriate folder on the MBMG network.

Examples of file names used for field-referenced, compensated, drift-assessed, and processed data ready for upload to GWIC:

- Solinst:
    - well 123456 NVPT_2020_01_15CompensatedGWIC
    - 2101234_well 123456 VPT_2020_01_15ReferencedGWIC
- In-Situ:
    - well 123456 2020-01-15 NVPTCompensatedGWIC
    - well 123456 2020-01-15 VPTReferencedGWIC

4.8.7 GWIC Upload

Copy files ready for upload to GWIC to an appropriate location on the computer network and email a notification of the incoming files to the GWIC office staff. MBMG staff may become trained in this procedure by contacting the GWIC office manager. After upload is complete, check GWIC to verify that data were properly uploaded (15-min updates). If upload was successful, indicate that on the route sheet or field book.

4.9 Documentation

Documenting all procedures and measurements in the field and during the compensation and upload process can prevent future confusion and uncertainty. Accurate manual SWL measurements at the time of PT installation and download are integral to data processing and accuracy assessment. Installation details can affect accuracy of data; therefore, field notes should include the brand, range, battery status, PT serial number, length of cord or cable (depth of install), date and time of installation, and attachment system. Write these measurements and details on the route sheet field form or field book and enter them into the GWIC SWL table. Submit completed field form or inventory/field visit sheet to the GWIC office for scanning into the GWIC Library. After scanning, file paper copy in appropriate program storage file.

4.10 Additional Information

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 p., available at https://pubs.usgs.gov/tm/1a1/ [Accessed October 2021].

U.S. Geologic Survey, 2004, Use of Submersible Pressure Transducers in Water-Resources Investigations: Techniques of Water–Resources Investigations 8-A3, available at https://pubs.usgs.gov/twri/twri8a3/#N106D7 [Accessed October 2021].

Solinst User Guide Levellogger Series Software Version 4.4.0, 2018. https://www.solinst.com/downloads/

Solinst User Guide Vented Dataloggers, 2018. https://www.solinst.com/downloads/

Win Situ 5, In-Situ Help, https://in-situ.com/us/

5.0 FIELD INSTRUMENT CALIBRATION AND MEASUREMENTS: SPECIFIC CONDUCTANCE, pH, DISSOLVED OXYGEN, OXIDATION-REDUCTION POTENTIAL, AND TEMPERATURE

5.1 Purpose

This document provides standard procedures for measuring water-quality parameters of groundwater and surface water, including specific conductance (SC), pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and temperature, using field instruments. It also outlines the procedures to calibrate field instruments. Field instruments can also be used in a laboratory setting, for example as a part of bench-scale experiments that may require water-quality parameter measurements.

5.2 Sample Handling and Preservation

The SC, pH, DO, ORP, and temperature should be measured in the field at the time of the field visit or water-sampling event. If the measurements cannot be performed in the field, a zero-headspace sample should be collected and stored at 4°C until the physical parameters can be measured.

5.3 Equipment and Supplies

- SC, pH, DO, and ORP meters and probes or multi-probe meter and probes (“sonde”)
- pH 4, 7, and 10 standard calibration solutions
- Specific conductance standard near the expected specific conductance of the samples or a standard(s) specified by the equipment manufacturer
- Zero-point solution for DO calibration
- Barometer, if needed for the DO meter selected for fieldwork
- ZoBell’s solution for ORP calibration
- Deionized (DI) water in a spray bottle
- Kimwipes or lint-free paper towels
- An optimally sized container or bottle for calibrating; match the size to the probes so that the probes are adequately submerged without wasting a large volume of calibration solution
- A bottle to store used calibration solutions for later disposal (for example, by flushing down a sanitary sewer with clean water)
- A thermometer traceable to National Institute of Standards and Technology
- Notebook

5.4 Procedures

Field instruments should be cleaned, maintained, serviced, and/or calibrated according to the manufacturer recommendations. Instruments should be inspected to make sure that they are in good working order prior to their first use for the season or after several weeks or months of disuse. Conduct a pre-trip inspection including checking batteries, replacing as needed, and inspecting and calibrating each instrument/probe to ensure that they are in good working order before leaving for the field site.

5.5 Calibration

Calibrated field instruments are required to produce reliable specific conductance, pH, dissolved oxygen, oxidation-reduction potential, and temperature measurements. A field instrument(s) must be calibrated:

- daily, before first use on the day the measurements will be collected
- on some projects, at additional intervals specified in a project-specific Sampling and Analysis Plan or project work plan

At the end of each day’s sampling, a post-calibration check should be performed using calibration standards to determine if the probe(s) drifted out of calibration.

The MBMG owns several brands and models of field instruments and probes. Refer to the user manual supplied with the instrument for specific calibration instructions. General instructions are presented below.

Record each instance of instrument calibration in field notebooks. Include in this calibration record:

- the date, time, and location of the calibration
- ambient temperature
- name of field personnel
- calibration standards used
- result of calibration

5.5.1 Specific Conductance

The ability of a solution to conduct an electrical current is a function of the concentration and the charge of the ions in solution. Conductivity is the measure of an aqueous solution's ability to conduct an electrical current; specific conductance is the conductivity value at 25°C. Modern specific conductance meters used at the MBMG have built-in temperature compensation and automatically report conductivity at 25°C. Older meters, including some YSI models, have one mode for conductance and one mode for specific conductance. Specific conductance mode must be selected to apply the automatic temperature correction. The units of specific conductance are microsiemens per centimeter (µS/cm), which is the equivalent of micro-mhos per centimeter (µmhos/cm). Most values reported prior to 1971 were in units of micro-mhos per centimeter.

Most SC meters can only be calibrated against a single standard. Typical standard solutions include 500, 1,413, and 12,900 µS/cm. The recommended calibration procedure uses a calibration standard at a conductivity near the anticipated value of the samples. The standard can be either above or below the anticipated specific conductance of the sample. Personnel can check the accuracy of the single-point calibration by measuring at least one additional standard that will bracket the expected specific conductance of the sample.

Calibration:

1. Allow the calibration standards to equilibrate to ambient temperature.
2. Rinse the calibration container and probe twice with DI water and a third time with the standard. Fill the calibration container with enough standard to cover the conductivity and temperature probes.
3. Allow the temperature to stabilize.
4. Select specific conductance calibration mode and enter the specific conductance standard value. Make sure that the measurement units and standard units are the same.
5. Select measurement mode, and the readings should remain within the manufacturer's error specifications. If readings are not within the manufacturer's error specifications, recalibrate the instrument. If readings continue outside the manufacturer's specifications, try a new calibration standard or consult manufacturer.
6. Discard calibration solution. Conduct a calibration accuracy check by rinsing the calibration container and probe twice with DI water and a third time with the second standard. The second standard should bracket the expected specific conductance of the sample(s). Fill the calibration container with enough standard to cover the conductivity and temperature probe.
7. Measure the specific conductance of the second standard and compare to its known specific conductance. Specific conductance of check standards should be within ±5 µS/cm for measurements ≤100 µS/cm or ± 3% for measurements >100 µS/cm, or the two values should agree within the specification of the instrument. If they do not agree, recalibrate; if the readings still do not agree, the second standard may be outside the linear range of the instrument. Use a standard that is closer to the first standard and repeat steps 6 and 7. If the values still do not compare, try cleaning the probe or consult the manufacturer.
8. Record the calibration information in the field notebook.

5.5.2 pH

Choose the pH standards that will bracket the expected sample values. If sample pH is unknown, calibrate with the three pH standard solutions (4, 7, and 10), which should bracket most natural waters. The instrument will have to be recalibrated if the water sample's pH is outside the initial calibration range described by the three standards.

Calibration:

1. Rinse the pH probe and calibration-solution container with DI water twice. Rinse a third time with the starting pH calibration buffer solution. The rinse solution and calibration buffer in this and subsequent steps should be disposed of by diluting with water and pouring into a sanitary sewer.
2. Turn on the meter and immerse the pH probe in a pH 7 buffer solution. After allowing the meter and probe to stabilize, calibrate to pH 7.

Some meters allow the opportunity to adjust the initially displayed pH value to a corrected pH value for that buffer solution. If the adjustment is equal to or less than 0.05 pH units, proceed with the adjustment, noting this in the calibration log book. If the adjustment would exceed 0.05 pH units, the pH electrode is not functioning properly; recondition the electrode or use another electrode.

3. Rinse the probe and calibration-solution container following step 1.
4. Immerse the pH probe in pH 4 buffer solution. After allowing the meter and probe to stabilize, calibrate to pH 4.
5. Rinse the probe and calibration-solution container following step 1. Record the calibration in the field logbook or continue to step 6 for a three-point calibration.
6. Immerse the probe in a pH 10 buffer solution. After allowing the meter and probe to stabilize, calibrate to pH 10.
7. Note that manufacturer instructions for some instruments call for calibration to pH 4 followed by calibration to pH 7 and then pH 10. Consult manual if in doubt.
8. Record the calibration in the field logbook.

5.5.3 Dissolved Oxygen

There are several brands and models of dissolved oxygen field-measurement meters. Most meters have automatic barometric pressure and salinity content compensation. Manufacturer's user manuals for each meter should be referenced for calibration and measurement instructions. In general, a one-point calibration procedure that creates a 100% saturated oxygen environment is sufficient when the sample water is saturated with oxygen such as in pristine streams. When sampling water that is less than saturated, a zero DO performance check can be used to assess the linearity in the instrument reading between zero and saturation.

Dissolved oxygen is generally measured using a membrane-based electrode, but the modern fluorescence quenching electrode or optical sensor is fast replacing the membrane-based electrode. Compared to a membrane-based sensor, an optical sensor holds calibration longer, drifts less, and requires less maintenance. If using a membrane-based electrode, the probe membrane and electrolyte solution should be replaced prior to initial calibration for the field season or if the probe has not been used for several weeks or months. Consult the manufacturer's manual on frequency of membrane replacement. Inspect the membrane for air bubbles and defects prior to calibration.

1. Turn the meter on and, if needed, place the meter in the DO calibration mode. Calibrate instrument as described in the meter-specific operating manual. Calibration should be conducted in the % saturation mode.
2. An air calibration is performed in water-saturated air using the calibration/storage sleeve. Moisten the sponge in the calibration sleeve with distilled water, if needed. Saturate the sponge and then allow any excess water to drain out of the chamber. The wet sponge creates a 100% water-saturated air environment for the probe. This environment is ideal for DO calibration and for storage of the probe during transport and periods of non-use of up to 30 days.
3. Allow the probe and calibration standard (in this case, water-saturated air) to reach equilibrium.
4. Calibration of some meters may require knowing the current local ambient barometric pressure. Determine ambient barometric pressure with a barometer. Local weather stations often report relative barometric pressure, and if relative barometric pressure is used in the calibration, the calibration will be incorrect.
5. For a zero mg/L DO calibration, place the probe into a 0.0 mg/L calibration solution and allow the temperature and DO readings to stabilize. The DO should read less than 0.5 mg/L. If readings are greater than 0.5 mg/L or negative, change the membrane and electrolyte solution; if this doesn't work, try a new 0.0 mg/L calibration solution. If the instrument continues to measure greater than 0.5 mg/L, contact the manufacturer.
6. A zero-calibration check can also be performed using the probe and flow-through cell. An inert gas purge, such as nitrogen, is used to displace any oxygen in the flow-through cell to create an atmosphere void of oxygen. This type of

calibration check is probably best performed in the lab where the nitrogen bottle can be properly and safely stored.

7. Record the calibration in the field logbook.

5.5.4 Oxidation-Reduction Potential

ORP is measured using an electrochemical sensor called an ORP or REDOX sensor. The most common type of ORP sensor is a combination sensor that includes a measuring electrode and a reference electrode. The measuring cell, typically a noble metal like platinum or gold, detects changes in REDOX potential, while the reference provides a stable comparison signal. Field ORP readings are converted to the potential (in millivolts) relative to the standard hydrogen electrode, by correcting for the electrode potential of the reference electrode:

$$Eh = Em + Eref,$$

where Eh is potential relative to the standard hydrogen electrode; Em is measured potential at the sample temperature; and $Eref$ is reference electrode potential of ZoBell's solution corrected for the sample temperature.

For example, assume a field measurement ORP of 200 mV at 10°C using a silver:silver-chloride (Ag:AgCl) saturated KCl electrode. The *Eref* for Ag/AgCl reference electrode and saturated KCl reference solution is 214 mV at 10°C (Nordstrom and Wilde, 2005).

$$Eh = 200\text{ mV} + 214\text{ mV} = 414\text{ mV}$$

Refer to the manufacturer's probe specifications and reference-solution concentration for specific *Eh* conversion procedures.

Calibration or verification procedure:

1. Allow the ZoBell's solution to equilibrate to ambient temperature.
2. Rinse the probe and calibration-solution container with DI water twice. Rinse a third time with the ZoBell's solution.
3. Allow the probe temperature to stabilize, and read the temperature.
4. If the instrument is to be calibrated, complete steps 5 and 6. If the instrument calibration is to be verified, go to step 7.
5. Find the temperature-corrected value (in mV) for the ZoBell's solution, typically provided on a temperature correction table located on the ZoBell's solution bottle or an instruction sheet provided with the ZoBell's solution. Select the instrument's ORP calibration mode and enter the temperature-corrected ORP value into the instrument.
6. Select measurement mode, and the ORP reading should remain unchanged within manufacturer's specifications. If the measurement changes, recalibrate. If the measurement continues to change after recalibration, try new ZoBell's solution or consult manufacturer. Go to step 8.
7. If the instrument's instruction manual specifies that the instrument is factory calibrated, verify the calibration against ZoBell's solution. If they do not agree within the specifications of the instrument, try new ZoBell's solution. If they still do not agree, the instrument will need to be recalibrated by the manufacturer.
8. After the calibration process, rinse the probe with deionized water and store the probe according to the manufacturer instructions. Although ZoBell's solution contains cyanide and should be handled with care, it is not a listed hazardous waste. Proper disposal of the rinse solution includes flushing down a sanitary sewer with clean water; you may also return used ZoBell's solution to the MBMG laboratory for disposal.
9. Record the calibration in a field notebook.

5.5.5 Temperature

Most instrument manuals state that a temperature sensor cannot be calibrated, but the temperature sensor should be checked to determine or verify its accuracy. Perform an accuracy check at least once per year, or anytime there is concern that the temperature measurements are not accurate. The accuracy-check documentation should be kept with the instrument; if the documentation is not included with the instrument, or if the prior check was more than a year previous, determine the temperature-sensor accuracy at the beginning of the sampling event.

Verification:

1. Fill a container with water and adjust the temperature to about 4°C with ice.
2. Place a thermometer traceable to National Institute of Standards and Technology and the instrument's temperature sensor into the water. Wait for both temperatures to stabilize.
3. Compare the two measurements. The instrument's temperature sensor must agree with the reference thermometer measurement within the accuracy of the temperature sensor (e.g., ±0.2°C). If the measurements do not agree, the instrument may not be working properly, and the manufacturer needs to be consulted.
4. Adjust the water temperature to about 25°C and place the thermometer traceable to National Institute of Standards and Technology and the instrument's temperature sensor into the water. Wait for both temperatures to stabilize.
5. Compare the two measurements. The instrument's temperature sensor must agree with the reference thermometer measurement within the accuracy of the temperature sensor (e.g., ±0.2°C). If the measurements do not agree, the instrument may not be working properly, and the manufacturer needs to be consulted.
6. Record the verification in a field notebook.

5.6 Measurement

There are numerous brands and models of field-measurement meters and probes. Some meters and probes measure a specific parameter and temperature (e.g., pH and temperature, SC and temperature, etc.). A more convenient configuration is a multi-probe meter or "sonde"—a meter connected to a cluster of probes through a common cable. The benefit of a multi-probe meter is that it can measure several field parameters simultaneously. Refer to user's manuals for each meter and probe for measuring instructions and considerations.

Where possible, physical parameters should be measured *in situ*. For lakes and gently flowing streams, lower the probes to the desired depth, allow the measurements to stabilize according to manufacturer specifications, and record the measurements in a field book or field sheet. At faster flowing streams, it may not be possible to measure parameters *in situ*; field parameters are measured in a container of sample water following section 5.6.1.

Under typical circumstances, a representative sample of groundwater cannot be measured *in situ*. Water is usually pumped or bailed from a well to obtain a representative sample of groundwater. In most cases, a diverter can be attached to a pump discharge line to direct a small portion of flow through a flow-through chamber that contains the probes. Field parameters are then measured according to section 5.6.2. In some situations, such as a bailed well or a discharge line that cannot be fitted with a diverter, a large container or bucket is filled with sample, and parameters are measured according to section 5.6.1. Note that in these cases, it may not be possible to collect a non-aerated groundwater sample, and DO measurements in particular are unlikely to reflect *in situ* conditions. Such conditions and observations should be noted in a field book, particularly if field personnel observe that measurements are likely affected by sampling artifacts, such as exposure of sample to air.

5.6.1 Measurement without Flow-Through Chamber

Measurement:

1. Rinse the probes and sample container with DI water twice. Rinse a third time with the sample water. Properly dispose of the rinse solution after each rinse.
2. Fill the sample container with enough sample to cover all of the probes
3. Gently stir the sample with the probe for thorough mixing until measurements stabilize according to manufacturer specifications.
4. For groundwater samples, repeat steps one through three at a frequency specified in chapter 6.
5. Record the measurements in a field book and/or Site Inventory/Field Visit Sheet (appendix 2.22.1).
6. Rinse the probes and sample container with DI water, and store the probes according to manufacturer specifications.

5.6.2 Measurements in a Flow-Through Chamber

Measurement:

1. Connect the probes to the flow-through

chamber. Connect the inlet (at the bottom of the chamber) and outlet (at the top of the chamber) discharge lines to the flow-through chamber.

2. Divert water into the flow-through chamber. About 1 to 2 L per minute is adequate. Avoid subjecting the flow-through cell to direct sunlight because this may affect the sample temperature.
3. Record measurements at a frequency specified in chapter 6.
4. Record the measurements in a field book and/or Site Inventory/Field Visit Sheet (appendix 2.22.1).
5. Rinse the probes and flow-through chamber with DI water, and store the probes according to manufacturer specifications.

5.7 Quality Control

Ensure the quality of field measurements by calibrating and maintaining the instrument according to the manufacturer specifications and the steps outlined in section 5.5.

5.8 Documentation

Record field measurements in a field notebook and/or Site Inventory/Field Visit Sheet (appendix 2.22.1). Enter measurements into the GWIC database. Note important details that may have affected the calibration and measurement in the “Remarks” column. In addition to data entry, scan and attach field notes and records to the corresponding well record in GWIC.

5.9 References and Additional Information

Nordstrom, D.K., and Wilde, F.D., 2005, Reduction-oxidation potential (electrode method) (ver. 1.2, September 2005): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9; chap. 6.5, doi: https://doi.org/10.3133/twri09A6.5.

Ritz, G.F., and Collins, J.A., 2008, pH 6.4 (ver. 2.0, October 2008), U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.4, doi: https://doi.org/10.3133/twri09A6.4.

Rounds, S.A., Wilde, F.D., and Ritz, G.F., 2013, Dissolved oxygen (ver. 3.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.2, doi: https://doi.org/10.3133/twri09A6.2.

U.S. Geological Survey, 2019, Specific conductance: U.S. Geological Survey Techniques and Methods, book 9, chap. A6.3, 15 p., doi: https://doi.org/10.3133/tm9A6.3 [Supersedes USGS Techniques of Water-Resources Investigations, book 9, chap. A6.3, version 1.2].

Wilde, F.D., Temperature, 2006: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. 6.1, doi: https://doi.org/10.3133/twri09A6.1.

6.0 GROUNDWATER SAMPLING

6.1 Purpose

This document provides standard procedures for the collection of groundwater samples from domestic and monitoring wells in a manner that ensures the water is representative of the particular zone or aquifer being sampled. Standing water in a well is generally not representative of water from the aquifer. Purging a sufficient volume of water from the well prior to sampling safeguards against collecting a non-representative sample. Wells are purged until at least one well volume has been removed and water-quality parameters (pH, temperature, and specific conductivity) have stabilized. Wherever possible, the minimum volume purged should be at least three well volumes.

Note that detailed procedures for conducting site visits, measuring water levels in wells, and using field instruments to measure specific conductance, pH, and other water-quality parameters are provided in sections 2, 3, and 5 of this report.

6.2 Equipment and Supplies

Specific equipment and supplies will be project-dependent; the following list contains the minimum equipment and supplies needed to sample wells.

1. Field GPS unit
2. Site Inventory/Field Visit Sheets (appendix 2.22.1) or field book for wells to be sampled
3. Submersible pump and generator or battery, or bailer (if the well does not have a dedicated pump); clamps or clips to secure pump cable if necessary
4. Water-level indicator (also referred to as “e-tape” or “sounder”)
5. Toolbox
6. Kimwipes or paper towels
7. 1-gal Ziploc bags
8. Waterproof pens (Sharpies)
9. Ice chests and ice if analyte preservation includes cooling (e.g., anions, volatile organic compounds)
10. Appropriate keys (for locked wells)
11. Plastic buckets, time piece to measure flow rates, and a calculator
12. Garden hose and hose splitters with extra washers
13. Spray bottles and carboy of deionized (DI) water
14. Decontamination solutions (e.g., dilute bleach solution, DI water, 1% nitric acid, or Alconox)
15. Electrodes and meters for measuring water-quality parameters, including: conductivity, temperature, pH, specific conductivity, redox potential, and dissolved oxygen
16. Flow-through chamber
17. Teflon tape
18. Equipment to filter water (typically a 0.45-mm filter), either single-use disposable unit or reusable filter holder with disposable filter membrane
19. Sample bottles and preservatives (see Timmer, 2020, table 6.1)

Note: Before leaving for the field, contact the MBMG Analytical Laboratory or other appropriate laboratory to obtain the necessary number and type of sample bottles and appropriate preservative(s). Table 6.1 provides sample containers, preservation, and hold times for common analytes.

6.3 Calculation of Well Volume

To calculate the well volume:

- Measure the depth to the static water level in the well in feet (note if non-static).
- Determine the total well depth from the owner, well listing, well log, or by sounding the well. Note: exercise caution when sounding a well with a water-level indicator to avoid damaging it.
- Determine the radius (r) of the well in feet.
- Calculate the water column height (h) in the well (total depth minus the static water level).
- Calculate the volume (V) of water in the well casing, in gallons:

$$V = \pi r^2 h 7.48,$$

where $\pi = 3.14$; r^2 is radius of the well in feet, squared; h is height in feet of standing water column in the well; and 7.48 is the conversion factor from ft^3 to gallons.

Table 6.1. Sample container, preservation, and hold time.

Parameter	Method	Volume (mL)	Container	Preservation	Filter		Holding Time (Days)
GENERAL CHEMISTRY							
Acidity	EPA 305.1	500	HDPE	Cool, 4°C	N	RU	14
Alkalinity	EPA 310.1	500	HDPE	Cool, 4°C	N	RU	14
Chloride	EPA 300	250	HDPE	Cool, 4°C	Y	FU	28
Conductivity	EPA 120.1	500	HDPE	Cool, 4°C	N	RU	28
Fluoride	EPA 300	250	HDPE	Cool, 4°C	Y	FU	28
Nitrate-N (IC)	EPA 300	250	HDPE	Cool, 4°C	Y	FU	28
Nitrite-N (IC)	EPA 300	250	HDPE	Cool, 4°C	Y	FU	48 hours
Nitrate/Nitrite-N (nutrient)	HACH	250	HDPE	H_2SO_4,Cool, 4°C	Y	FU	28
pH	EPA 150.1	500	HDPE	Cool, 4°C	N	RU	ASAP
Ortho-Phosphate-P	EPA 300	250	HDPE	Cool, 4°C	Y	FU	28
Radon	EPA 913.0 Mod	125	Glass	Cool, 4°C	N	RU	ASAP
Sulfate	EPA 300	250	HDPE	Cool, 4°C	Y	FU	28
Water Isotopes	Picarro	25	HDPE		Y	FU	NONE
METALS/TRACE METALS							
ICP-OES/ICP-MS-Dissolved	EPA 200.7/ 200.8	500	HDPE	HNO_3	Y	FA	180
ICP-OES/ICP-MS-Total Recoverable	EPA 200.7/ 200.8	500	HDPE	HNO_3	N	RA	180
ORGANICS							
Pentachlorophenol	EPA 528.0 Mod	1000	Glass	HCl, 4°C	N	RA	14 to extract 14 to analysis
Organic Carbon Dissolved / Total	EPA 415.3	40	Glass	H_2SO_4, 4°C	Y/N	FA/ FU	28

Note. Reprinted from Timmer, 2020. RU, raw, unpreserved; RA, raw, acidified; FU, filtered, unpreserved; FA, filtered, acidified.

Alternatively, use values in table 6.2 for the volume of water in a well, per linear feet, to calculate the well volume. A rule of thumb for 2-in-diameter wells is to multiply the column of water (“*h*”; in ft) by ½ to estimate the gallons of water in three casing volumes (0.16 x 3 = 0.48). Similarly, for 4-in wells, multiply the column of water (in ft) by 2 (0.65 x 3 = 1.95).

Record the well-volume calculation or the value used from table 6.2. To calculate purge time, divide the total number of gallons to be purged by the flow rate (gpm).

6.4 General Procedure for Domestic Well Sampling

Conduct the following activities at each well site:

1. Confirm landowner permission to sample the well.
2. Collect GPS coordinates of well location (if not already in GWIC or not correct in GWIC).
3. Identify sample collection location at, or as close as possible to, the well head.
4. Measure static water level in well with a decontaminated probe and calculate the volume of water in the well (well volume) as described above.
5. Set up flow-through chamber and field meter.
6. Purge the well until at least one well volume (if the well is regularly used) has been evacuated and purging parameters stabilize. Purge at least

Table 6.2. Linear volumes for common well diameters.

Well Diameter (inch)	Volume (gal./linear ft.)	Volume (liter/linear ft.)
2	0.16	0.61
4	0.65	2.5
6	1.5	5.7
8	2.6	9.8
12	5.9	22

three well volumes when sampling wells that are not regularly used. Record the well use (e.g., domestic, stock, monitoring) and well volumes evacuated.

7. Collect groundwater samples and bottle and preserve as appropriate (table 6.1).
8. Collect quality assurance and quality control (QA/QC) samples as necessary (e.g., blanks and replicates).
9. Confirm that all bottles are properly labeled and that the field logbook or field data sheet is completely and accurately filled out. Be sure to record the complete mailing address of the well owner for sending the results of the water-quality analyses.

6.4.1 Location and Equipment Setup

Collect groundwater samples at, or as close as possible to, the well head. Preference should be given to sampling locations where the sample can be collected before the water enters a pressure tank or water-treatment system. In some research studies, groundwater samples collected following treatment may not be useful. However, some projects conducted by the MBMG require evaluation of drinking water quality, and post-treatment water samples may be required. If project-specific circumstances allow for collection of treated groundwater, document the location and type (e.g., water softener or filter) of the treatment system relative to point of sample collection. Record this information in the “Field Remarks” section of the GWIC data entry to document as a post-treatment sample.

The following are general steps for equipment setup:

1. Rinse the faucet threads and garden hose splitter with well water, if not clean.
2. If possible, attach the Y-adapter to the sampling faucet. If connection is leaking excessively, wrap the faucet threads with Teflon tape or replace washer.
3. Attach the garden hose to one end of the Y-adapter and place the other end of the garden hose at an appropriate drainage area.
4. Attach a threaded coupling or barbed hose adaptor to the faucet Y-adapter. Then connect the flow-through cell to the coupling or hose adaptor with tubing.
5. Route the discharge water from the flow-through cell to an appropriate drainage area.

6.4.2 Stabilization of Purging Parameters

The sample may be collected after the minimum of one or three well volumes, depending on well usage, have been pumped from the well and the purging parameters (temperature, pH, and specific conductance) are stable. To document stable parameters, record the purging parameters at regular intervals (e.g., every 5 min) in the field logbook and/or Site Inventory Sheet. Collect samples after the field measurements stabilize about the mean of three consecutive readings recorded over a period of at least 10 min:

- temperature ≤±2°C
- pH ≤±0.1
- Eh ≤±20 mV
- specific conductance ≤ ±5%

Record field measurements in the field logbook and/or Site Inventory/Field Visit Sheet. Record the number of well volumes pumped from the well.

The degree of well use is subjective; the well use and well volumes evacuated need to be documented. Some wells may not reach stable parameters even after purging many well volumes (>6 to 10 well volumes, depending on the well). In these cases, field personnel should use their judgment as to when to sample or continue purging. The quality of well completion can differ greatly between domestic wells, and over-purging can result in excessive sediment entering some wells; for this reason, take care not to drop the water level near the bottom of the well. If a sample is collected without reaching stable parameters, document the non-stable conditions in field notes and in a “Field Remarks” entry for MBMG Laboratory samples.

1. Completely open the diverter on the Y-adapter that controls flow to the garden hose. Turn on the faucet (pump). Record the time that pumping was initiated.
2. Measure the flow rate through the garden hose. Time how long it takes (in seconds) to fill a bucket to a known volume. The flow rate should be checked at least three times during the well purging procedure.
3. Carefully open the diverter on the Y-adapter that controls flow through the tubing to the flow-

through cell. Only a gentle flow is needed to keep water circulating through the flow cell. Do not over-pressurize the flow-through cell because damage to the cell or probes could result.

4. Monitor physical parameters until they have stabilized and the required well volume(s) has been purged. Record the readings to document stabilization.

Operation and maintenance of the meters and probes used for field measurements should follow procedures identified in chapter 5 and as outlined by the manufacturer.

For wells that are flowing under artesian pressure when you arrive at the site, "purging" the well is not necessary, but measure and record the water-quality parameters.

6.5 General Procedure for Monitoring Well Sampling

At each well site, conduct the following activities:

1. Confirm permission to access and sample the well.
2. Obtain keys or codes necessary to access the well.
3. If sampling multiple wells, sample them in order from the least contaminated well to the most contaminated well to mitigate potential cross-contamination between wells.
4. Collect GPS coordinates of well location (if not already in GWIC or not correct in GWIC).
5. Measure static water level in well with a decontaminated probe and calculate the volume of water in well.
6. Set up flow-through chamber and field meter(s).
7. Purge at least three well volumes until field parameters stabilize. Record the number of well volumes purged.
8. Collect groundwater samples.
9. Collect quality assurance and quality control (QA/QC) samples as necessary (e.g., blanks and replicates).
10. Confirm that all bottles are properly labeled and that the field logbook is completely and accurately filled out.

6.5.1 Equipment Setup

The following are general steps for equipment setup when pumping a well:

1. Remove all transducers or other equipment from the well.
2. Lower the pump, tubing (if purging with a peristaltic pump), or bailer slowly into the well.
3. When purging with a centrifugal pump, the end of the discharge tube should have a splitter to allow two discharge streams.
4. Connect the flow-through cell to one of the discharge streams or the discharge tube, if using a peristaltic pump. Direct the other discharge line to an appropriate drainage area away from the well and working area. Collect purge water from a bailer in a bucket and collect water-quality parameters in the instrument storage cup to reduce atmospheric interactions, if possible.

6.5.2 Stabilization of Purging Parameters

Wells must be purged to obtain a sample that is representative of the aquifer. Purging procedures include pumping or bailing standing stagnant water from the well prior to sampling. Typically, monitoring wells are purged using a stainless steel or PVC submersible pump or a PVC, stainless steel, or Teflon bailer. Occasionally, the well volume may be small enough, and the depth to water sufficiently shallow, to purge the well with a peristaltic pump. Record purging parameters at regular intervals (e.g., every 5 min) in the field logbook and/or Site Inventory Sheet. Collect samples after field measurements have stabilized about the mean of three consecutive readings recorded over a period of at least 10 min:

- temperature ≤±2°C
- pH ≤±0.1
- Eh ≤±20 mV
- specific conductance ≤±5%

Record field measurements in the field logbook and/or Site Inventory Sheet. Record the number of well volumes pumped from the well. A minimum of three well volumes should be purged prior to sampling. It's possible that purging may exceed many well volumes (>6 to 10 well volumes, depending on the well) without reaching stable parameters. When this happens, field personnel should use their judgment as to when to sample or continue purging. If a sample is collected without reaching stable parameters, document the non-stable conditions in field notes and in a “Field Remarks” entry for MBMG Laboratory samples.

1. Completely open the diverter on the splitter that controls flow. Record the time that pumping was initiated.
2. Measure the flow rate by timing how long it takes (in seconds) to fill a bucket to a known volume. Check the flow rate at least three times during the well purging procedure.
3. Carefully open the splitter that controls flow through the tubing to the flow-through cell. Only a gentle flow is needed to keep water circulating through the flow-through cell. Over-pressurizing the flow-through cell can damage the cell or probes.
4. Monitor physical parameters until they have stabilized and the required well volumes have been purged. Record the readings to document stabilization.

Note: Operation and maintenance of the pH and specific conductance meters should follow procedures outlined by the manufacturer.

Note: For wells that are flowing under artesian pressure when you arrive at the site, “purging” the well is not necessary; in this case, measure and record the water-quality parameters.

6.6 Sample Collection

After well purging is completed, collect water samples directly from the discharge hose. A PVC valve and polyethylene tubing may be used to split the flow discharging from the pump to allow a flow rate that minimizes turbulence and splashing in sample containers. Recommended practice to prevent contamination from a garden or other hose is to collect samples from water passing through clean, decontaminated tubing. For samples collected from a bailer, transfer the water to a clean bucket and filter with a peristaltic pump and clean tubing.

Using a waterproof pen, record on the sample bottle label the GWIC identification number for the site or well (or designation detailed in the project-specific Sampling and Analysis Procedures), the sample date, the preservative, and the filtration status (i.e., filtered or unfiltered). Also record on this label the project ID (e.g., ARWWS), number of the bottle (e.g., 1 of 4, 2 of 4, etc.), and sampler’s initials. Filtration and preservation status are noted as follows:

- RU—raw, unpreserved
- RA—raw, acidified
- FU—filtered unpreserved
- FA—filtered, acidified

Care should be taken to ensure labels remain legible and affixed to bottles following sample collection. Labels can become detached, especially when the labels are wet. One way to avoid this problem is to place all samples from a well into a single Ziploc-type bag. Another approach is to write the GWIC identification number and the filtration and preservation status on the sample bottle as well as the label.

High-density polyethylene or glass sample bottles with screw-on caps should be used. While collecting samples, hold the cap in a gloved hand or place upside down on a clean surface to avoid contact with dust. Rinse cap with sample water before capping. Avoid sample collection from a garden hose or any other hose that has not been decontaminated.

To collect samples:

1. Turn off flow to the flow-through cell and remove this discharge line from the splitter. The apparatus may change depending upon specific site requirements. If using other apparatus or set up, note the details in the field logbook.
2. Collect the unfiltered samples after rinsing the RU and/or RA sample bottle(s) and cap(s) three times with unfiltered water.
3. Collect the filtered samples. Place a new filter cartridge on the sample line (typically 0.45-µm filter, but filter selection should be based on the water quality and the intended analytes). Flush the filter by allowing the water to run through the filter for 3 to 5 min. Prior to sample collection, rinse the FU and FA sample bottles and caps three times with filtered sample water by filling the bottle approximately one-third full and shaking vigorously.

Note: For samples that require preservative (metals, trace metals, nitrate–nitrite), do not completely fill the sample bottle; leave a small amount of head space to accommodate the acid preservative. For samples that do not require preservative (fluoride, inorganic ions, lab alkalinity, and specific conductance), completely fill the bottle to prevent the loss of carbon dioxide and other dissolved gases.

4. Add preservative if required, tightly replace the cap, and gently invert the bottle to disperse the preservative. Unless instructed by lab, do not add acid prior to sample collection. Typically, the laboratory will provide premeasured ampules of acid (nitric acid preservative for metals analysis, metals and sulfuric acid preservative for nitrate–nitrite analysis). These acid preservatives lower the pH of the sample to less than 2, in order to prevent biological and chemical reactions.

5. After filling the required number of sample bottles and completing the labels, place all the bottles in a Ziploc-type bag. Store samples according to the preservation requirements for the appropriate analytes (table 6.1); note that many samples should be stored in a cooler on ice until delivered to the laboratory.

6.7 Sample Handling and Preservation

Following sample collection, take necessary precautions to ensure that the chemistry of the sample is not altered between the time of sampling and analysis. As outlined in the procedures above, samples are filtered to remove any particulate or colloidal material that could adsorb metals in solution. Some samples are preserved with acid (nitric and sulfuric) to keep metals in solution and prevent precipitation. To inhibit bacterial growth, transfer un-acidified samples to coolers packed with ice immediately after sampling to keep the sample temperature as close to 4°C as possible and to keep the sample out of the sunlight. Storing the samples in a cooler also helps protect the sample bottles from damage during transport. Check coolers frequently and re-stock with ice as needed to maintain appropriate temperatures throughout extended sampling trips, especially during warm months.

6.8 Equipment Decontamination

Equipment that comes in contact with the aqueous sample should be decontaminated in order to avoid cross-contamination and preserve sample integrity. Circumstances unique to each project may be addressed through a project work plan or a quality assurance plan. For example, local groundwater contaminants or regulatory requirements may dictate specific procedures. Sampling protocols and decontamination procedures may require adjustment for specific analytes, such as volatile organic compounds, personal care products, or pharmaceuticals. In general, decontamination procedures between sampling events typically consist of these steps:

1. Wash equipment with non-phosphate soap
2. Rinse with tap water
3. Rinse with deionized water as a final step

Additionally, bacteria can be transferred from one well to another on the water-level indicator. Decontaminate the water-level indicator with a dilute (1:10 by volume) bleach solution between sampling events.

6.9 Quality Control

Quality control should be maintained by thoroughly documenting the sampling effort and routinely analyzing duplicate samples and, if the sampling plan warrants, equipment and field blanks.

Thorough documentation provides a means of accountability to ensure that the sampling effort meets the program design.

Duplicate samples are used to assess the reproducibility of analytical results. At a minimum, one duplicate sample should be collected for every 20 samples (5%). For projects that collect less than 20 samples, collecting a duplicate sample every sampling trip may be required, depending on project objectives.

Equipment and field blanks are used to determine whether sample bottles, handling procedures, or site conditions have had an effect on the sample chemistry. One equipment or field blank should be collected for every 20 well-water samples (5%). For projects that collect less than 20 samples, collecting an equipment or field blank every sampling trip may be required, depending on project objectives.

6.10 Collection of Quality Assurance/Quality Control Samples

Collect a complete set of sample bottles for each type of quality assurance/quality control sample: duplicates, equipment blanks, and field blanks.

6.10.1 Collection of Duplicate Samples

Duplicate samples should be collected simultaneously with well-water samples. One set of sample bottles should be labeled "duplicate" with the sample/well number. If "blind" duplicates are required, appropriate labeling and sample tracking procedures should be developed in a project-specific sampling plan.

6.10.2 Collection of Equipment Blanks

Bottles used for equipment blanks will be labeled as "Equipment Blank" and assigned to a project-specific GWIC identifier (contact the GWIC administrator for project identifier assignments). Fill bottles designated as equipment blanks by passing deionized water supplied by the MBMG lab through the decontaminated equipment in the same way as sample is collected. Note that project-specific analyte lists may require other types of "blank" water, such as ultrapure water available from scientific supply companies. Collect equipment blanks at the same field location where well-water samples are collected, immediately after decontamination of the equipment.

6.10.3 Collection of Field Blanks

Bottles used for field blanks will be labeled as "Field Blank" and assigned to a project-specific GWIC identifier (contact the GWIC administrator for project identifier assignments). Fill bottles designated as field blanks in the field by pouring directly from a bottle of deionized water supplied by the MBMG lab or appropriate type of ultrapure water for a specific analyte list. Collect field blanks at the location where the well-water samples are collected and at the same time as the well-water samples.

6.11 Data Analysis

The results of the equipment blanks, field blanks, and duplicates should be reviewed by the program manager. Any detections or discrepancies should be brought to the attention of the Program QA Officer and steps taken to identify and rectify the problem.

The analytical results from the samples should be checked using methods such as:

- Comparing the relative percent difference between duplicate samples,
- Comparing the sum of cations with the sum of anions (relative percent difference);
- Comparing determined and calculated values for dissolved solids;
- Comparing specific conductance with the sum of cations or anions;
- Comparing specific conductance with determined and calculated values for dissolved solids; and
- Comparing specific conductance and values for selected major constituents with expected results from regression curves.

Data from samples that exceed the established acceptance criteria should be flagged and/or the sample reanalyzed.

6.12 Documentation

In general, the information documented in the field logbook and/or the Water-Quality Data Sheet should include the sampler(s), date and time of sample collection, the location of the sampling site, the sampling project, condition of the sample (e.g., turbid or clear), stabilization criteria, and the purging method. In addition, document the total number of bottles, the filter and preservation status, and the desired analyses. It is impossible to over-document your work; if you are not sure if a bit of information is necessary, record it. A summary of the minimum data to record is listed in table 6.3 (next page).

6.13 References

Timmer, Jacqueline, 2020, MBMG Analytical Laboratory: Quality assurance manual: Montana Bureau of Mines and Geology Open-File Report 729, 8 p.

Table 6.3. Minimum field information collected during well sampling.

Start on a new field book page or a new Site Inventory/ Field Visit Sheet

Date
Site ID
GPS location as necessary
SWL (record time), TD, diameter, and stick up
Casing volume calculation (one and three)
Discharge rate (record time) and estimated purge time
Field Parameters (stable for 3 readings over 10 min)
Temperature ≤±2°C; pH ≤±0.1; Eh ≤±20 mV; SC ≤±5%
Sample condition (i.e., clear, turbid, discolored, or noticeable odor)
Sample time
Type of sample (dissolved/total recoverable)
Note type of decon and what pieces of equipment
    (i.e., 2-in pump, peristaltic pump, sample splitter)
If QA/QC samples are collected, note type and time
    [i.e., site duplicate, equip blank, field (DI) blank]
Document why missing data could not be collected
Sampler's initials at bottom of page

7.0 WATER-QUALITY SAMPLING FROM A LAKE OR STREAM

7.1 Purpose

This document provides recommended methods for collecting water samples for laboratory analysis from lakes and streams. Although standardizing sampling methods supports collection of consistent and comparable data, field personnel should coordinate with the project supervisor to ensure that the selected surface-water sampling methods are appropriate for the scientific goals of the project.

7.2 Scope

These recommended methods are selected from a broad array of techniques developed for surface-water investigations; references are provided to support further understanding of issues relevant to specific hydrologic settings. Water chemistry within lakes and streams varies in time (for example, seasonally), and spatially (for example, by depth or by distance from shore). A brief overview of typical spatial and temporal variation is presented as an appendix to this chapter, to support selection of a sampling approach suited to project goals. The USGS (2018c) provides a comprehensive discussion of limnological studies, including a wide spectrum of data types (for example, measuring solar radiation or conducting a macrophyte survey) and various approaches to sample design.

This document presents standard procedures for collecting samples from surface water, but readers are referred to sections 6.6 and 6.7 of chapter 6 for sample handling procedures (for example, filtering or preserving) following collection. In general, surface-water samples are rarely field filtered, although analysis for total or dissolved constituents will be project-specific. Timmer (2020) reports sample containers, preservation, and hold times for common analytes. Stream samples frequently require a contemporaneous streamflow measurement; chapter 9 presents standard procedures for measuring streamflow.

7.3 Health and Safety

Personal and team safety are of paramount importance in all field activities, and safety precautions will be exercised at all times by MBMG staff. Surface-water sampling usually involves wading through streams and rivers or riding in a boat, and safety precautions around water are a priority for staff.

Staff are required to wear personal flotation devices (PFDs, or life jackets) at all times when working in, on, over, or near water. This includes while carrying out activities in, on, over or near a cableway, bridge, water-control structure (a dam), on ice, in a boat, or wading in streams or lakes. Staff are required to wear high-visibility vests in addition to PFDs when working on bridges.

7.4 Background

Streams and lakes can be complex systems in regard to selecting sampling sites and sampling methods (Averett and Schroder, 1994). There is no single quantitative approach for sampling site selection. Sites should be selected in accordance with the scientific approach that will be used for the analysis and interpretation of the data, with consideration of what the data from that location represent (USGS, 2018). The MBMG performs reconnaissance, diagnostic (sometimes referred to as monitoring), and interpretive studies of lakes and streams, as defined by Averett and Schroder (1994) and USGS (2018c). In some instances, there may be little to no existing relevant data or information, and reconnaissance data are needed before focusing on data collection to answer specific questions (USGS, 2018c). Understanding changes in water quality over time may require diagnostic studies. Interpretive studies are designed to answer specific questions about the processes that influence parameters and surface-water quality, such as studies of groundwater/surface-water interaction, irrigation recharge, and point/non-point contaminant source loading.

Water chemistry sampling from a lake or stream requires consideration of variability in the system; such variability may be related to natural or anthropogenic causes. Photosynthesis and respiration can cause large diurnal variations in pH, specific conductance (SC), dissolved oxygen (DO), and heavy metal concentrations (Stumm and Morgan, 1996). Lakes can stratify by temperature (thermocline) and/or by chemistry (chemocline), producing zones that require a discrete sampling approach. The vertical profile of temperature or chemistry in a lake may be seasonally variable due to stratification. An appendix to this document includes examples of natural variation in lakes and rivers in Montana.

Consideration of these temporal and spatial variations is necessary to develop a sampling program that characterizes aspects of the water body of interest to the researcher. Understanding the typical or expected variation in water chemistry supports data collection that addresses the research questions of interest.

7.5 Study Design

7.5.1 Reconnaissance Study

This approach applies when a general characterization of the lake or stream is needed. The site is evaluated using field parameters (pH, SC, temperature, or DO may be included) to determine stratification and spatial variation. If variations are minimal or not apparent in field parameters, the researcher can consider collecting a single sample near the midpoint. The researcher may decide to collect multiple samples in order to document stratification in a lake or change over the area of the body. For stratification, identify the depth of the thermocline and sample above and below it. To sample for spatial variability, consider sampling near both inflow and outflow areas. If investigating a possible point source of influence, sample near the inflow to a lake or upstream in a stream, and near the point-source shore but in the direction of outflow.

Field notes collected during a reconnaissance study should include GPS coordinates at the sample location and a description relative to the stream or lake geography (for example, "mid-channel in the thalweg" or "10 feet off the south shore"), and the weather including air temperature, time of day, and stage. Also record the method of collection (grab sample, depth integrated, width integrated, or flow integrated) and the sample bottles filled, noting any preservation method.

7.5.2 Diagnostic Study

Diagnostic (or monitoring) studies focus on the cause and effect of specific constituents in the lake or stream. Comparison to concentrations in other parts of the hydrologic system (for example, in streams or groundwater that discharge to a lake) and comparison to some target or standard also motivate diagnostic studies. These studies may require estimates of both the concentration and quantity (mass) of constituents over a period of time (for example, tons per year). Following reconnaissance sampling, monitoring samples should be collected using consistent sampling protocols, times of day, and on-site conditions. Examples of on-site conditions that may require rescheduling of sampling for a diagnostic study include a storm that causes unusual sediment loads or turbulence, or a heavy precipitation event that might dilute shallow water along a shoreline. Samples should be collected throughout the year to define seasonal variability, and at a variety of locations and depths to assess spatial variability of the target constituent. Flow must be measured or a rated discharge value must be available for the stream reach or lake at the time of sample collection if concentrations of constituents will be converted to estimates of mass.

7.5.3 Interpretive Study

The purpose of an interpretive study is to understand the abundance of constituents and the processes that influence them. Interpretive studies typically require one or more years of data. Analyses and interpretation may involve modeling trends and forecasting future conditions based on water management scenarios. Sampling programs are designed to define spatial and temporal variations within the hydrologic system and sources of water to the system (such as contributions from tributaries or groundwater discharge).

After completing reconnaissance sampling, a monitoring plan should be designed to meet the needs of the interpretive study. Samples may be collected throughout the year to define seasonal variability, and characterize spatial and vertical variability, as dictated by the study purpose and site-specific hydrologic conditions. In small lakes, a single sample location established near the deepest point may be sufficient to characterize lake water quality. In larger lakes, multiple sample sites (and if stratified, multiple sample depths) may be required. Consistent sampling protocols and timing should be followed. Timing of seasonal sampling can be based on stage conditions, such as rising limb, falling limb, high stage, or low stage, or subdivisions of those conditions, depending on the level of definition needed.

7.6 Methods

7.6.1 Sample Collection from a Stream

The method of collecting water samples from a stream depends on the type of study and the stream conditions. A "good" sampling site conforms to the project goals. Some typical characteristics include:

- A cross-section site with uniform flow that allows adequate mixing
- Away from backflowing eddies
- Far enough downstream of influences such as tributaries to provide adequate mixing
- Upstream of any potential contaminant sources, unless these are investigative targets of the project (examples include deicing chemicals from nearby roads and bridges, effluent from irrigation drain tiles, water treatment plant effluent)
- Accessible at the desired stage conditions for the duration of the study

If sampling immediately downstream of a tributary, make sure that the tributary and main channel waters are well-mixed. An easy way to evaluate this is to measure SC in several locations along a cross-section. Changes in SC along the cross-section indicate incomplete mixing.

Sample types from streams include dip, equal discharge, or equal width (USGS, 2006). Equal discharge and equal width methods involve weighted sampling from stations along a cross-section; these are useful for estimating mass loading and are described in detail by the USGS (2006). Most interpretive studies at the MBMG characterize surface-water quality as opposed to mass loading, and a dip sampling method is often appropriate.

Dip samples from a stream should be collected from the center of flow if possible, or as near as feasible to it. The thalweg (that is, the deepest point in the channel) is a good target. Collect a depth-integrated sample at the selected location unless the stream is very shallow. Avoid stirring up bottom sediment when collecting a water sample. Samples may be collected by (1) using a peristaltic pump and tubing, as described below for lake sampling or (2) in a triple-rinsed container, such as a distilled water jug. If the stream can be waded, face upstream and push the jug through the water column to near the streambed, then raise it. Repeat until the container is full. If the stream is relatively deep, use a weight or attach a rod to lower and raise the jug through the water column.

If sampling with a peristaltic pump, the pump can be stationed at the stream edge and the tubing carried to the sample position, or a jug can be filled and sampled from the stream edge.

If the sample will be processed away from the stream, for example at the field vehicle, cap the jug or otherwise protect the sample from windblown dust to prevent sample contamination. *In situ* measurement of field parameters (SC, T, pH) is strongly preferred, by submerging probes or a multi-parameter sonde in the stream or lake. *In situ* measurement avoids sampling artifacts, such as atmospheric effects on temperature.

Refer to chapter 5 for standard procedures related to measuring water-quality parameters such as pH, DO, and SC.

7.6.2 Sample Collection from a Lake

Lake sampling methodologies are similar for reconnaissance, diagnostic, and interpretive studies. Samples may be collected at each sample location at a discrete depth or using a depth integrated method. For studies with multiple sample events, use the same sampling approach each time at each location. Grab samples collected along a lake shore are seldom defensible because these locations are not well mixed, nor are they expected to be representative of the deeper parts of the lake. Additional topics related to lake sampling that exceed the scope of this document are presented by the USGS (2018c). Topics include data types useful to limnological studies (for example, measuring solar radiation or conducting a macrophyte survey), and guidance on design of random or systematic approaches to selecting sample locations.

Lake sampling typically requires use of a boat. Small, stable boats with oars or electric motors are preferred if feasible. Less stable boats such as canoes, and boats with gasoline-powered outboard motors, present additional challenges for the sampling team. Keep safety at the forefront. If using a gas-powered boat, keep the exhaust downwind and downstream of the sampling points and sampling supplies to avoid contamination.

In ponds, a sample can be collected remotely. Use a peristaltic pump stationed at the shore and a small flotation device that can be pushed or pulled from shore to the target sample location. Select a long length of small-bore tubing that can be attached to the tubing in the peristaltic pump head. Bend the tubing to form a “J” on one end and attach a weight. Run the weighted end over the pulley on the flotation device and then position the flotation device at the desired sample location. Once the float is positioned, let out tubing to allow the weight to pull the intake to the targeted sample depth.

In a well-mixed lake, water quality at the lake's deepest point is typically representative of the lake overall. In such cases, a single sample collected at the midpoint of the water column, or a depth integrated sample from the lake's deepest point can be sufficient. A sampling event in a stratified lake requires isolation of samples collected at specific depths below the water surface. Typically, *in situ* parameters such as pH, temperature, SC, and DO are measured at the same depths as water is sampled. Upon arriving at a sampling location, take a GPS reading and use the motor or oars to maintain position during sampling. Use of anchors is discouraged because agitated bottom sediment may contaminate a sample, and the anchor line can entangle the equipment lowered for sampling.

7.6.3 Depth Integrated Sampling

To collect a depth integrated sample with a peristaltic pump, insert a short piece of appropriate flex tubing in the pump head. Attach a length of semi-rigid tubing, such as 1/4-in polyethylene, to the flex tubing that is long enough to reach the bottom of the lake. Make a gentle upward bend at the inflow end of the tubing to avoid pulling in bottom sediment. Attach a weight to the end of tubing. Purge the sample tubing with a minimum of three volumes of sample water before collecting a sample. For example, #15 GeoTech™ tubing contains 16.5 ml/ft (54.3 ml/m) of tubing, and three volumes requires purging 49.5 ml/ft of tubing.

Begin collection of a depth integrated sample by starting at the shallowest sampling point. Purge three volumes from the tubing, being careful not to discharge the purge water back into the water column. Following purging, collect the sample while lowering the weighted tubing hand over hand through the water column at a consistent rate, while pumping. Turn the pump off immediately upon reaching the lowest sampling point. Collect the sample in a clean container such as a covered bucket or a rinsed distilled water jug and take it to shore for filtering and preservation as needed. Dissolved oxygen and temperature should be measured *in situ* if possible, or in a flow cell before the sample encounters atmospheric oxygen and temperature levels. All field parameters are best measured similarly to DO and temperature, though if the shore is near, SC and pH can be completed at the field vehicle. To avoid sample contamination, measure field parameters in an aliquot of water that is not subsequently processed for laboratory analysis.

If a peristaltic pump is unavailable, a Van Dorn sampler (described below) may be used at progressively deeper points in the water column. Empty the Van Dorn into a clean container to collect a composite sample.

7.6.4 Discrete Depth Sampling

Water samples from a lake can be collected using depth-specific samplers such as a Van Dorn device (fig. 7.1) or a peristaltic pump. The Van Dorn sampler consists of a cylindrical body with end seals held open by a latch. The latch is activated by a "messenger," a heavy brass cylinder with a hole in the center that is sent down the rope from the surface when the Van Dorn is at the desired depth. The messenger trips the latch to close the end caps, isolating the sample at the prescribed depth. Prior to sending down the messenger, swing the Van Dorn slightly at the sample depth to ensure movement of representative water through the sampler.

Although field parameters can be measured in water from the Van Dorn, a multi-probe sonde is ideally suited for lake measurements. Use a sonde to measure and record parameters while lowering it through the water column alongside the Van Dorn. Be careful to ensure that the sonde does not interfere with the messenger. Calibration of instruments associated with a sonde are described in chapter 5.

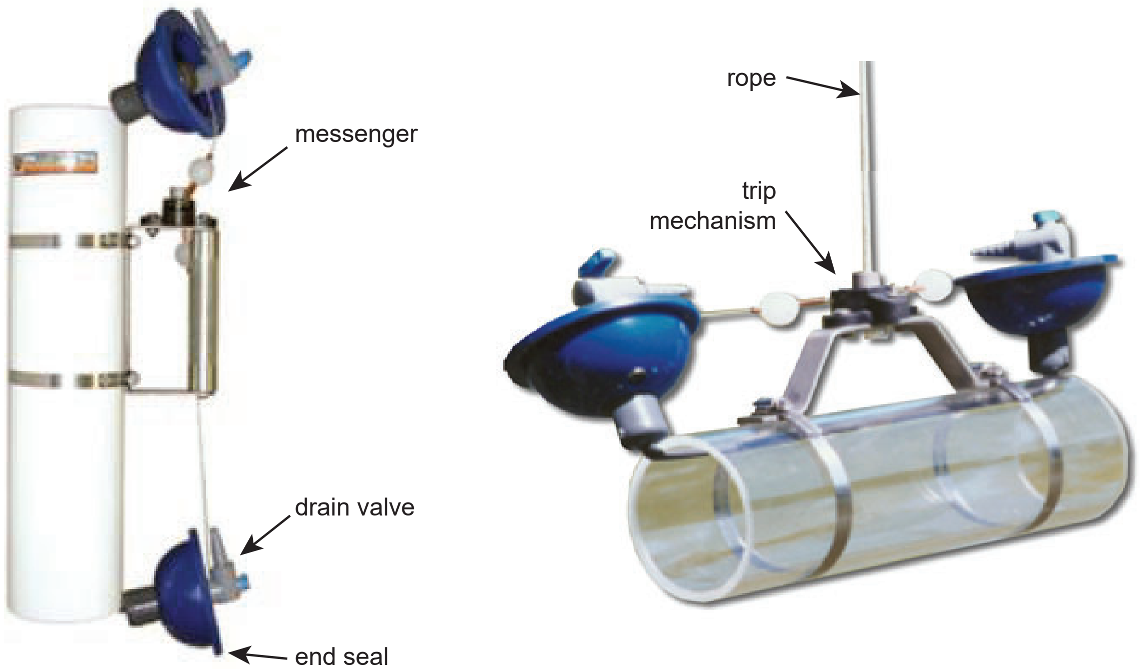
7.7 References

Averett, R.C., and Schroder, L.J., 1994, A guide to the design of surface-water-quality studies: U.S. Geological Survey Open-File Report 93-105, 39 p., available at https://pubs.usgs.gov/of/1993/0105/report.pdf [Accessed October 2021].

Minister of Supply and Services, 1983, Sampling for water quality: Water quality branch, inland waters directorate: Ottawa, Canada, Catalog no. En 37-64/1983E, ISBN 0-662-12380-8.

Stumm, W., and Morgan, J.J., 1996: Aquatic chemistry: Chemical equilibria and rates in natural waters: New York, Wiley, 1040 p.

USGS, 1999, Section A: National field manual for collection of water-quality data: Techniques of



Vertical Configuration
PVC body

Horizontal Configuration
Acrylic body

Figure 7.1. Schematic of Van Dorn samplers (images from: http://envcoglobal.com/catalog/term/water/limnology/water-quaity-sampling/water-sampling-bottle/surface-water-sampling/van accessed 10/6/2021).

Water-Resources Investigations of the U.S. Geological Survey, book 9, Washington, D.C.

USGS, 2006, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, available at http://pubs.water.usgs.gov/twri9A [Accessed October 2021].

USGS, 2018a, General introduction for the "National Field Manual for the Collection of Water Quality Data" (ver. 1.1, June 2018): U.S. Geological Survey Techniques and Methods, book 9, chap. A0, 4 p., doi: https://doi.org/10.3133/tm9A0.

USGS, 2018b, Preparations for water sampling: U.S. Geological Survey Techniques and Methods, book 9, chap. A1, 42 p., doi: https://doi.org/10.3133/tm9A1 [Supersedes USGS Techniques of Water-Resources Investigations, book 9, chap. A1, ver. 2.0].

USGS, 2018c, Lakes and reservoirs—Guidelines for study design and sampling: U.S. Geological Survey Techniques and Methods, book 9, chap. A10, 48 p., doi: https://doi.org/10.3133/tm9a10 [Supersedes USGS Techniques of Water-Resources Investigations, book 9, chap. A10, ver. 1.0].

7.8 Appendices

Appendix 7.8.1 Examples of Temporal and Spatial Variations in Surface-Water Quality

Photosynthesis and Respiration

During the daytime, phytoplankton and aquatic plants produce oxygen and consume carbon dioxide through photosynthesis, causing an increase in pH. During the night, these plants consume oxygen and produce carbon dioxide through respiration; carbon dioxide combines with water molecules to form carbonic acid, causing a decrease in pH. The result is a daily cycle in the pH and DO in lake or stream waters (USGS, 2018; Parker and others, 2009). This daily cycling of pH results in a daily cycle in SC and metals concentrations. The diurnal variation related to photosynthesis can strongly affect metals concentrations, resulting in significant variation in water-quality analyses (Nimick and others, 2003).

Diurnal Variation

When sampling a site multiple times during the year or within a season, conduct sampling at a consistent time of day to reduce or eliminate the diurnal variability in water quality. A water-parameter profile collected in a lake at 0500 hours may be quite different from one collected at 1700 hours on the same day (USGS, 2018). Preferred sampling time is between 1000 and 1500 hours, when the sun is relatively high in the sky (USGS, 2018). If a sample will be compared to a historic value, sample close to the same time of day as the initial sampling event.

Stratification

Larger lakes, on the order of 20 ft and greater in depth, can be stratified (Parker and others, 2016). Stratification, which is a seasonal process, occurs when there is an abrupt change in water density within the water column (USGS, 2018). Although this may be caused by salt concentrations, stratification is typically due to the cooling of surface water during the winter, which then traps warmer and less dense water at the bottom of the water body. Turnover occurs in a stratified lake as the dense upper layer sinks into the lower layer and the buoyant lower layer floats upwards. This process often occurs as an event when a threshold is reached; the density contrast becomes so great that the warmer, less dense bottom layer cannot support the colder, denser top layer. This results in the entire lake profile mixing anoxic water with oxic surface water, and can potentially suffocate fish due to a lack of dissolved oxygen.

Bibliography of Natural Variations in Rivers and Lakes

Nimick, D.A., Gammons, C.H., Cleasby, T.E., Adison, J.P., Skaar, D., and Brick, C.M., 2003, Diel cycles in dissolved metal concentrations in streams: Occurrence and possible causes: Water Resources Research, v. 39, no. 9, p. 1247, doi:10.1029/2002WR001571.

Nimick, D.A., Moore, J.N., Dalby, C.E., and Savka, M.W., 1998, The fate of geothermal arsenic in the Madison and Missouri Rivers, Montana and Wyoming: Water Resources Research, v. 34, no. 11, p. 3051–3067.

Parker, S.R., West, R.F., Boyd, E.S., Feyhl-Buska, J., Gammons, C.H., Johnson, T.B., Williams, G.P., and Poulson, S.R., 2016, Biogeochemical and microbial seasonal dynamics between water column and sediment processes in a productive mountain lake: Georgetown Lake, MT, USA: JGR Biogeosciences, v. 121, no. 8, p. 2064–2081, doi:https://doi.org/10.1002/2015JG003309

Parker, S.R., Poulson, S.R., Smith, G.M., Weyer, C.L., and Bates, K.M., 2009, Temporal variability in the concentration and stable carbon isotope composition of dissolved inorganic and organic carbon in two Montana, USA Rivers: Aquatic Geochemistry, v. 16, p. 61–84, doi: 10.1007/s10498-009-9068-1.

8.0 INSTALLING STAFF GAGES AND STILLING WELLS ON STREAMS

8.1 Purpose

This document presents standard procedures and considerations for the installation of staff gages and stilling wells on streams.

8.2 Scope

Staff gages are installed to provide a measure of the stage of a stream, pond, or lake. Stage is the water-surface level relative to a local or absolute datum. The stage measurement can be automated by pairing a staff gage with a stilling well containing a water-level measurement device (such as a recording pressure transducer). A stilling well typically consists of a vertical pipe with small intakes (holes) in the bottom or sides to maintain a hydraulic connection to the stream. The stilling well dampens the effects of oscillating water or waves, and protects the pressure transducer.

Stage measurements can be paired with stream discharge measurements taken at a variety of flow rates. The measured discharges and stages are used to develop a stage–discharge rating curve. The rating curve can then be used to estimate discharge from recorded stage measurements. This section addresses the installation of staff gages and stilling wells on streams. Guidance for measuring streamflow is presented in chapter 9. Methods described here for installation of staff gages on streams may be adapted for lakes or ponds.

Staff gages are typically attached to a post or pipe driven into the streambed; however, in some cases staff gages may be attached to bridge pilings or similar structures. The most important criterion is that the gages are vertically stable, at least on a seasonal basis.

8.3 Staff Gage and Stilling Well Construction

Standard staffs include USGS Type A or Type C gages, which can be ordered from various suppliers (e.g., https://www.forestry-suppliers.com/). These gages have an iron frame coated with a baked enamel coating and are 4 in (type A) or 2.5 in (type C) wide (fig. 8.1). These staffs are easily fastened to a support using the grommeted holes.

A pressure-treated 2 x 4 works well as a support for the type C gage. The type A gage is 1/2 in wider than the 3.5 in actual width of a 2 x 4, so they should be mounted on a 2 x 6, or with the “vane” (the portion of the gage that extends beyond the width of the mounting board) pointing downstream. Attach the gage to the support with 3/4-in no. 8 screws or similar. If a notch is cut in the 2 x 4 (fig. 8.2C), ensure that the gage is offset so that the screws do not extend into the notch.

For many installations, the support can be attached to a tee-post driven into the streambed. The tee-post is first driven into the streambed, and adjusted as needed so that it is vertical, and then the gage support is attached. We recommend using a dado blade to cut a 1-in x 1/4-in notch centered on the support to accommodate the long leg of the tee-post and then attach the support to the tee-post with countersunk carriage bolts and backing plates (fig. 8.2). Stainless steel hardware is recommended. The bolt holes for the bottom attachment should be high enough so that a wrench can make a full rotation without hitting the streambed.

Stilling wells are used to protect pressure transducers and dampen fluctuations in the stream surface caused by wind and turbulence. For installation on small streams, stilling wells are typically con-

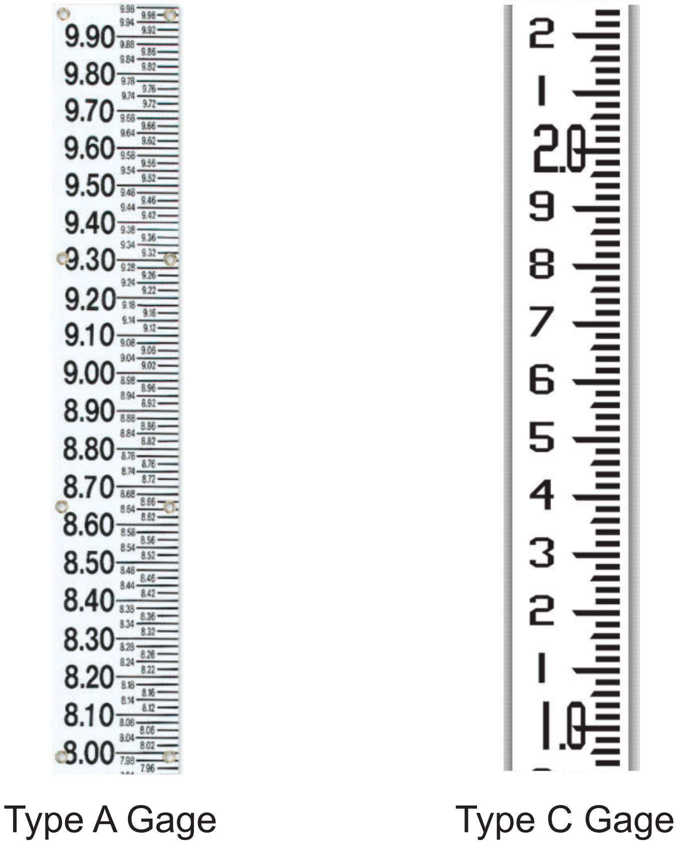


Figure 8.1. Type A and Type C staff gages.

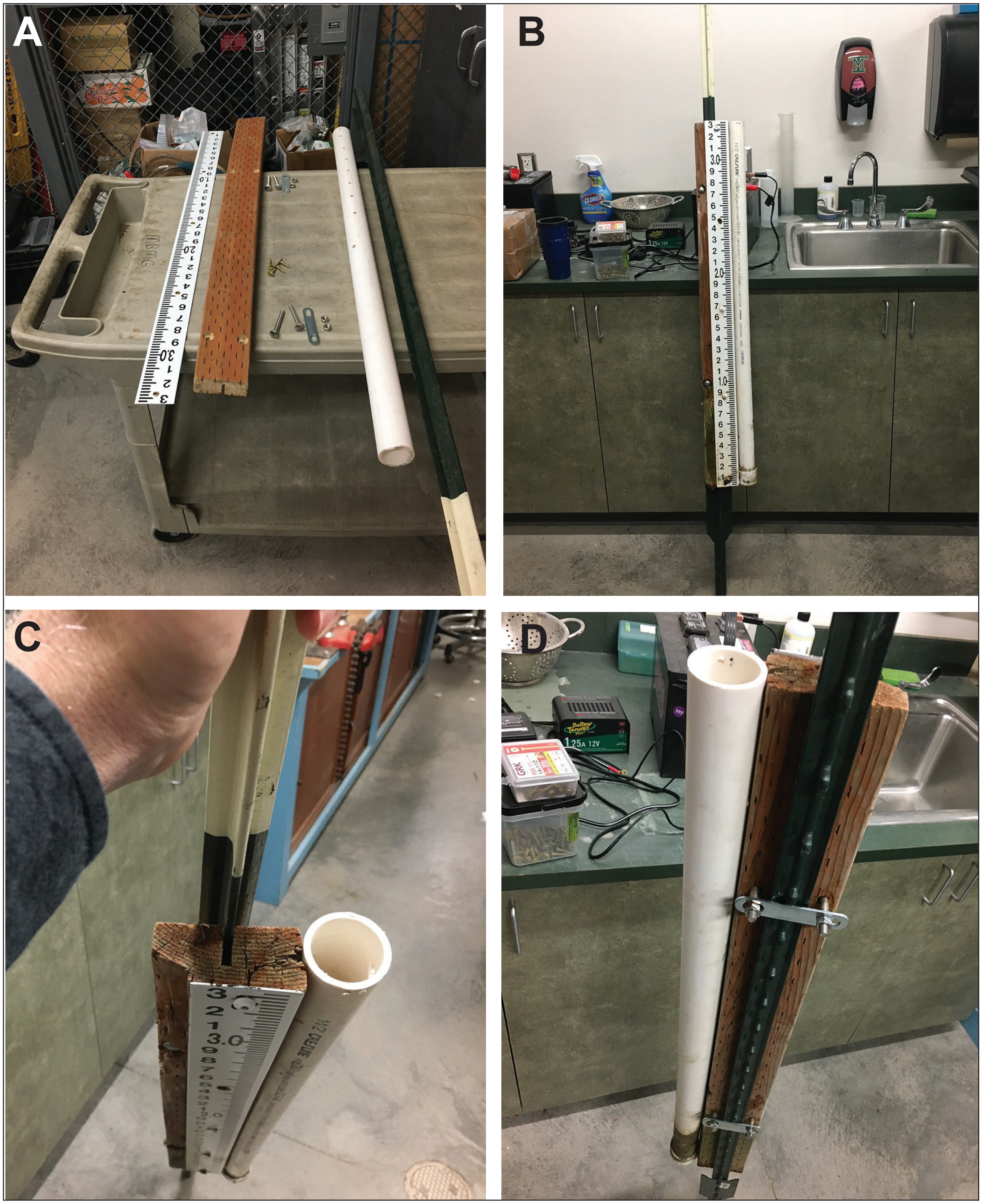


Figure 8.2. Constructing a staff gage and stilling well attached to a tee-post. A, disassembled; B, front view of assembled gage (back plates not tightened down; downstream to the right); C, top view; D, back view.

structed from PVC pipe attached to the staff gage support. The stilling well should be large enough to easily accept the pressure transducer. PVC sizes from 1.25 to 2 in typically work well. Stilling wells may have open bottoms to facilitate flushing of sediment, but should have some obstruction (e.g., a bolt) so that pressure transducers can't accidently fall out the bottom. If a cap is placed on the bottom end, the stilling well will need to be removed for cleaning. A sufficient number and size of holes are needed along the sides of the stilling well to provide for hydraulic connection to the stream; however, too many holes can lead to turbulence in the stilling well. Typically, eight 1/4-in holes near the base of the stilling well, with additional holes to aid in attaching the stilling well to its support, are adequate.

The stilling well can be attached to the downstream side of the support (before installation) with 1.5-in screws through the sides of the pipe, with a small pilot hole on the support side, and a hole large enough to accommodate the screw head and driver on the other. Screws longer than 1.5 in may block the notch. If a cap will be installed on the top of the stilling well, maintain a gap between the stilling well and the support using a spacer or install the stilling well so that it extends above the support.

8.4 Site Selection and Staff Gage Installation on Streams

Select the location for a staff gage based on the stream morphology, paying particular attention to the types of in-stream structures (“controls”) that will define the stage–discharge relationship. In most cases these structures are natural (e.g., rocks and boulders), but in some cases they are constructed (e.g., weirs). When selecting a site, consider the potential for a staff gage to be washed out during high flows, and for debris accumulation. Control types may change over time because they are affected by the streamflow and stage. Types of controls include:

1. Section—occurs when riffle heads in a typical pool/riffle are not overtopped and each pool has a stage control (e.g., rocks, boulders, islands that split flow, log jams that accumulate and dissipate over time) at the outlet (section control; fig. 8.3).
2. Channel—in some reaches, particularly at higher flows, riffle heads are overtopped and the control is determined by channel roughness and constriction.
3. Overbank—occurs when banks are overtopped and flow extends onto the floodplain.

If possible, install the staff gage in a pool where there is section control during baseflow (fig. 8.3). If the elevation of the downstream control changes, then so will the rating curve, so pools with sturdy controls are preferred. If a site with section control is not available, then select a site in the channel that is deep enough so that stream stage can be measured at its lowest flows. Sites with fewer controls are ideal, since they add complexity to the rating curve.

Compile field notes that include a description of the control type when installing a staff gage. Note possible controls anticipated at higher stages (for example, if dense vegetation or a secondary channel will be encountered at a certain stage). Complete the Surface-Water Site Inventory Form (appendix 9.5.1) to establish the site.

At sites with section control, the lowest point on the control structure is the point of zero flow (PZF) elevation, below which flow cannot continue. The PZF elevation is recorded by the staff gage as gage zero flow (GZF; also referred to as “e”), where a stage is recorded but flow is zero at the GZF or below (fig. 8.3).

Following installation of the staff gage, measure and record the relative elevations of 0.00 on the staff gage (the site datum), the PZF on the control (if section control), the top of bank, and any other anticipated controls at higher flows. The relative elevations of these points are needed to develop a rating curve for the site. It is often more convenient to survey the

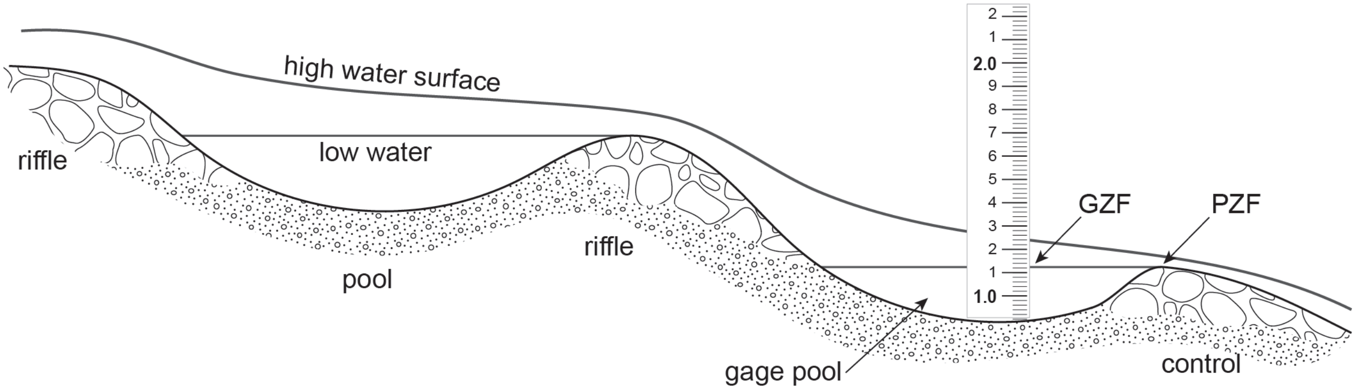


Figure 8.3. Diagram of a staff gage installation in a pool riffle sequence (section control; modified from https://www.nps.gov/articles/fluvial-geomorphology-monitoring-stream-systems-in-response-to-a-changing-environment.htm).

top of the staff gage and calculate the relative elevation of the 0.00 datum. Some staff gages do not include the 0.00 mark (for example, a staff that extends from 6.67 to 9.99 ft). Regardless of the range on the staff gage, the site datum is always the zero level (e.g., 9.99 ft below the top of a 9.99 staff), even if that results in a 0.00 location below the streambed. In some cases (such as when the stream stage measurements will be used in a numerical model), the 0.00 site datum should be surveyed and tied to an absolute datum (e.g., NAVD 88; ft-amsl).

Record stage as the actual number measured ("read") on the staff gage. That way, no matter what range of staff gage installed, all stages are the 0.00 site datum plus the staff reading. For the example above, with a staff gage that reads from 6.67 to 9.99, a stream stage that reaches the 7.28 mark is recorded as a stage of 7.28.

If a bridge is present that can be safely accessed, mark a measuring point over the thalweg (that is, the deepest point in the channel), and measure down to the water surface from that point using a water-level indicator. Combine this with the staff gage reading to establish the elevation of the bridge measuring point relative to the site datum. This provides a backup means for measuring the stage if the staff gage is underwater or disturbed. A bridge measuring point can also serve as a benchmark (see below).

In some cases, staff gages will be disturbed by ice, debris, or high flows. If data are to be collected for more than one season, it is important to have at least two benchmarks that will not be disturbed by flooding. Staff gage elevations relative to the benchmarks should be confirmed each spring following high flow to ensure that any shifts are accounted for. Record distance and compass directions from all benchmarks to the staff gage. At least two benchmarks provide a primary and a backup benchmark. These should be vertically stable and if possible be out of the floodplain. Typical benchmarks include:

1. A horizontal nail in the base of a large tree—use flagging or paint to increase visibility
2. ~18-in length of rebar driven most of the way into the ground, with a survey cap installed on top
3. Easily identifiable place on a bridge—the bridge measuring point described above, or a durable mark (survey paint) on cement directly above the thalweg; a cement corner nearest the staff gage; a permanent survey mark installed on the bridge
4. Culvert inlets or outlets: use the top of the first full corrugation (fig. 8.4). Draw a mark with survey paint or marker.

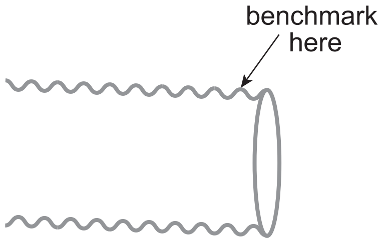


Figure 8.4. Using a culvert for a benchmark.

8.5 Stilling Well and Pressure Transducer Installation

Many instruments have been developed to measure stage in stilling wells (Sauer and Turnipseed, 2010). At the MBMG, we typically use non-vented pressure transducers, with a Barologger deployed nearby. Data processing is easiest if the Barologger and transducer are from the same manufacturer.

Suspend the transducer in the stilling well with the bottom of the logger about an inch above the bottom of the stilling well. A cap may be placed over the top of the stilling well to secure equipment as long as there are vent holes to the atmosphere. Methods for hanging the transducer in the stilling well will vary by site (chapter 4 describes options for hanging transducers). At each installation, ensure that the transducer is vertically stable and can be easily removed for downloading.

When programming a pressure transducer to collect stage readings, the typical settings are:

1. Pressure in PSI, temperature in °C, depth in feet
2. 1-hour collection intervals starting at the top of the next hour
3. Set to record the height of water above logger
4. Note memory used and battery used each time the logger is accessed

8.6 Reference

Sauer, V.B., and Turnipseed, D.P., 2010, Stage measurements at gaging stations: USGS Techniques and Methods book 3, chap. A7, 45 p.

9.0 MEASURING STREAMFLOW

9.1 Purpose and Scope

This document presents standard procedures for measuring surface-water discharge. These procedures are based in part on methods and reports by the USGS (Rantz, and others, 1982; Turnipseed and Sauer, 2010) and the Montana Department of Natural Resources and Conservation (DNRC; Norberg, 2015). The MBMG and DNRC often work cooperatively on surface-water programs and to that end, consistency and uniformity between these agencies is desirable.

This SOP provides general guidelines for field measurements of streamflow. It also describes appropriate training for staff who are assigned to collect these measurements. Special considerations for synoptic measurements, which involve collecting a series of discharge measurements along a stream reach or canal within a short time frame, are provided in chapter 10. Use of consistent field methods is particularly important for synoptic stream gaging because multiple teams of field personnel may participate and their results must be within a small margin of error in order to be of value.

9.2 Health and Safety

Personal and team safety is of paramount importance in all field activities, and safety precautions will be exercised at all times by MBMG staff. Surface-water sampling and gaging usually involves wading through streams and rivers or riding in a boat, and safety precautions around water are a priority for staff.

Staff are required to wear personal flotation devices (PFDs, or life jackets) at all times when working in, on, over, or near water. This includes while carrying out activities in, on, over or near a cableway, bridge, water control structure (a dam), on ice, in a boat, or wading in streams or lakes. Staff are required to wear high-visibility vests in addition to PFDs when working on bridges. Working on ice requires experience, training, and knowledge of the specific water body. Staff must consult with their program area manager about their intent to work in iced-over conditions prior to any on-ice activity. Such work should never be conducted alone.

9.3 Streamflow Measurement—General

Visits to sites to collect stream measurements should be documented with the appropriate set of field notes (section 9.3.4.4) in addition to standard MBMG forms. These include the Surface-Water Site Inventory Sheet for the first visit to a new field site and the Surface-Water Site/Streamflow Field Sheet for additional site visits (appendices 9.5.1 and 9.5.2, respectively).

9.3.1 Training

All personnel, including technicians, students, and others assigned to collect stage and discharge measurements will be trained by experienced MBMG personnel before any fieldwork is performed. Training will address profile selection, instrument operation, data collection, and post-processing of data. This will include the selection of equipment to measure stream discharge and the corresponding field techniques. MBMG managers are responsible for arranging training for newly hired staff members and for staff who are new to stream gaging.

MBMG personnel with experience in stream gaging are encouraged to review this document and those described in section 9.3.2 on an annual basis.

9.3.2 Technical Manuals

MBMG procedures for measuring stream discharge have been largely adapted from protocols established by the USGS. Review of these technical manuals and familiarization with equipment are recommended on an annual basis:

- Rantz, S.E., and others, 1982, Measurement and computation of streamflow, v. 1, Measurement of stage and discharge; v. 2, Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, doi: https://doi.org/10.3133/wsp2175.
- Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p., doi: https://doi.org/10.3133/tm3A8.

9.4 Equipment and Materials

Commonly used equipment includes, but is not limited to, the following:

- Personal flotation device (PFD)
- Waders and/or wading boots[1]
- Reflective vest
- Safety cones and bright flashing safety lights if working near traffic
- Current meter, also referred to as a velocity meter
- Fiberglass measuring tape (graduated in tenths and hundredths of a foot)
- Kevlar tagline: for wider streams and windy conditions
- Chaining pins or stakes to anchor tape or tagline
- Field notebook and/or forms
- Handheld GPS or equivalent
- Digital camera
- Field computer with appropriate software installed for sites with data loggers
- Communication hardware (docking ports, USB cables, BlueTooth antennae, etc.)
- Water chemistry probes—minimally, an SC meter

[1] Soft-soled boots are recommended for additional traction. Felt-soled boots are discouraged, and may be prohibited on some streams, because of the potential transfer of invasive species from stream to stream.

As of January 2021, the MBMG owns various types of current meters:

- ADV—Acoustic Doppler Velocity Meter: SonTek FlowTracker 1 and 2; this is a standard meter useful for flows that can be waded safely
- ADCP—Acoustic Doppler Current Profiler: SonTek M9 River Surveyor or Steam Pro; useful for flows of magnitudes that cannot be waded safely, due to depth and/or velocity; sometimes referred to as a “boat” because operators stationed at the stream edge pull it along a tag line
- EVM—Electromagnetic Velocity Meter: Hach Marsh-McBirney 2000 and Hach MF Pro; EVMs can be used in place of ADVs; EVMs have thinner sensors to accommodate small channels and low flows but can also measure flows similar to the ADV.

The stream reach of interest will in part determine what type of meter to use. Table 9.1, largely adapted from Turnipseed and Sauer (2010), lists appropriate minimum depths for various current meters.

Consider using portable Parshall flumes or v-notch weirs, or a volumetric method (i.e., bucket and stopwatch), to measure flows that are too small for a current meter. Such settings include shallow streams or canals. If properly installed, flumes or weirs may improve accuracy compared to current meters. These methods are fully described in referenced materials. If installing flumes or weirs, pay particular attention to sealing the wing walls and bottom, and confirm that water is free-falling at the outflow. Following installation, collect repeated measurements to ensure that the stage has stabilized.

Following each field expedition, equipment should be returned to the appropriate storage area clean, dry,

Table 9.1. Range of measurements for various classes of meters.

Depth Range (ft)	Current Meter Technology	Models	Velocity Measurement Method	Stream Velocity (ft per s)
0.3–2.5	ADV	Flow Tracker	0.6	0.003–13
>2.5	ADV	Flow Tracker	0.2 and 0.8	0.003–13
0.2–2.5	EVM	Marsh McBirney Flo-Mate, MF-PRO	0.6	>0.5
>2.5	EVM	Marsh McBirney Flo-Mate, MF-PRO	0.2 and 0.8	>0.5
0.5–7.25	ADCP	Stream Pro	Profile	<11
1–131	ADCP	River Surveyor	Profile	±65.6

Note. Adapted from Turnipseed and Sauer (2010) and SonTek M9 specifications. Measurement methods are described in Section 9.3.4.

and in good condition, ready for the next team to use. It is also good practice to remove batteries prior to storage.

9.5 Generalized Procedure for Measuring Streamflow

9.5.1 Selecting a Cross-Section ("Profile") Location

The following characteristics of cross-section locations support accurate discharge measurements (from Rantz and others, 1982, unless otherwise cited):

- Flow is relatively uniform and free from eddies, slack water, and excessive turbulence.
- Streambed is free from large obstructions, such as boulders and aquatic vegetation.
- Streambed banks have minimal undercutting.
- Water velocity is within the range of the meter. If velocity is too slow, find a narrow section. If velocity is too fast, find a wider section.
- Average water depth is at least 0.5 ft. Instruments are calibrated to operate accurately within specific ranges of depth, and some instruments are accurate to a minimum depth of 0.2 ft (table 9.1).
- Tagline can be stretched across the stream in such a way that flow is perpendicular to it at all points.
- Avoid converging or diverging flow. Ideal sites lie within a straight reach of stream with parallel flow lines.
- Avoid sites directly downstream of sharp bends.
- Avoid sections with obstacles or immediately downstream of obstacles, such as downed trees or fences that have collected trash.

Finding a cross-section that meets all of these criteria in the natural environment may prove difficult. It may be necessary to "engineer" the stream by moving rocks, logs, branches, algae mats, rooted aquatic vegetation, debris, shelf ice, or other obstructions in order to construct a cross-section that is free of turbulence and supports accurate measurement.

When selecting a cross-section, avoid disturbing fish spawning beds or "redds." A redd is a depression in a streambed that appears as a light-colored spot, relatively bare of fine sediment and algae. Redds are often found in riffles, and riffles also make good areas to collect velocity measurements.

Adjusting the site conditions to improve the measurement setting can include placement of rocks or other obstructions in the slack water. This can create an artificial bank to eliminate or reduce streamflow over or through any obstructions (Rantz and others, 1982). If this is necessary, make all adjustments and wait a few minutes for the system to stabilize prior to collecting streamflow measurements.

As described below, a good-to-excellent discharge measurement can be made at a less than ideal cross-section through careful spacing of "verticals" and by increasing their number within a cross-section. "Verticals" refer to the depth and velocity measurements of each measuring station at specified distances along the cross-section.

If measuring discharge at a gaging station, the cross-section need not be directly at the station. Walk upstream and downstream to find the best section, but do not cross the station's stream control structures, diversion points (irrigation pumps, for example), or inflows (irrigation return flow or tributaries).

9.5.2 Setting the Tagline and Spacing of Verticals

Stretch a tape measure across the stream so that it is taut and perpendicular to the streamflow. Install the tagline directly over the cross-section to be measured; the tagline must not touch the water surface. Identify the starting edge as left edge of water (LEW) when facing downstream, or right edge (REW). Determine the approximate width of the stream with active streamflow that is of sufficient depth to measure.

At least 20 verticals should be collected across the width of the cross-section. Importantly, the average discharge within one cross-sectional area of the profile (i.e., discharge measured between two verticals) should not exceed 10% of the total stream discharge (Rantz and others, 1982). The goal is to get a near-equal amount of discharge (5% of total stream discharge) into each of the 20+ cross-sectional areas, rather than equally spacing them across the stream. A typical number of stations is 25 to 35, depending on the width and degree of variation in depth and velocity. Another one or two verticals may be added, if any of the cross-sectional area's discharge exceeds 10% of the total profile discharge.To calculate the approximate spacing of verticals, divide the stream width by

20. Use this distance as a base interval until a location is reached along the cross-section where depth or velocity vary significantly. Typically, verticals are more closely spaced in sections that are deeper or have a greater velocity, such as a thalweg. Collect verticals within larger features in the channel shape, if possible. Conversely, the spacing of verticals may be farther apart along cross-sections with consistent flow conditions, or that have lower velocity compared to the majority of the stream. Vertical spacing should not change by more than half the width of the adjacent vertical. In other words, if you are moving out of fast water with a 1 ft vertical spacing into slow water, increase to 1.5 ft, then 2.25 ft, etc. Do not increase from a width of 1 ft to 4 ft in adjacent verticals. Uniform spacing across the entire tagline should only be used at cross-sections where the stream is relatively uniform in depth and velocity; these conditions often exist in irrigation canals.

Although spacing of verticals can vary across a section, verticals should almost never be less than 0.2 ft apart. Where the width of a cross-section is less than 4 ft, set verticals at 0.2 ft apart and collect as many velocity and depth measurements as possible within the cross-section. This is consistent with the DNRC's practices at narrow streams (Norbert, 2015).

9.5.3 Measuring Depth

The depth of measurement is determined with a goal of measuring velocity at a depth that represents the average velocity within the stream's vertical profile. There are two common categories of stream depth measurement associated with handheld current meters (table 9.1). The single point, "0.6 depth," method is typically used where stream depth is 2.5 ft or less. A two-point method is applied where stream depth exceeds 2.5 ft: velocity readings are collected at 0.2 and 0.8 depths in each vertical. In the two-point method, the two velocities are averaged and applied to the entire vertical.

The top-setting rod is used to both measure the effective depth of the water, and to position the sensor at the desired depth. The top-setting rod consists of two parallel rods connected at the top handle (fig. 9.1). The main rod is graduated in feet and the sliding rod is marked in intervals based on 40% the length of a foot (discussed below). Note that top-setting rods index off the bottom of the water column whereas the velocity

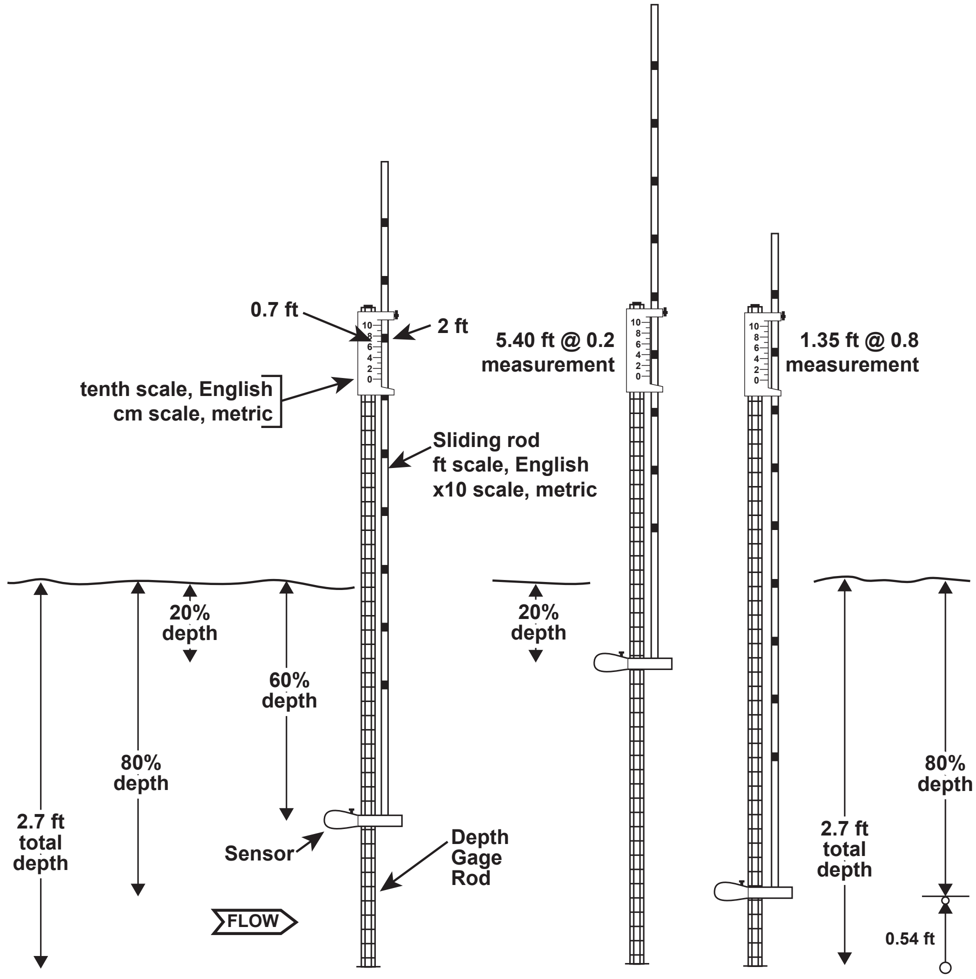


Figure 9.1. Diagram illustrating the 0.6 method and the 0.2/0.8 method using a top-setting rod.

measurement is taken at a depth below the top of the water column.

Using the top-setting rod, measure the depth of water at the vertical with the main rod, then adjust the sliding rod to read the measured depth. Enter the depth into the field notes.

Where the vertical depth of the water is 2.5 ft or less, use the single-point, or "0.6-depth" method. The sliding rod is designed to properly position the probe at 0.6 of the vertical depth, measured from water surface when adjusted to the same reading as the main rod (fig. 9.1). The ideal velocity profile varies logarithmically from bottom to top, with the average value at 0.4 above the bottom, or 0.6 below the top of the water surface. In streams with depth of 2.5 ft or less, collect one velocity measurement at each vertical, at the depth of the average velocity. This 0.6 depth method approximates the mean velocity for that vertical (fig. 9.1; Rantz and others, 1982, p. 134).

Where the vertical depth of the water exceeds 2.5 ft, use the two-point method (fig. 9.1; Rantz and others, 1982, p. 134). Measure velocity at two depths (0.2 and 0.8 of the total depth below the water surface) in each vertical.

For example, if the stream depth is 2.7 ft at a particular station, take a velocity measurement at 0.2 x 2.7 ft (0.54 ft) below the water surface (this is the same point as 2.16 ft above the bottom). Collect a second measurement at 0.8 x 2.7 ft (2.16 ft) below the water surface (this is the same point as 0.54 ft above the bottom). Estimate the velocity at the vertical using an average of these two readings. The FlowTracker and MF Pro measuring devices calculate the average automatically; the field technician will manually average the velocities when using Marsh-McBirney devices.

A standard top-setting rod can be adapted for the two-point method by following these instructions:

- To set the rod at the 0.2 depth, multiply the water depth by two and set the rod to that value.
- To set the rod at the 0.8 depth, divide the water depth by two and set the rod to that value.

For the example above, with a stream depth of 2.7 ft, set the rod at 5.4 ft for the 0.2 measurement. Set the rod at 1.35 ft for the 0.8 measurement. These rod settings will achieve the correct depths of 2.16 and 0.54 ft, respectively, above the bottom.

Estimate the 1/100th mark between the 0.10-ft hash marks on the rod as best you can. Be aware of the stacked water on the upstream edge of the rod and the water-surface dip just downstream. Measure the actual water depth. You may need to cup your fingers around the rod to sufficiently calm the water for an accurate reading, or you can take an average of the upstream and downstream watermarks.

9.5.4 Measuring Velocity and Stream Depth

1. If using a Marsh-McBirney current meter, zero the meter prior to collecting the first measurement of the day (see appendix 9.10.3).
2. Construct a data table in the field notes with three column headings: "*x*" for tagline distance of vertical, "*D*" for depth of vertical, and "*v*" for velocity. Record the time and stage in the field notes prior to taking any measurements.
3. The first vertical is at the water's edge, if possible. Record the distance, which is the position on the tagline where water meets the bank. Record the depth at water edge. Depth is typically zero where the channel meets the edge of water at a slope, but may not be zero if the channel is vertical at the water edge.
4. Place the rod at the next vertical and record the position of the rod on the tagline. Record the depth and adjust the sliding rod to match the depth to properly position the probe. Use the bubble level (if present) to ensure vertical placement of the rod. Begin measuring velocity, holding the rod and probe perpendicular to the tagline at all times. Even if flow is not completely perpendicular to the tagline at some verticals, do not twist the probe into the flowline; the probe should be held perpendicular to tagline. Use an averaging period of 40 s for all current meters. The meters automatically count down from 40 s and display the averaged value in real time. Once the 40-s averaging is complete, record the velocity at that vertical.
5. Continue measuring and recording *x*, *D*, and *v* at each vertical until the ending stream edge is reached. FlowTracker and MF Pro meters also require the user to enter the data using a keypad.

6. Record the location and water depth (typically zero) of the ending edge.
7. Record the ending time and stage after completing the cross-section profile to determine if stage has increased or decreased during the measurement. If the stream stage changed, use the average of the two stages for the final stage number.

MBMG best practices for stream gaging include the following:

- Large cobbles on the channel bottom cause turbulence that may interfere with collecting reliable, representative velocity measurements. If conditions permit, safely walk and groom the cross-section area to improve the streambed; if cobbles exist at, or slightly upstream of, your cross-section, try to roll them downstream using your foot, past the cross-section. If working in a relatively shallow and warm stream, reach in and move them.
- Clear stream edges of debris at and upstream of the cross-section to reduce turbulence during edge measurements. You may also need to rake out any new vegetation growth since the last measurement. Rake out enough vegetation upstream of the profile to eliminate any influence of the vegetation, such as "velocity shadows" or dead spots (shadows and dead spots refer to areas where the stream velocity changes due to obstacles such as vegetation, boulders, or logs). If it is not possible to clear the vegetation, collect an additional velocity measurement within the vertical (e.g., use a two-point method even if the stream depth is less than 2.5 ft, or increase from two to three measurements in the vertical). Allow the stream several minutes to stabilize after making any changes to the streambed or banks.
- Once the process of measuring velocity has begun, do not move rocks, logs, or other obstructions as this may cause the velocity to change in an area of the stream where velocity has already been measured.
- Stand at least 1.5 ft downstream from the wading rod while making measurements (Rantz and others, 1982). Notice water stacking up against your legs and make sure the instrument is not within the influence. Simply adjusting your stance can help.
- Keep the rod vertical by checking the bubble level (if present) during measurement.
- Hold the sensor perpendicular to the tagline at all times, even if flow at some stations is not perpendicular to the tagline.
- Use a small, waterproof field book (such as Rite in the Rain®) to record *x, D*, and *v* values while wading the stream. These are easy to carry along with the meter and wading rod, and can survive a drop in the stream.
- In rare cases, the best available cross-section may have a large boulder situated upstream and nearby in the middle of the channel that produces a velocity shadow or dead spot. The velocity profile downstream, below the boulder, may be distorted at the 0.6x depth below the water surface. Ideally, you would use a 0.2/0.8 measurement near the boulder. If using a FlowTracker, the meter may notify the user of a "non-typical velocity profile" after collecting velocity measurements at 0.2 and 0.8. If the profile is deemed non-typical, the software will query the user about adding a 0.6 measurement. Accept this, because the notification confirms the distorted profile and the extra measurement benefits a complete record. After the additional 0.6 velocity measurement, the flow estimate of the vertical is complete. The average of a three-point velocity measurement is automatically calculated by the FlowTracker. This calculation must be performed by those using a Marsh-McBirney meter by taking the average of the 0.2 and 0.8 depths and then averaging that with the 0.6 depth velocity:

$$V = \frac{\left\{\left[\frac{(V_{0.2}+V_{0.8})}{2}\right]+V_{0.6}\right\}}{2},$$

where V is average velocity of the vertical; and $V_{0.x}$ is velocity measured at the 0.x depth.

- The 0.6 method is used for unobstructed flow in an open channel. Select the 0.2/0.8 method when you observe conditions likely to cause the velocity profile to deviate from "typical" conditions, where the average velocity occurs at 0.6 x depth from water surface.

9.5.5 Recording and Archiving Data

Record-keeping practices vary with instrumentation:

When using a Marsh-McBirney EVM, record data for each vertical in the field notes. Upon return to an office, use the MBMG discharge calculation spreadsheet developed specifically for the Marsh-McBirney (appendix 9.10.4) or an equivalent spreadsheet to process field measurements. This spreadsheet calculates flow for each vertical and sums all verticals for total discharge at the cross-section. It also reports percent of total flow for each vertical.

When using the MF Pro, record data in two ways. The instrument records data in real-time and calculates discharge at the end of the profile. After completing the cross-section, go through the "Discharge Summary" menu. Check to ensure that the depths were entered correctly and, by advancing to the station percentage bar graph, check for any vertical area discharges that exceed 10%. A red bar indicates that a station exceeds 10%. In this case, collect an additional vertical measurement along the tag line close to the station(s) indicated by the red bar. After the additional measurement(s), check again for stations that exceed 10%. If all stations are less than 10% of the total, record field notes for the cross-section. Include the discharge, number of stations, what control the staff gage is under, and any comments regarding the quality of the measurement. Once back in the office, download the MF Pro file to the appropriate network location.

When using the ADV or ADCP, record data in two ways. The instruments record in real-time and summarize data in a report generated using the instrument software. Critical data, including discharge (*Q*) and the discharge uncertainty estimate (section 9.7), should also be recorded in field notes at the site, at the time of data collection. If using the M9 ADCP, in addition to the average *Q*, coefficient of variation (COV), and standard deviation, record *Q* for each transect, and note which transects were used in the final average of *Q*. Once back in the office, download the data file to the appropriate network location.

Upload field measurements and velocity estimates in GWIC, including the data entry associated with the field visit (appendix 9.10.5).

- If a Marsh-McBirney EVM was used, scan and upload data in the field notes to GWIC. Include a screenshot or PDF of the completed MBMG discharge calculation spreadsheet (appendix 9.10.4.)
- If the MF Pro, ADV, or ADCP was used, scan and upload the summary report forms to the associated GWIC ID.

9.6 Calculations

Velocity measurements collected with the Marsh-McBirney should be used to calculate stream discharge with the mid-section discharge equation described in Hipolito and Loureiro (1988).

The basic equation for calculating discharge is:

$$Q = \Sigma\ (w_i D_i v_i),$$

where Q is total discharge; w_i is the section width using the mid-section method; D_i is the depth of water at vertical (at top-setting rod position on tagline); and v_i is average velocity of the current at the mid-section. For details, see Rantz and others (1982, page 81).

Velocity measured with the ADV provides the basis for stream discharge calculations performed by the instrument while the discharge measurement is collected; the instrument must be set on mid-section method. The ADCP uses a proprietary method developed by Sontek, wherein the entire area of the cross-section is dynamically gridded into cells with a velocity value. The cell size (or resolution) changes depending on the velocity:depth relationship. Velocities calculated for each cell are converted to volumes based on cell sizes of the final grid and are summed to reach a final discharge value.

9.7 Accuracy of Discharge Measurements

Accuracy is affected by the conditions in the measured section, type and condition of equipment used, spacing of verticals, changing stage during the measurement, obstacles, and the ability of the individual to apply best practices in making the measurements. Field staff should evaluate elements that affect accuracy at the time of measurement and record them in the field notes. For a full discussion of accuracy of discharge measurements, see Turnipseed and Sauer (2010, p. 79–80).

Qualitative ratings of accuracy (excellent, good, etc. as described below) are determined by field personnel immediately after completing measurements along a cross-section, using flow and channel characteristics of the measurement reach. It is understood that assessing influences that affect the quality of the measurement, such as shallow depths or the presence of cobbles, is at the discretion of the technician.

The discharge uncertainty estimate (FlowTracker only; USGS, 2013) is also recorded. Discharge uncertainty with the FlowTrackers may be characterized using one of two available methods for error calculation: ISO Standard 748, or the Statistical Uncertainty Calculation by the USGS. Record the error provided by the Statistical Uncertainty Calculation (USGS, Cohn and others, unpublished). The ISO uncertainty calculation is based on ISO Standard 748. It does not provide a reliable indicator of data quality; however, it provides a published reference for determining uncertainty. The Flowtracker2 applies the USGS statistical method (Cohn and others, 2013) and ISO 748. Again, use the USGS version. The USGS version is default on both FlowTracker devices.

The ratings scale varies from excellent to poor based on cross-section conditions, as described on the Surface-Water Site/Streamflow Field Sheet (appendix 9.10.2):

- Excellent: 2% error. Consistent stage during measurement, linear flow, even velocity across width of cross-section (no slow sections adjacent to fast sections). Streambed is even and consistent, smooth transition from shallow to deep—no sudden drops, no large boulders, no overhanging banks, no interference from vegetation. Depth is greater than 0.5 ft at every vertical. Velocity at each vertical is greater than 0.5 if using MF-Pro. Less than 5% of total is included in each vertical.
- Good: 5% error. Generally consistent flow, linear flow lines. Stage constant during measurement. Some faster and slower verticals, but no dramatic adjacent velocities. Good streambed: some changes in depth and drops but no large boulders. No overhanging banks, minimum interference from vegetation. Depth is greater than 0.5 ft at every vertical. At least 20 verticals measured with nearly 5% of flow in each.
- Fair: 8% error. Some, but not all, of the following: stage may be slowly rising or falling during measurement; some converging or diverging effects; minor turbulence; inconsistent streambed, some large rocks; overhanging banks; vegetation.
- Poor: Greater than 8% error. Numerous, and possibly all, of the following: stage may be slowly rising or falling during measurement; some converging or diverging effects; minor turbulence; inconsistent streambed, some large rocks; overhanging banks; vegetation; overbank conditions; multiple controls.

Duplicating velocity measurements along the same cross-section (that is, wading the stream twice in succession) can improve confidence levels. However, this requires additional time in the field and may not be required or warranted on all projects. Measuring a cross-section twice to assess and/or improve the data quality may be very important during seepage runs (chapter 10) in which the overall purpose of the discharge estimates is to identify losing and gaining sections of a stream or canal.

The software associated with the ADV and ADCP current meters provide an evaluation of the confidence in the data. However, these instruments cannot observe stream conditions; they report repeatability. A consistent error can be reported as high confidence. In addition to the repeatability reported by the instrument, field staff should apply their experience to assign an accuracy rating to the data collected along each transect and document it in the field form.

9.8 Summary

Typically, only one set of velocity measurements (one cross-section) is collected at a location during the site visit. Due to the cost associated with staff time and travel, measurements should be as high quality as possible. In summary, field staff should feel confident that the data were acquired with the safest, most accurate, defendable, and well-documented practices. Best practices include:

Complete a MBMG Surface-Water Site Inventory Sheet (appendix 9.10.1) for a new site or an MBMG Surface-Water Site/Streamflow Field Sheet (appendix 9.10.2) for an existing site.

1. Wear a personal flotation device as required

when working in, on, over, or near water.

2. Record time and stage after removing any debris from the staff gage.
3. Identify a cross-section that meets the criteria outlined in section 9.5.1, *Selecting a Cross-Section*, and record any exceptions on the field visit sheet.
4. Establish the tag line perpendicular to flow.
5. Groom cobbles, sticks, leaves, vegetation, etc., from the cross-section and edges as necessary.
6. Zero the Marsh-McBirney and MF Pro daily, if applicable (appendix 9.10.3).
7. Keep the current meter vertical and perpendicular to tape for all verticals.
8. Use a sample period of 40 s.
9. Stand downstream of the top-setting rod, at a distance that avoids influencing the velocity at the rod.
10. Use the two-point method where the stream depth >2.5 ft or where the assumption of average flow at 0.6 from surface may be invalid.
11. Measure velocity at the appropriate number of stations, typically >25. Exceptions apply when width <4 ft.
12. Record the time and stage upon completion of discharge measurement.
13. Record discharge and QAQC data from FlowTracker and discharge from the MF Pro in field visit sheet and field book.
14. Rate the qualitative accuracy of the discharge measurement (section 9.7) on the field visit sheet.
15. Collect water-chemistry parameters if appropriate, typically specific conductance and temperature at a minimum.

9.9 References

Caldwell, R.R., and Eddy-Miller, C.A., 2013, Groundwater and surface-water interaction within the upper Smith River Watershed, Montana 2006–2010: U.S. Geological Survey Scientific Investigations Report 2013–5051, 88 p., doi: http://dx.doi.org/10.3133/sir20135051.

Cohn, T., Kiang, J., and Mason, R., Jr., 2012, Estimating discharge measurement uncertainty using the interpolated variance: Journal of Hydraulic Engineering, v. 139, no. 5 (May 2013), doi: 10.1061/(ASCE)HY.1943-7900.0000695; USGS Publications Warehouse, http://pubs.er.usgs.gov/publication/70038087.

FlowTracker, Handheld ADV Technical Manual, July 2007, SonTek/YSI Inc., San Diego, Calif.

FlowTracker2 User's Manual, January 2019, SonTek-Xylem, San Diego, Calif.

Hipolito, J. N., and Louriero, J.M., 1988, Analysis of some velocity-area methods for calculating open channel flow: Hydrological Sciences Journal, v. 33, no. 3, p. 311–320, doi: 10.1080/02626668809491250.

Marsh-McBirney Inc., 1990, Flo-Mate Model 2000 portable flow meter instruction manual: Marsh-McBirney, Inc., Frederick, MD, rev. D, 11/00: 45.

Norberg, M.A., 2015, Standard operating procedure for wading discharge measurements and operating procedures for the SonTek® FlowTracker® Handheld ADV: Montana Department of Natural Resources and Conservation, Water Resources Division, Water Management Bureau, 24 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, v. 1: Measurement of stage and discharge; v. 2: Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, doi: https://doi.org/10.3133/wsp2175.

Sauer, V.B., 2002, Standards for the analysis and processing of surface-water data and information using electronic methods: U.S. Geological Survey Water-Resources Investigations Report 01–4044, p. 93.

Sauer, V.B., and Meyer, R.W., 1992, Determination of error in individual discharge measurements: U.S. Geological Survey Open-File Report 92–144.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p.

9.10 Appendices

Appendix 9.10.1 Surface-Water Site Inventory Sheet

ENTERED GWIC ☐ **SAMPLED**____________ ☐

SURFACE-WATER SITE INVENTORY SHEET

Date ________________
GWIC ID:_____________
Project Code(s)__________________________________

Water body Info

Site name____
Site Identifier____
Water body type (stream, lake, ditch, pond)_______________

Landowner access info

Name_______________________________________
Address______________________________________
Phone#______________________________________

LOCATION: T _____$^{N}_{S}$ R ______$^{E}_{W}$ S ______ Tract ___/___/___/___ Sequence ______________ Irreg. Sect? Y__N__
Latitude___________________Longitude________________________Geomethod________________ H Datum_______
County____________________ USGSMap7$^1/_2$'____________________________Altitude ___________ V Datum_______

SITE DESCRIPTION:____
____
____
____
____
____

DISCHARGE AND STAGE If discharge measurement is performed for site inventory, include surface-water field visit sheet with this inventory sheet
Time___________Discharge, cfs ___________ Stage, ft____________ method__________________________
Specific conductance__________________Temp _____________

Additional site details

STAFF INSTALLATION
Gage Range: ___________ ☐ Datalogger installed? Filename____
Serial #____________________ Type_________
Barologger : Type_____________File name ____ Serial #________________
location____

SURVEY
Key elevations: BM elevation____________ Top of staff elevation ____________ MP elevation @ 0.00'__________
Channel bottom elevation_______________ = ground surface. Point of Zero Flow (PZF) elevation ______________
Note: Report MP elevation at 0.00' for staff gage ranges of 3.33'- 6.66' and 6.66'-9.99' also.

Survey rod numbers: BM________ BM2________Top Staff gage ________ Channel bottom__________PZF________
Description of benchmark (BM) location(s) Include distance and compass reading from benchmark(s) to staff gage
____
____
____

Alternate measuring point MPa (i.e., top of bridge, top of culvert)
Distance from MPa to water surface___________ stage, ft (from staff above)________ difference (offset)__________
MPa description/location ____

M:\GWIP\Forms\Field work\Surface Water Site Inventory vJuly 2018.docx

SITE SKETCH MAP

Give directions to site. Show location of BM, staff gage, cross section, and any pertinent landmarks. Show control features if any (downstream riffle, island, large log jam, rock jam, diversion/check structure, etc.).

NOTES:____
____
____
____
____
____
____
____
____
____

SAMPLE: ☐ Standard (250 ml **RA** {H_2SO_4}, 250 ml **FU**, 500 ml **FA** {HNO_3}, 500 ml **RU**)

Other (nitrate only, tritium, radon, isotopes, etc.)____

Name____ **Agency** _____________________________

Appendix 9.10.2 Surface-Water Site/Streamflow Field Sheet

Surface-Water Site/Streamflow Field Sheet

SCANNED__________ ☐

for established sites

Date: ____________________________________ **Project:** ___________________________________

GWIC ID: _________________________________ **Agency:** ___________________________________

Site Name: _______________________________ **Personnel:** _________________________________

STREAMFLOW MEASUREMENT PROFILE DETAILS

Flow measurement profile location relative to staff gage or measuring point/land feature

____

Surface-Water Parameters

Time	Stage	Flow (cfs)	Temp	pH	SC	# of Stations/ Other

Method (Visual estimate, float and area, ADV, ADCP, other): ____________________________________

Flow Instrument: ___________________**Flow Output filename**: __________________________________

Start time __________________ **End time** ________________

Flow Rating: ☐ Excellent ☐ Good ☐ Fair ☐ Poor

See back of form

Comments on Flow Rating ____

Cross section condition: (sand and gravel, vegetated, boulder, overhung banks, ice, etc.)

____

Description of Current Control (section/channel/overbank): ______________________________________

See back of form

Description of flow condition (consistent for full width, fast and slow flow tubes, turbulence):

____

<u>WATER SAMPLE</u>: ☐ Standard Water-Quality ☐ nitrate only ☐ isotope ☐ other ___________

Collection time: _____________Collection details (grab, composite) _______________________________

Collection location (edge, mid-stream, bottom, integrated): ____________________________________

Method
(*if depth is < 2.51 ft measure velocity at 60%; > 2.5 ft measure velocity at 20% and 80%*)
Example instruments are shown.
ADV–Acoustic Doppler Velocity Meter (FlowTracker)
ADCP–Acoustic Doppler River Profiler (River Surveyor)
EM–Electro Magnetic Current Meter (Marsh-McBirney)
VACM–Vertical Axis Current Meter (ie, Price AA, Pygmy)
Estimated
Float and stop watch
Gaging Station Rating Curve (include operating agency)
Flume
Weir

Description of Control (*The "control" of a stream refers to the nature of the channel downstream from the measuring section which determines the stage–discharge relation.*)
Section–The channel width is a smaller distance downstream, such as at a riffle, bridge, or culvert, limiting outflow from the measured cross-section.

Channel–The roughness and geometry of the channel is consistent far enough below that the channel itself controls the stage at the measured flow.

Overbank–In flooding conditions, both the channel and the overbank conditions are the control.

Artificial–Intentional flow-control structure such as a weir plate.

Flow Rating *(based on cross-section conditions)*
Excellent: 2% error. Consistent stage during measurement, linear flow, even velocity across width of cross-section (no slow sections adjacent to fast sections). Streambed is even and consistent, smooth transition from shallow to deep—no sudden drops, no large boulders, no overhanging banks, no interference from vegetation. Depth is greater than 0.5 ft at every vertical. Velocity at each vertical is greater than 0.5 if using MF-Pro. Less than 5% of total is included in each vertical.

Good: 5% error. Generally consistent flow, linear flow lines. Stage constant during measurement. Some faster and slower verticals, but no dramatic adjacent velocities. Good streambed, some changes in depth and drops but no large boulders. No overhanging banks, minimum interference from vegetation. Depth is greater than 0.5 ft at every vertical. At least 20 verticals measured with nearly 5% of flow in each.

Fair: 8% error. Some, but not all of the following: Stage may be slowly rising or falling during measurement. Some converging or diverging effects. Minor turbulence. Inconsistent streambed, some large rocks. Overhanging banks. Vegetation.

Poor: Great than 8% error. Numerous and maybe all of the following: Stage may be slowly rising or falling during measurement. Some converging or diverging effects. Minor turbulence. Inconsistent streambed, some large rocks. Overhanging banks. Vegetation. Overbank conditions. Multiple controls.

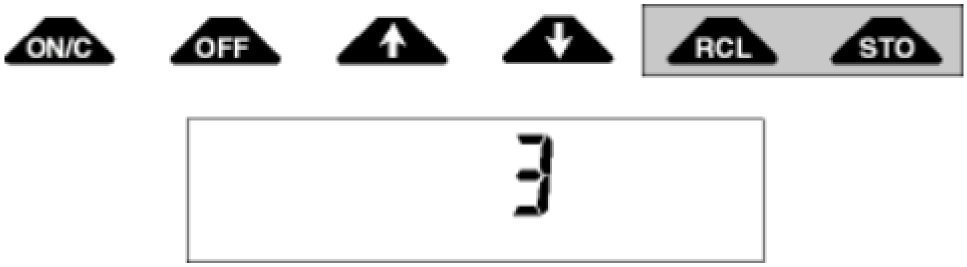
Appendix 9.10.3 Zero Adjust the Marsh-McBirney Flo-Mate 2000

Zero Check

First clean the sensor (Page 12) because a thin film of oil on the electrodes can cause noisy readings. Then place the sensor in a five gallon plastic bucket of water. Keep it at least three inches away from the sides and bottom of the bucket. To make sure the water is not moving, wait 10 or 15 minutes after you have positioned the sensor before taking any zero readings. Use a filter value of 5 seconds. Zero stability is ± 0.05 ft/sec.

Zero Adjust

- Position the sensor as described in the zero check procedure.
- To initiate the zero start sequence, press the STO and RCL keys at the same time. You will see the number 3 on the display.
- Decrement to zero with the ↓ key.



- The number 32 will be displayed.
- The unit will decrement itself to zero and turn off. The unit is now zeroed.

Appendix 9.10.4 MBMG Discharge Calculation Spreadsheet

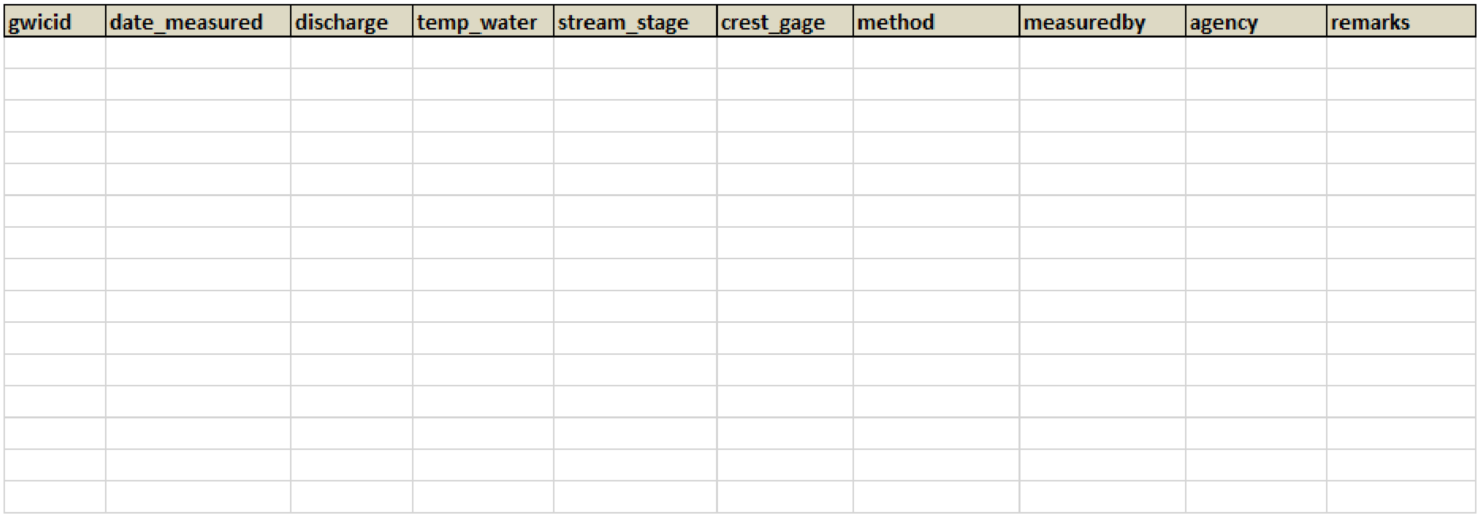
Stream Gaging Station Name:	Webfoot - Upgradient pump house
Stream Gaging Station ID:	Measurement 1
Date:	
Start Time:	
Stop Time:	
Staff Gage:	

FLOW (cfs):	**=SUM(D15:D58)**	**=B7*7.48*60**	gpm

Formulas from Hipolito and Loureiro 1988

tape	depth	velocity	flow	% total
			=(A15-A14)/2*(B15*C15+B14*C14)	=(D15/B$7*100)
			=(A16-A15)/2*(B16*C16+B15*C15)	=(D16/B$7*100)
			=(A17-A16)/2*(B17*C17+B16*C16)	=(D17/B$7*100)
			=(A18-A17)/2*(B18*C18+B17*C17)	=(D18/B$7*100)
			=(A19-A18)/2*(B19*C19+B18*C18)	=(D19/B$7*100)
			=(A20-A19)/2*(B20*C20+B19*C19)	=(D20/B$7*100)
			=(A21-A20)/2*(B21*C21+B20*C20)	=(D21/B$7*100)
			=(A22-A21)/2*(B22*C22+B21*C21)	=(D22/B$7*100)
			=(A23-A22)/2*(B23*C23+B22*C22)	=(D23/B$7*100)
			=(A24-A23)/2*(B24*C24+B23*C23)	=(D24/B$7*100)
			=(A25-A24)/2*(B25*C25+B24*C24)	=(D25/B$7*100)
			=(A26-A25)/2*(B26*C26+B25*C25)	=(D26/B$7*100)
			=(A27-A26)/2*(B27*C27+B26*C26)	=(D27/B$7*100)
			=(A28-A27)/2*(B28*C28+B27*C27)	=(D28/B$7*100)
			=(A29-A28)/2*(B29*C29+B28*C28)	=(D29/B$7*100)
			=(A30-A29)/2*(B30*C30+B29*C29)	=(D30/B$7*100)
			=(A31-A30)/2*(B31*C31+B30*C30)	=(D31/B$7*100)
			=(A32-A31)/2*(B32*C32+B31*C31)	=(D32/B$7*100)
			=(A33-A32)/2*(B33*C33+B32*C32)	=(D33/B$7*100)
			=(A34-A33)/2*(B34*C34+B33*C33)	=(D34/B$7*100)
			=(A35-A34)/2*(B35*C35+B34*C34)	=(D35/B$7*100)
			=(A36-A35)/2*(B36*C36+B35*C35)	=(D36/B$7*100)
			=(A37-A36)/2*(B37*C37+B36*C36)	=(D37/B$7*100)
			=(A38-A37)/2*(B38*C38+B37*C37)	=(D38/B$7*100)
			=(A39-A38)/2*(B39*C39+B38*C38)	=(D39/B$7*100)
			=(A40-A39)/2*(B40*C40+B39*C39)	=(D40/B$7*100)
			=(A41-A40)/2*(B41*C41+B40*C40)	=(D41/B$7*100)
			=(A42-A41)/2*(B42*C42+B41*C41)	=(D42/B$7*100)

Appendix 9.10.5 GWIC Upload Format



gwicid	date_measured	discharge	temp_water	stream_stage	crest_gage	method	measuredby	agency	remarks

Definitions

gwicid	Record identifier within the GWIC database. Required for ALL records.
date measured	Date (and time) of recorded measurement.
discharge	Recorded/measured stream discharge reported in cubic feet per second (cfs).
temp water	Water temperature (deg C) recorded at time of measurement. Used for transducer measurements.
stream stage	Stage measurement recorded at the time of measurement.
crest_gage	Crest gage measurement recorded at the time of measurement.
method	Method used to determine static water level.
measured by	Name of person responsible for taking measurements. Enter in LAST, FIRST format.
agency	Name of agency/entity responsible for taking measurements.
remarks	Comments regarding measurement conditions.

10.0 SYNOPTIC MEASUREMENTS OF STREAMFLOW

10.1 Purpose

This document presents guidelines and standard procedures for synoptic discharge measurements in streams and irrigation canals. Also referred to as a “seepage run” or “gain/loss survey,” synoptic measurements along a stream reach or irrigation canal are typically performed to measure groundwater gains or losses to the surface-water body. The difference in flow between two measurement sites is used to calculate the loss or gain. Ideally, streamflow would be measured simultaneously at numerous sites along the reach of interest. In practice, seepage runs are completed during relatively short time periods, typically within a day or two, so that hydrologic conditions remain relatively constant throughout the period of measurement.

This document addresses logistical and technical considerations specific to synoptic measurements. Individual measurements of streamflow made within a synoptic run should follow the procedures for measuring streamflow described in chapter 9 of this report.

10.2 Health and Safety

Personal and team safety are of paramount importance in all field activities, and safety precautions will be exercised at all times by MBMG staff. Surface-water sampling and gaging usually involve wading through streams, rivers, and canals or riding in a boat, and safety precautions around water are a priority for staff.

Staff are required to wear personal flotation devices (PFDs, or life jackets) at all times when working in, on, over, or near water. This includes while carrying out activities in, on, over, or near a cableway, bridge, water control structure (a dam), on ice, in a boat, or wading in streams or lakes. Staff are required to wear high-visibility vests in addition to PFDs when working on bridges. Working on ice requires experience, training, and knowledge of the specific water body. Staff must consult with their program area manager about their intent to work in iced-over conditions prior to any on-ice activity. Such work should never be conducted alone.

10.3 Planning the Synoptic Run

Determine the purpose of the synoptic run and the accuracy of the flow data necessary to meet the purpose.

Choose a synoptic run coordinator if more than one staff person is involved. The coordinator generally:

- Understands the purpose of the synoptic run and measurement accuracy needed
- Coordinates staff efforts, assigns staff to specific sites along the run
- Ensures all data are collected as planned and data quality objectives are met
- Provides a point of contact should any issues arise
- Ensures all staff involved in the synoptic run have contact information (i.e., cell phone numbers) of those involved

10.4 Minimize Delays

Minimize potential delays during the synoptic run by designing an efficient plan before the event. Good planning supports a synoptic run that optimizes data quality. Minimizing delays decreases the influence of weather, reduces the potential for change in hydrologic conditions, and minimizes inconvenience to landowners.

10.5 Site Selection

Determine the number and location of measuring sites including any inflows/outflows (e.g., tributaries, springs, irrigation diversions) within the reach. Use the following list to identify good measurement sites; these characteristics will help to reduce measurement error.

Preferred measurement sites include those where:

- The measurement can be rated as “excellent” (chapter 9, section 9.7).
- The distance between measurement sites is long, ideally a mile or more, to increase likelihood of a measurable change in flow.
- There are few to no tributary inflows or surface-water diversions between measurement sites. Any inflows and withdrawals must also be measured. Each additional measurement requires

more time and adds to the error in the gains or losses calculated.

Although conditions may change during the synoptic run, check all sites in advance:

- Know the access route and specific locations of each measurement site.
- Identify where you will set the tagline at each site.
- Clear the cross-section of vegetation or debris as needed.
- Examine surface-water depth and determine if 0.6 or 0.2/0.8 measurements are appropriate (chapter 9, section 9.5); this will factor into the approximate time required to measure discharge at each site.
- Estimate the number of velocity measurements for the cross-section at each measurement site.

10.6 Landowner Considerations

Check with the landowners well in advance of a synoptic run to coordinate stream measurements with planned irrigation diversions. Consider the following issues:

- Obtain landowner/ditch rider permission for site access.
- Minimize the number of diversions (outflow) from the stream/canal by requesting landowners or the ditch rider to shut down head gates.
- Discuss dates and times with landowners/ditch riders during which they could shut down head gates; ultimately arrive at a specific date for the synoptic run.
- If landowners/ditch riders cannot shut down head gates during the synoptic run, request that the head gates are not adjusted during the synoptic run. This is critical to the accuracy of the effort.
- Plan the work carefully to avoid scheduling changes if landowner/ditch riders are altering their irrigation schedule to accommodate the work.

If irrigation practices change flow in the canal or stream beyond what you can account for (by estimating or measuring), the results of the synoptic run may not be sufficiently accurate to meet the project goals. Consider rescheduling the synoptic run or eliminating certain reaches, rather than spending time collecting unusable data.

10.7 Other Considerations

Check the weather. Excessive precipitation/snowmelt can affect runoff and other sources of inflow to streams, which may influence your results.

10.8 Personnel and Equipment

10.8.1 Personnel

Once you determine how many sites are involved in the synoptic run, and the complexity of the sites (size of channels, access route, etc.), identify how many staff are needed to perform the synoptic run in the time allotted.

Make sure teams are trained on the equipment, stream gaging protocol, time constraints, any landowner considerations, and site access routes. Personnel new to measuring discharge can accompany the team as a note-taker or observer but should not be assigned primary responsibility for collecting measurements.

10.8.2 Equipment

Determine the best type of equipment based on expected flow and depth of the channel. Teams must collect comparable measurements to result in a useful synoptic run. If there is sufficient time, test measurement devices against each other to determine repeatability of measurements (e.g., measure flow at the same location using a FlowTracker and an MF Pro, ideally at the same time).

Choose an appropriate instrument(s) based on anticipated conditions (chapter 9, table 9.1). To the extent possible, avoid mixing manufacturers and models of equipment.

In small streams or canals, consider using portable Parshall flumes or v-notch weirs to measure flow. These should be installed ahead of time so that during the synoptic run the hydrologist reads the stage and determines flow using the stage–discharge equation developed for the weir/flume. Pay particular attention to sealing the wing walls and bottom, and confirm that water is free-falling at the outflow. Following installation, collect repeated measurements to ensure that the stage has fully stabilized.

10.9 Accuracy

Accurate discharge measurements are particularly important to seepage runs because changes in flow along a reach may be within or near the margin of error of discharge measurements. The quality and accuracy of the measurements can be affected by the technical ability of the field staff, site selection, and the equipment used.

Although time consuming, one way to verify the accuracy of a discharge measurement is to measure the cross-section in its entirety more than once. This can help identify measurements that may have been in error. Another way to improve the overall accuracy of a discharge measurement is to increase the number of measurements along the cross-section. Collecting more measurements along the cross-section results in applying the velocity measured at a point to a smaller section of the stream. The percent of discharge measured at each station is reduced relative to the total discharge. Surface-water discharge measurements that are rated “poor” (chapter 9, section 9.7) are unlikely to support identifying areas of gain or loss.

The repeatability of discharge measurements is important to the success of the overall run. Sources of error in synoptic runs include both the repeatability and accuracy of measurements, as discussed above, and changes in flow along portions of the stream that may occur during the synoptic run. The latter source of error underlies efforts to complete a synoptic run in a short time frame.

10.9.1 Precision between Measurements

The difference between inflow and outflow measurements is the basis for interpreting synoptic run data. Duplicate or replicate discharge measurements can establish the overall precision achieved during a synoptic run that relies on multiple instruments and personnel. Duplicate measurements are those made by multiple teams as they measure the same cross-section in succession. Ideally, teams make duplicate measurements the day before the seepage run. If your plan for a synoptic run calls for less than 2% error to estimate gains and losses, each team reports “excellent” measurements (2%) and yet the teams’ discharge estimates at the cross-section are not within 2%, the results of the run will not be useful (that is, gain or loss calculated along the reach is less than the measurement error). If there are large errors in these practice measurements, look for potential problems, make corrections, and repeat the test measurements. Common issues involve differences between instruments and differences in methods used by staff members.

When duplicate measurements are not practical, replicate measurements can help support increasing measurement accuracy and developing consistency between teams. Replicate discharge measurements are collected by personnel along different cross-sections located only a few to tens of feet apart. Replicate measurements are:

- Performed by teams at the same time to ensure similar conditions,
- Performed along closely spaced cross-sections,
- Made with the same instruments each team will use during the synoptic run, and
- Performed even if only one person is involved in the synoptic run; that is, the individual should ensure that their measurements are repeatable.

If possible, improve accuracy during a synoptic run by using a single instrument and having only one member of the team collect measurements. Other members of the team can set taglines and take notes. If it is not possible to have one hydrologist collect all the velocity measurements, split the stream or canal into as few measurement sections as possible. A single instrument and hydrologist should complete all measurements within a designated section of the reach (do not “leap frog” instruments within a particular section). At the point where the sections meet, have both teams collect replicate measurements at the same time.

10.9.2 Changes in Flow

Monitor stage at the top and bottom (inflow and outflow) of the overall reach to determine if the inflow changes, or if the relationship between inflow and outflow changes, during the run. This is typically accomplished by installing staff gages with transducers at the top and bottom of the run, the day before the synoptic run. Transducers are often set to record at 15-min intervals, although this can vary depending on the number of measurement sites and the distances between them. If it is not possible to install transducers, manually record the stage (it could be from a fixed point if there is no staff gage) at the top and bottom of the run, and before, during, and after the synoptic run. Account for any changes to the inflow rate during the run when interpreting results.

10.10 Performing the Synoptic Run and Data Collection

Teams should communicate with the synoptic run coordinator if they are falling behind, and/or need help.

10.11 Data Collection

Download the transducers (if installed) after the synoptic run or manually record stage before, during (when possible), and after the synoptic run.

- At each measurement site, record:
- The time and location
- Personnel
- Equipment used (including serial number if there are multiple meters of the same model),
- Weather
- Note any irregularities in flow, obstructions, inflows or diversions, and any other factor that may influence interpretation of the data. Take pictures and/or visually estimate flow rates of inflows or diversions if they cannot be measured.

After completing assigned discharge measurements and prior to leaving the area, check with the coordinator to determine if measurement help is needed elsewhere.

10.12 Post Synoptic Run

Compile field notes, download transducers, and perform any calculations as soon as possible following the synoptic run.

10.13 Calculations

Complete discharge calculations for each measurement site in accordance with MBMG guidance for streamflow measurements (chapter 9, section 9.3.5) and USGS protocols (Rantz and others, 1982; Turnipseed and Sauer, 2010). Gain and loss calculations must include the measurement accuracy and error associated with the calculated gain or loss (section 10.14, below).

10.14 Inflow Changes during Synoptic Run

If a change in flow rate, or stage, was observed at the inflow site, consider how it affects the data. Changes that are within the margin of error can be documented and discussed in the project report, but may not factor into the computations.

First determine if the change arrived at downstream sites before or after discharge measurements. Average the stream velocities measured for each reach (from the inflow site to each additional site). Divide the stream distance by the velocity to estimate the time lag from the inflow point to each successive site. For example, if the average velocity is 0.5 cfs and it is 1/2 mi to the next downstream site, the change in flow will arrive approximately 5,280 s or roughly 1.75 h later. In that case, you may have stayed ahead of the change in inflow and do not need to allow for the change.

If calculations suggest that the change in flow rate affected some of the measurements, and that change is greater than the margin of error, there are two ways to proceed. You may estimate an adjusted inflow rate based on the change in stage, or repeat the survey another day.

Performing gain/loss calculations between measurement sites will decrease the likelihood of inaccuracies due to changing inflow conditions. Calculating each site as gain or loss from the original discharge measurement at the uppermost inflow site increases the chance for errors due to changes in inflow.

10.15 Gain/Loss Calculation

Gain to or loss from the stream/canal can be reported as a flow rate [for example, cubic feet per second (cfs)] or as a flow rate over a distance (for example, cubic feet per second per mile (cfs/mi)). The flow rate per distance along each subreach is:

$$\text{flow rate/distance} = [(\sum \text{Inflow}_{\text{Reach } x}) - (\sum \text{Outflow}_{\text{Reach } x})]/(\text{distance between sites}_{\text{Reach } x}),$$

where flow rate is expressed as a volume per time (for example, cubic feet/second); $\sum \text{Inflow}_{\text{Reach } x}$ consists of the flow measured at the upper measurement site, and contributions from tributaries, return flows, or other additions to flow; and $\sum \text{Outflow}_{\text{Reach } x}$ is the streamflow at the lower measurement site and withdrawals from streamflow, such as diversions.

The calculation is performed for each subreach within the length of the stream/canal of interest (Inflow site to Site 2; Site 2 to Site 3; Site 3 to Site 4; etc. to Outflow site) and for the entire synoptic run (Inflow to Outflow).

10.16 Accuracy and Margin of Error

The discharge at each site is the measured discharge plus or minus the error. Determine the data quality and associated error for each discharge measurement (section 9.3.6 of chapter 9).

Gain or loss can only be identified along reaches where the difference between the two measurements exceeds the range in error-adjusted measurements. For example, consider a case where the measured inflow of 100 cfs has a margin of error of 5%. Inflow is therefore within 95 to 105 cfs. If the associated outflow measurement is 95 cfs with a 5% margin of error, we regard the outflow as within the range of 90.3 to 99.8 cfs. Because the range of inflow and range of outflow overlap, we would conclude that gain or loss along the reach, if any, is less then we can detect (Weight, 2019).

In cases where the measurements along a reach confirm a gain or loss, standard practice for synoptic runs includes estimating the error associated with that gain or loss. The approach described here, based on error propagation, assumes that the errors associated with the measurements are uncorrelated and random (Harvard University, 2007). In this case, the error in the estimated gain or loss factors in the error associated with each discharge measurement. This overall error is taken to be the square root of the sum of squares of each error:

A gain or loss over a reach, *V*, is the sum of other inflow and outflow velocities:

$$V = v_1 + v_2 + v_3 \dots - v_4 - v_5,$$

and each flow rate has an associated uncertainty, ∂, then the uncertainty around *V* is:

$$\partial V = \sqrt{(\partial v_1)^2 + (\partial v_2)^2 + (\partial v_3)^2} \dots$$

Table 10.1 provides an example using two sites (A, upgradient and B, downgradient) with a diversion located between them. To calculate the error associated with a gain or loss within a reach:

1. Calculate the error for each measurement (±5 percent measurement error in example);
2. Calculate the sum of the squares of all measurement errors; then
3. The error of the gain or loss calculated for that reach is the square root of the sum of squares.

The gain or loss in streamflow is calculated as the difference in discharge between B and A, minus the discharge from the stream at the diversion. In this example, the measurements show a gaining reach of the stream, of 50 cfs. The error associated with this estimate is the square root of the sum of squares:

$$\sqrt{292.13} = 17 \text{ cfs.}$$

The gain for this reach is reported as within 33 to 67 cfs.

10.17 Interpretation and Presentation of Data

Synoptic run data can be presented as text in a report, a table, or a graph. At a minimum, present all the inflows and outflows within the synoptic run and include the measurement error.

A graph of streamflow rates against distance downstream from the inflow site illustrates gain and loss. This may be done as a point graph, or, to show the margin of error, a box-and-whisker plot. Interpret gains and losses with respect to changes in geology or soils, water table, and land uses, as appropriate.

Table 10.1. Error calculation associated with an estimate of stream gain or loss.

	Velocity (cfs)	Measurement Error (assume ±5%, cfs)	Square of the Measurement Error
Site A	200	10	100
Diversion	25	1.3	1.69
Site B	275	13.8	190.44
	Gain/Loss: 50 cfs		**Sum of squares: 292.13**

10.18 References

Harvard University, 2007, A summary of error propagation, p. 2, available at http://ipl.physics.harvard.edu/wp-uploads/2013/03/PS3_Error_Propagation_sp13.pdf [Accessed June 16, 2021].

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, v. 1; Measurement of stage and discharge, v. 2, Computation of Discharge: U.S. Geological Survey Water-Supply Paper 2175.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p.

Weight, W.D., 2019, Practical hydrogeology: Principles and field applications, 3rd ed.: New York, McGraw-Hill Education, 777 p.

11.0 CONDUCTING AND REPORTING A CONSTANT-DISCHARGE AQUIFER TEST

11.1 Purpose and Scope

This document establishes a set of procedures for conducting an aquifer test to generate data useful to estimate aquifer properties such as transmissivity (*T*), hydrologic conductivity (*K*), storativity (*S*), and anisotropy. Planning and conducting aquifer tests and data processing are addressed. However, interpretation of aquifer test data requires training in the principles of well hydraulics. Aquifer test data analysis is not well suited to a set of standard procedures. Appendix 11.9.1 provides some general considerations and outlines a few methods that MBMG hydrogeologists have found useful in interpreting test data.

11.2 Introduction

This SOP reflects aquifer test theory under ideal conditions. Field conditions often fall outside of the ideal, requiring personnel to respond to situations that can develop throughout the test period. Fluctuating discharge rates, generator failure, or excessive drawdown in the pumping well are examples of conditions that may necessitate deviations from this SOP. Field staff are encouraged to compile extensive field notes before, during, and after the test. Such notes will support accurate reporting of the test and data collection methods under conditions that depart from these recommended procedures.

A primary goal of an aquifer test is to collect data that sufficiently meet the assumptions of the analytical method that will be applied to the test results. Generally meeting the assumptions of the method supports developing reasonable estimates of aquifer properties. Thus, consider these methods and their associated assumptions while designing and planning an aquifer test.

11.3 Site Selection

An aquifer test can be conducted at any location where there is a well. However, the following conditions are strongly preferred:

- Well completion details (casing depth, screened interval, etc.) are known.
- Geologic and hydrogeologic characteristics are known to some extent (lithology, aquifer thickness, hydrologic boundaries, etc.).
- Observation wells are located at appropriate distances and depths from the pumping well so that they fall within the radius of influence. For planning purposes, assume that a minimum drawdown of approximately 0.25 ft or more is needed to ensure a measurable response.
- Stresses (such as nearby pumping) that may affect water levels during the test are not present or can be minimized or eliminated during the test.

11.4 Apparatus and Materials

- Water-level indicator (also referred to as “e-tape” or “sounder”); preferably one dedicated indicator for the pumping well and each observation well; two indicators at a minimum—one for the pumping well and one for observation wells
- Spare batteries for monitoring equipment
- Pressure transducers with data loggers (referred to as “transducers” throughout this document)
    - Direct-read, vented transducers are preferred so that water levels can be checked during the test without disturbing the transducer
    - If non-vented (absolute) transducers are used, a transducer will be required to monitor barometric pressure (e.g., a Barologger)
- Attachment hardware and non-stretch cord, or other means, to suspend transducers in wells
- Field computer
    - Spreadsheet program (i.e., Excel)
    - Software and cables for programming and downloading transducers
    - Power cord and power supply (inverter)
- Toolbox with tools necessary to access wells, mount and install transducers, and repair and adjust other equipment
- Waterproof pens and “sharpies”
- Field book
- Pump
- Control valve (installed downstream of flow meter—preferably a gate valve) unless some other means to control pumping rate is available (e.g., a variable-frequency drive, VFD)
- Discharge line of sufficient length to discharge pumped water out of the site’s recharge area

- Generator
- Generator fuel
- Flow meter (preferably a meter that displays flow rate and records cumulative flow)
    - An orifice weir and piezometer tube may also be helpful for monitoring flow (https://pubs.usgs.gov/tm/1a1/pdf/GWPD10.pdf). The piezometer tube is easily viewed from around the worksite and makes it easy to see changes in flow.
    - Flow may also be monitored and recorded with a flume and stage recorder.
- Bucket and stopwatch for manually measuring flow rate, if practical given pumping rate

11.5 Pre-Test Procedures

11.5.1 Pre-Test Office Procedures

- Develop a site hydrogeologic conceptual model, based on site reconnaissance, well logs, and area geology. This will aid in selection of appropriate aquifer test analysis method(s).
- Determine if the pumping and observation wells are completed in the same aquifer, using well logs or other available information. This will aid in the interpretation of the drawdown data from each location.
- Determine the approximate duration of the constant-rate test based on estimated aquifer properties. Longer tests are preferred for several reasons. They typically result in greater drawdown and stress a larger area of the aquifer. This is more likely to produce a response to pumping that averages across heterogeneities within the aquifer. Longer tests may also yield more information about hydraulic boundaries, such as streams that recharge the aquifer or effects of adjacent aquitards. While 72-h aquifer tests are common, each test should be planned by considering the site conceptual model and the specific questions of interest.
- Calculate the maximum allowable pumping rate based on the well construction. This rate will only be achievable if the aquifer is sufficiently productive. Using available well completion details, determine the length of screen and the slot size. Calculate the maximum pumping rate that can be used without causing the entrance velocity to exceed 0.1 ft/s (Heath, 1983, p. 57; Driscoll, 1986, appendix 12A and appendix 13I). A low entrance velocity minimizes turbulent flow through the screen.
    - Example calculation of a maximum pumping rate to maintain an entrance velocity <0.1 ft/s, for a 20-ft length of 4-in 20 slot screen:

      4-in, 20 slot = 0.30 ft^2/ft of screen length (table 2 of Heath, 1983)

      20 ft x 0.30 ft^2/ft = 6.0 ft2

      0.1 ft/s x 6.0 ft^2 = 0.6 cfs

      0.6 cfs x 448.8 gpm/cfs = 269 gpm
- Calculate the expected drawdown in the pumping and observation wells, assuming a likely test pumping rate. Use the Theis equation and estimated aquifer properties to (1) determine the size of the pump needed for the aquifer test to ensure a measurable response at the observation wells and (2) inform the selection of pumping rates for the step-drawdown test.
- Determine the pumping rates for evaluation during a step-drawdown test through consideration of the reported well yield and the maximum allowable pumping rate.
- If pumped water will be discharged into waters of the State (a stream, for example), check with the Water Protection Bureau, Montana Department of Environmental Quality. Unaltered groundwater may be discharged to surface water without a permit as long as it does not contain industrial waste, sewage, or other wastes and does not cause the receiving water to exceed any applicable standards.
- Organize field staff for the test. More than one technician onsite is recommended, particularly during the first 2 h after the start of pumping, and about 2 h after the pump is shut off.
- Check performance and consistency of instruments:
    - Synchronize all transducers with the field computer that will be used for the test. Ensure that at least two watches for field staff use are also synchronized with the laptop.
    - If possible, test the transducers in a bucket of water by starting them dry and then adding water to a recorded level.

  - Test the water-level indicator in a bucket of water.
  - The use of only one field computer is recommended to download data in the field, to avoid confusing or losing data files.
  - Calibrate all meters if measuring water-quality parameters of the discharge water (dissolved oxygen, specific conductance, pH, etc.; see section 5).

11.5.2 Pre-Test Field Procedures

- Measure water levels in pumping and observation wells (table 11.1). Always use the same water-level indicator at each well to avoid inaccuracies introduced by varying the measuring device.
  - Ensure that each well has a clearly marked measuring point.
  - Determine antecedent water-level trends by measuring water levels in the pumping and observation wells. At a minimum, this monitoring should extend for the same duration as the pumping portion of the aquifer test. Ideally, monitor antecedent water levels for at least a week before the test. This can be accomplished by the use of transducers, typically programmed for hourly readings. Additional rounds of manual water-level readings should be taken as frequently as practical during this pre-test period.
  - Record the date and time for each manual water-level measurement. We recommend using 24-h time notation to avoid confusion. During the beginning of the aquifer test and immediately after pumping has ceased, record seconds in addition to minutes and hours.

Table 11.1. Times to collect manual water-level readings while conducting an aquifer test (modified from ASTM 2008; D4050-96).

- Pre-test (ideally 1 week before the step test)
  - Upon arriving at site (all wells) before any other work is done
  - In pumping well after pump and stilling well are installed
  - Before setting transducers (all wells)
  - Before leaving site (all wells)
  - When practical before the step test
- Step Test (at least 1 day before constant-rate test)
  - Upon arriving at site (all wells) before any other work is done
  - Before starting the pump
    - Collect at least 3 rounds
  - For each step
    - Pumping well
      - 0–5 min @ 30-s intervals
      - >5 min @ 5-min intervals
    - Observation wells @ 5-min intervals
  - After pump is off = 5-min intervals for 30 min
  - Before leaving the site (all wells)
  - When practical before the constant rate test
- Constant-Rate Test
  - Upon arriving at site (all wells) before any other work is done
  - Before starting the pump
    - Collect at least 3 rounds
  - During the test—see table 11.3
  - After pump is off for 30 min—see table 11.3
  - Before leaving the site (all wells)
  - When practical during recovery
  - Before removing transducers at the end of recovery

- Install the pump, if there is not one already in the pumping well.
  - Install a check-valve in the discharge line, just above the pump, to prevent discharge-line water from flowing back into the well after pump shut off (backflow into the well negatively affects measuring water-level recovery following the aquifer test).
  - Install the pump above the screen, typically at least 5 ft above it.
  - If possible, install a drop tube (or stilling well) within the pumping well to avoid tangling pump wires, transducer cables, and water-level indicator. The drop tube should extend to just above the pump. If the discharge line is large, there may not be enough room in the well casing to accommodate a drop tube. Ideally, the drop tube will:
    - be large enough to accommodate the transducer and water-level indicator;
    - have an open bottom and/or slotted sides;
    - have an obstruction at the bottom (e.g., a bolt or drilled cap) to prevent the transducer from falling out if dropped;
    - be easily accessible at the surface; and
    - be marked with a measuring point at the top that is referenced to the well's designated measuring point.
  - Use a water-level indicator to obtain readings in the drop tube before the transducer is installed. Select a transducer with a depth rating appropriate for the anticipated conditions. Program the transducer to collect readings each minute and install it below the depth of maximum anticipated drawdown.
  - Some transducers can be programmed to record pressures on a log time interval. In theory, this optimizes aquifer test data collection, but the exact time that pumping will start must be known in advance. In practice, the test start time is difficult to predict, and often changes, due to logistical challenges. Logging at 1-min intervals provides sufficient early time data for analysis, and modern transducers have sufficient memory to collect at this rate for weeks at a time. Any data that exceed that needed for test analysis can be removed in post-processing.
- Pump discharge and flow meters
  - Plumb the discharge water through the flow meter, the control valve, and then the discharge line. The flow meter may need to be installed in a specified length of a level discharge pipe. The control valve will be used to control the pump flow rate unless some other means of control is available, such as a VFD.
  - Route the discharge line away from the recharge area of the site and observation wells, to prevent the pumped water from recharging the aquifer.
  - If practical, place an orifice weir or flume at the end of the discharge line to provide an independent record of the flow rate.
  - If practical, collect estimates of the flow rate using a bucket and stopwatch to verify flow meter readings.
  - Implement erosion control measures if needed at the discharge point.
- Test the pump following installation by running it for a short time to ensure that it works and the rotation is set up correctly. If the pump is installed by contractors, test the pump and make sure the flow meter is working correctly before the contractors leave the site. If possible, test the pump with the same power supply (e.g., generator) that will be used for the aquifer test.

11.5.3 Determining an Appropriate Pumping Rate

A step-test is typically conducted before the constant-rate test to determine a pumping rate that can be sustained for the duration of the constant-rate aquifer test. During the step-test, the initial pumping rate is relatively low and is subsequently increased by "steps" to higher flow rates. Each step is typically held for 1 h. Include a minimum of three different pumping rates in the step-test. Increase the pumping rate to the next step if the water level in the pumping well stabilizes. If water levels continue to decline through the hour-long step, a lower pumping rate may be needed for the constant-rate aquifer test. For example, a step-test at a well that reportedly produces 40 gpm would start at 10 gpm for an hour, step up to 20 gpm for the second hour, step up to 30 gpm for an hour, and end with pumping at 40 gpm for an hour.

Before starting the step-test:

- Measure water levels in all wells using a water-level indicator;
- Download transducers, reprogram for readings at 1-min intervals, and reinstall them; and
- Manually measure all water levels a few more times.

During the step-test:

- Monitor discharge rates and manually measure water levels in the pumping and observation wells, frequently at the start of each step, and less often as water levels stabilize (table 11.1).
- Graph water levels (on graph paper or the field computer) during the test to visualize drawdown. Be prepared to modify the planned steps based on these observations.
- Maintain the water level in the pumping well at least 5 ft above the pump and do not allow the pumping rate to exceed that; a too-high pumping rate causes excessive entrance velocity in the well screen (section 11.5.1).

After the step-test, evaluate the data to determine a sustainable pumping rate for the duration of the aquifer test.

- Review the water levels in the pumping well during the step-test to determine if water levels stabilized by the end of each step.
- Water levels that did not stabilize suggest that a flow boundary, such as an aquitard, is affecting the aquifer and long-term drawdown may be underestimated. If the step-test results indicate the presence of boundaries, a pumping rate about half of that calculated (described below) from the step-test data is often appropriate; however, careful monitoring of water levels during the main test will be required to avoid excessive drawdown and running the pump dry.
- Calculate the specific capacity (gpm/ft of drawdown; Q/s, where Q is volumetric discharge rate and s is drawdown) for each of the steps. Use the average measured pumping rate for that step and the drawdown at the end of the step (table 11.2; also Driscoll, 1986, p. 557).
- Use the Q/s value from the highest, stable-drawdown pumping rate to select a pumping rate for the long-term test.

  Example: Suppose the data from table 11.2 were collected from a site where the pump was set with the intake at 95 ft below the measuring point (bMP), the top of screen was at 100 ft bMP, and the static water level was at 10 ft bMP; maintaining 10 ft of water above the pump intake is desired.

  First, calculate the maximum allowable draw down:

$$s = 95 \text{ ft} - 10 \text{ ft} - 10 \text{ ft} = 75 \text{ ft}.$$

  Use the specific capacity value from step 4 of table 11.2 to estimate the pumping rate:

$$Q = (0.86 \text{ gpm/ft}) \times (75 \text{ ft}) = 65 \text{ gpm}.$$

  Select a pumping rate that is somewhat less than the maximum allowable based on step-test data, since the constant-rate test will typically continue for much longer than the step-test, drawdown increases with time, and the likelihood of intersecting a hydraulic boundary increases. For the example above, for a 72-h constant-rate test, a *Q* of about 60 gpm, with a projected drawdown of ~70 ft, is appropriate.

- A second consideration in selecting a pumping rate is the control valve or VFD used to control the flow rate. Select a pumping rate that is small enough to be maintained throughout the test without fully opening the valve. If the control valve is fully open initially, no upward adjustment is possible.
- If a low-flow rate is needed, but the pump cannot run at that low of a rate without overheating, the discharge can be split, with a portion routed back into the pumping well. If this arrangement is

Table 11.2. Specific capacity calculation example.

	Discharge Rate (Q; gpm)	Maximum Drawdown (s; ft)	Specific Capacity (Q/s; gpm/ft)
Step 1	10	16.9	0.59
Step 2	36	45.72	0.79
Step 3	44	53.24	0.83
Step 4	51	59.16	0.86

needed, rather than allowing the return water to cascade down the well casing, run the discharge line down to the pumping water level. Install a plumbing arrangement on the surface that allows control of the return flow to the well in addition to the pumping rate.

- It is better to pump at a low rate for a longer duration during a constant-rate aquifer test. If in doubt, use a lower pumping rate. The rate should be high enough, however, to cause measurable drawdown in the observation wells.

Set the control valve to obtain the desired pumping rate. If possible, pump for a short duration (~15 min) to ensure the valve is set properly. Discharge rates at the start of pumping (~ first 5 min) will be greater relative to later in the test, because discharge will decrease as drawdown in the pumping well increases. Mark or tape the valve so that the desired position is obvious in case the valve is moved.

After the step-test and before the constant-rate test is initiated, ensure that the discharge line and flow meter are drained if freezing temperatures are possible. Disassembly may be required; however, leave the control value at the desired opening. Flow meters, discharge orifices, and other sensitive equipment should be stored at temperatures above freezing.

Depending on the time delay until the start of the constant-rate test, transducers may be left to record water levels each minute, or switched back to one per hour. Collect manual water-level readings from all wells before leaving the site.

11.6 Constant-Rate Aquifer Test

11.6.1 Prior to Starting the Constant-Rate Test

The constant-rate test is typically started the day after the step-test. Do not start the constant-rate test until water levels have recovered to their pre-step-test levels (accounting for antecedent trends). Use several rounds of water-level measurements and the transducer data to ensure that water levels have returned to pre-step-test levels.

Immediately prior to the start of the constant-rate test:

1. Synchronize all time-keeping instruments.
2. Collect a round of manual water-level measurements.
3. Ensure that transducers and Barologgers are recording at 1-min intervals.
4. Reassemble the discharge line and flow meter if they were disassembled to avoid freezing.
5. Ensure that the control valve is set as desired.
6. Check the generator oil, antifreeze, and fuel levels.
7. Start the generator and let it warm up.
8. Collect another round of water-level measurements.
9. Coordinate the pumping start time with all field staff. If a change is needed, let everyone know.

11.6.2 During the Aquifer Test

Table 11.3. Typical frequencies for measuring pumping rates and water levels.

0–5 min	Pumping well at 30 s Observation wells as staffing allows
5–60 min	5 min
1–2 h	10 min
2–4 h	15 min
4–8 h	30 min
8–16 h	1 h
>16 h	4 h

Collect pumping water-level and pumping-rate data as per table 11.3. During the first 5 min of the test, prioritize collecting water levels in the pumping well. If possible, have more than one person onsite for the start of the test. Manual water-level measurements should be collected from each well during the aquifer test at a frequency that provides a representative record of drawdown in the event of transducer failure.

If using bucket and stopwatch discharge measurements, record pumping rates using only the flow meter during the first 5 min of the test because there may not be sufficient time to measure with the bucket and stopwatch. After the first 5 min, measure flow rates using both the flow meter and bucket and stopwatch methods.

During the test, graph the pumping rate versus time and the water levels in each well versus time.

The pumping rate may decrease as water levels decrease. Therefore, the pumping rate may need to be adjusted, to maintain a near-constant rate. However, adjustments should not be made during the first 5 min of the test unless the pump is in danger of running dry or the pumping rate is not settling at an acceptable rate. While it is not necessary to maintain a perfectly constant rate during the test (so long as the rate is known), analysis of the test is simplified by keeping the rate near constant. USBR (1995) suggests maintaining the pumping rate within a ±5% range of the target pumping rate.

Carefully monitor the water level in the pumped well and chart the drawdown as a semi-log plot (drawdown versus log time). In most cases, this relationship will form a nearly straight line and the chart can be used to anticipate the drawdown at the end of the test. Generally, water levels should be maintained at 5 ft or more above the pump. If the water level drops to the pump inlet, air will be drawn in along with water. Resulting turbulence can affect well efficiency, and damage the pump. If site conditions required setting the pump within the screened interval of the well, maintain water levels above the screen. If water levels are projected to drop to unacceptable levels, reduce the pumping rate. If pumping rates cannot be sufficiently reduced, end the test and collect recovery data (section 11.6.3).

Occasionally equipment failures, typically the generator or pump, occur during an aquifer test. If this happens, staff must decide whether or not to restart pumping. If the equipment failure is quickly caught and repaired, restarting the pump may be a good option. If the pump is off for an extended period it is typically better to collect good recovery data (section 11.6.3). If needed, a new test can be conducted after water levels recover.

11.6.3 Recovery Period

Collection of recovery water-level data begins immediately after the pump has been shut off, or if equipment failure occurs. Record the exact time, including seconds, at which pumping ends. Also note the total water produced as recorded on the flow meter. If the test ended due to equipment failure it may be necessary to estimate this time from the pumping well transducer data, and/or from a transducer in an orifice weir stilling well or similar setup.

Record manual water-level measurements during recovery at the same frequency as the pumping period for the first 30 min (tables 11.1, 11.3).

Download transducers and Barologger (if used) before leaving the site. Disassemble and drain the discharge assembly (flow meter, discharge line, weir, etc.), particularly if freezing is possible. Clean up the site and remove any unneeded equipment.

Collect recovery water-level data using transducers and manual measurements for at least the same duration as the pumping period (e.g., 72 h) or until water levels recover to at least 95% of the pre-test antecedent trend, in all wells. If antecedent water-level trends will be removed from the dataset, collect water levels after recovery for a period of time similar to those collected prior to the start of pumping (section 11.5.2). Do not remove the pump until the minimum recovery data collection has been completed.

11.7 Data Handling and Initial Reporting

11.7.1 In the Field

During the aquifer test, record pumping rates and groundwater levels in a field book or on forms specific to aquifer tests (appendix 11.9.2). During the test, enter these data into spreadsheets and graph them as the test progresses. Regularly make backup copies of these electronic files. The following graphs are useful to construct and consult during the test:

- Pumping rate versus date-time on an x–y plot with arithmetic scales.
- For each well:
  - depth-to-water versus date-time on an x–y plot with arithmetic scales, and
  - drawdown (*s*) versus elapsed time since pumping started (*t*), with *t* on a log scale x-axis.
- A combined or “composite” plot for all observation wells, consisting of drawdown (*s*) versus time divided by distance from the pumping well squared (r^2) on a log–log plot (i.e., $\log_{10} s$ vs. $\log_{10}$) t/r^2 ; see example composite plot, fig. 11.2 of appendix 11.9.1).

These graphs support identification of unexpected behavior during the constant-rate test [e.g., drawdown caused by other (non-test) pumping wells, turbulence in the pumping well, etc.]. Identifying these issues during the test can provide staff with the opportunity to identify and measure interfering factors, adjust the final data, or, if needed, terminate the test.

11.7.2 In the Office

Process transducer data. Correct the transducer data for barometric pressure if unvented transducers were used. Correct the baro-corrected or vented transducer data to the manual measurements to account for any instrument drift.

Develop the following graphs from the corrected transducer data and manual water-level measurements for each well:

- depth-to-water vs. date-time on an x–y plot with arithmetic scales;
- data collected during pumping: drawdown (s) versus elapsed time since pumping began (t), with t on a log-scale x-axis;
- recovery data: drawdown (s) versus the ratio of time since pumping began (t) to time since pumping ended (t') with t/t' on a log-scale x-axis.
- a combined or "composite" plot for all observation wells: drawdown (s) versus time divided by distance from the pumping well squared (r^2) on a log–log plot (i.e., $\log_{10} s$ vs. $\log_{10}\ t/r^2$).

Appendix 11.9.3 provides suggested content and structure for reports on aquifer tests and data analysis.

11.8 References and Additional Information

Abdo, G., Butler, J., Myse, T., Wheaton, J., Snyder, D., Metesh, J., and Shaw, G., 2013, Hydrogeologic investigation of the Beaverhead River study area, Beaverhead County, Montana: Montana Bureau of Mines and Geology Open-File Report 637, 132 p.

AQTESOLV Software, 2015, Hydrosolv, Inc.

ASTM, 2008, Standard test method for (field procedure) for withdrawal and injection well tests for determining hydraulic properties of aquifer systems (D4050-96), in ASTM standards for determining subsurface hydraulic properties and groundwater modeling, 3d ed.

ASTM, 2004, Standard guide for selection of aquifer test method in determining hydraulic properties by well techniques (D4043-96),in ASTM standards for determining subsurface hydraulic properties and groundwater modeling, 3d ed.

Bouet, Yannick, 2017, Aquifer test interpretation using derivative analysis—Introduction and examples, available at https://www.linkedin.com/pulse/aquifer-test-interpretation-using-derivative-analysis-yannick-bouet/ [Accessed November 2021].

Bourdet, D., Whittle, T.M., Douglas, A.A., and Pirard, Y.M., 1983, A new set of type curves simplifies well test analysis: World Oil, May 1983, p. 95–106.

Bourdet, D., Ayoub, J.A., and Pirard, Y.M., 1989, Use of pressure derivative in well-test interpretation: SPE Formation Evaluation, June 1989, p. 293–302.

Cooper, J.J., Jr., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: Transactions of the American Geophysical Union, v. 27, no. 4, p. 526–534.

Driscoll, F.G., 1986, Groundwater and wells: St. Paul, Minn., Johnson Well Screens, 2nd ed., 1089 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 86 p.

Renard, P., Glenz, D., and Mejias, M., 2009, Understanding diagnostic plots for well-test interpretation: Hydrogeology Journal, v. 17, p. 589–600.

Samani, N., Pasandi, M., and Barry, D.A., 2006, Characterizing a heterogeneous aquifer by derivative analysis of pumping and recovery test data: Journal of Geological Society of Iran, v. 1, p. 29–41.

United States Department of the Interior–Bureau of Reclamation, 1995, Ground water manual, a water resources technical publication, 2nd ed., 695 p.

van der Kamp, G., 1989, Calculation of constant-rate drawdowns from stepped-rate pumping tests: Ground Water, v. 27, no. 2, p. 175–183.

11.9 Appendices

Appendix 11.9.1 Considerations for Aquifer Test Analysis

Analysis of aquifer test data is not well suited to a set of standardized procedures. MBMG hydrogeologists compiled this appendix to provide some general considerations and outline a few methods they have found useful in analyzing datasets from constant-rate tests. We recommend formal training in applied well hydraulics prior to undertaking this type of analysis.

Background

Selection of analysis procedures and curve-fitting techniques depends upon a combination of the site hydrogeologic conceptual model and the aquifer test results. Successful analysis often involves beginning with application of relatively simple interpretations and adding complexity as needed.

As described below, transmissivity (*T*) can be estimated from data from each observation well; however, this typically results in a range of transmissivity values due to anisotropic subsurface conditions at the test site. Calculating an average, or "bulk" transmissivity across this range of estimates will skew the average *T* towards an outlier value. Consider the use of composite plots, described below, to estimate bulk transmissivity.

Similarly, analysis of storativity (*S*) will likely result in a range of values because storativity is flow-path-specific. If a single value of S is desired, select the storativity value estimated from the furthest observation because this distance represents the largest volume of the aquifer included in the test.

Compare the resulting aquifer properties to values expected for the aquifer geologic material. Driscoll (1986) and many other hydrogeologic reference books present representative values from many aquifer tests.

Derivative Plots

Derivative analysis, a technique used in the petroleum industry (Bourdet and others, 1983, 1989), can inform the type of analysis (e.g., unconfined, confined, leaky-confined, etc.) applied to a given aquifer test. A derivative analysis consists of a plot of the derivative of drawdown data versus logarithmic time. This allows visualization of the flow behavior around the pumping well, identification of the radial flow regime and other flow regimes, and detection of boundaries. The logarithmic derivative is sensitive to subtle variations in the shape of the drawdown curve, and it facilitates detection of minor variations in drawdown that are difficult to observe on a standard plot of drawdown. The interpretation of the derivative plot should include consideration of the site geology and other characteristics. Analysis of the plot facilitates development or modification of the site conceptual model. More discussion of derivative plot analysis can be found in Renard and others (2009), Samani and others (2006), and Bouet (2017).

The AQTESOLV program includes a tool to easily create derivative plots. AQTESOLV also provides a summary of diagnostic derivative plots from a variety of aquifer types. These can be found by searching for "derivative plots" in the help section of AQTESOLV. Figure 11.1 shows a few example derivative plots from AQTESOLV in different geologic regimes. Note that application of a smoothing technique for the derivative plots can aid in the diagnostic analysis. The derivative plot can be quite "noisy" without the smoothing option.

Derivative plots support identification of drawdown data appropriate for the Cooper–Jacob analysis. The drawdown data that correspond to when the derivative plot is flat (for late time data) are the data to use for the Cooper–Jacob analysis (e.g., in fig. 11.1A, the drawdown data to use for the Cooper–Jacob analysis would be the drawdown data from about 80 min to the end of the test. This is where the derivative plot is flat). Derivative plots may also help identify interference noise in the data that will affect the aquifer parameter estimation results.

Cooper–Jacob Analysis for Unconfined Aquifers

The Cooper–Jacob analysis method was developed for confined aquifers, but it can be applied to unconfined aquifers to achieve a reliable estimate of transmissivity for the aquifer. There are some additional criteria to be aware of when applying Cooper–Jacob to unconfined settings.

Fully Penetrating Well in an Unconfined Aquifer

For a fully penetrating well in an unconfined aquifer, the Cooper–Jacob analysis can give reasonable estimates for transmissivity (*T*), specific yield (S_y), and storativity (*S*). Use AQTESOLV to achieve estimates of transmissivity and specific yield by matching the

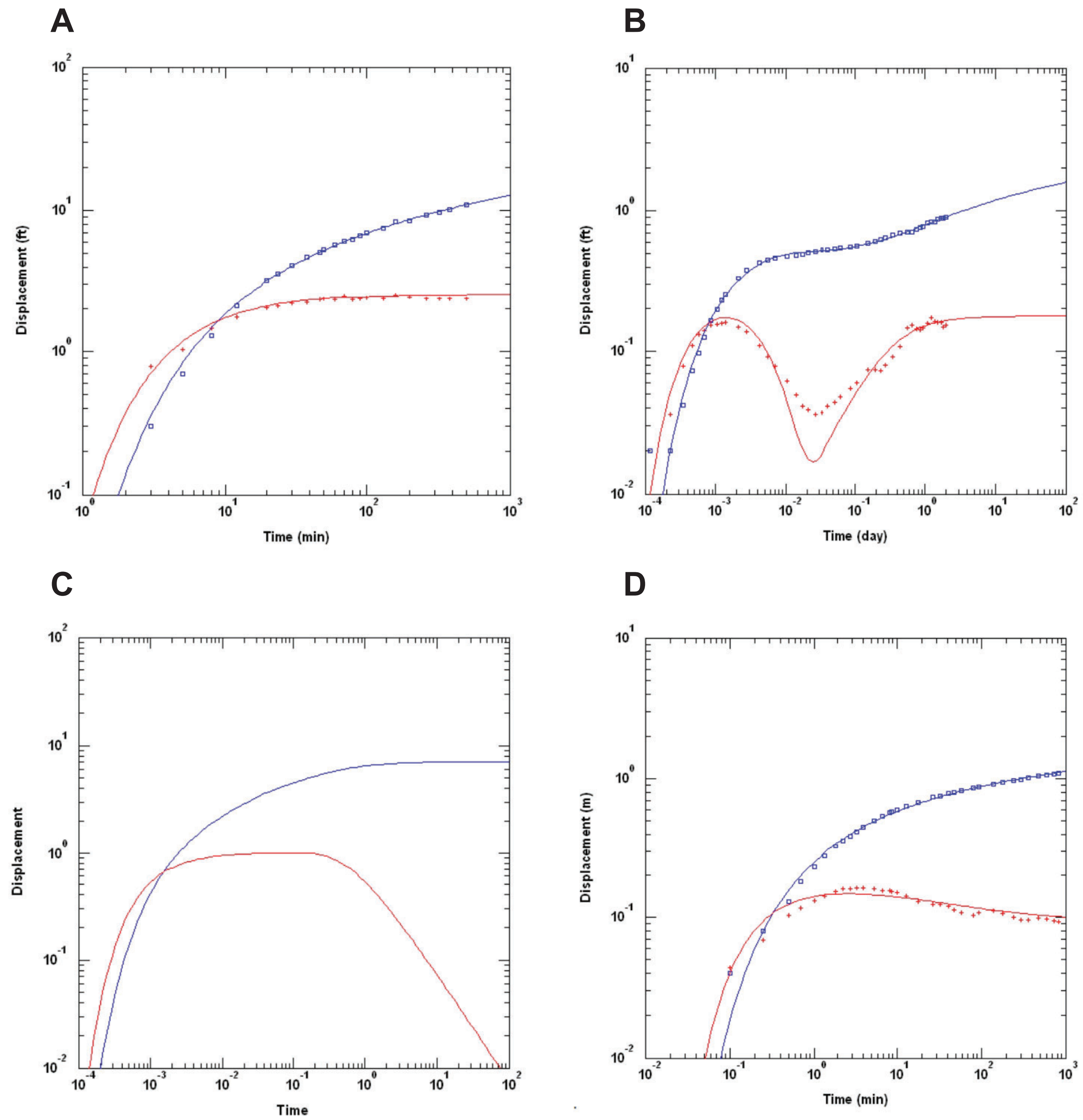


Figure 11.1. Samples of derivative plots for various geologic settings from AQTESOLV. Blue curves represent drawdown data and red curves are derivative data. Plot A, observation well in a nonleaky confined aquifer with no boundaries. Plot B, observation well in an unconfined aquifer. Plot C, observation well in a nonleaky confined aquifer with a recharge boundary. Plot D, observation well in a leaky-confined aquifer (figures from AQTESOLV Help). More diagnostic plots and discussion can be found in Renard and others, 2009.

Cooper–Jacob straight-line to late time data where the derivative plot is flat. AQTESOLV can be used to estimate storativity from early time data using the Cooper–Jacob method. To do this, use AQTESOLV's "parameter tweaking" feature to hold transmissivity constant, then adjust the straight-line to match early time data and yield an estimate of storativity.

In summary, for fully penetrating wells:

- use Cooper–Jacob to estimate T and S_y from late time data and
- use Cooper–Jacob to estimate S from early time data.

Partially Penetrating Well in an Unconfined Aquifer

For a partially penetrating well in an unconfined aquifer, use Cooper–Jacob to estimate transmissivity from late time data as described above. To estimate specific yield and storativity, use the Theis solution on late time data and early time data, respectively. To refine all the parameter estimates, use the Neuman solution in AQTESOLV to estimate β, a dimensionless value representing delayed gravity drainage from the aquifer, by matching the Neuman solution to intermediate time data with AQTESOLV's "parameter tweaking" feature. Finally, using the estimated β, turn off "parameter tweaking" and use active type-curve matching to refine estimates of transmissivity, storativity, and specific yield.

In summary, for partially penetrating wells:

- use Cooper–Jacob to estimate T from late time data,
- use Theis to estimate S_y from late time data,
- use Theis to estimate S from early time data, and
- use Neuman Solution to refine estimates obtained with Cooper–Jacob and Theis solutions;
- use parameter tweaking or active type curves to match β and refine the estimates of T, S, and S_y.

Composite Plot Analysis

The composite plot is a useful tool to help interpret aquifer tests in confined aquifers (fig. 11.1A). First suggested by Cooper and Jacob (1946), a composite plot consists of drawdown graphs from each monitored well presented on a single graph. The composite plot is a semi-log plot that emphasizes late time data and represents conditions from a larger areal extent of the aquifer. This is important in estimating the bulk transmissivity of an aquifer.

The composite plot analysis has several advantages:

- It helps to identify drawdown responses that differ from other responses. This allows identification of different hydrologic regimes within the aquifer as reflected in the observation well responses to pumping. If the drawdown data from one observation well do not plot near or on the same line as the other drawdown data, then the assumptions of the Theis solution are violated. This may indicate that the observation well is not completed within the same aquifer as the pumping well, or that the observation well is completed in different geologic material (e.g., a clay lens) within the same aquifer.
- Composite plots provide a method to estimate an aquifer's average, or bulk, transmissivity from a set of observation well data (if the wells are all located within the same aquifer as the pumping well). The data from many wells can be viewed and interpreted in a single analysis. Transmissivity (T) estimated from data from each observation well typically results in a range of transmissivity values because of the anisotropy in subsurface conditions at the test site. Averaging these values is not recommended because each well does not necessarily represent an equal volume of the aquifer. The response in a single observation likely represents conditions around a limited area beyond the well. Thus, calculating the average transmissivity across the range of estimates will skew the average T towards an outlier value. If a single estimate of transmissivity is desired, generate this estimate after developing a composite plot. For example, observations from three of the six monitoring wells fall within Area 1 in figure 11.2. A bulk average T for that area of the aquifer could be developed based on a best line fit to the three plots using the Cooper–Jacob method.

Cooper–Jacob Method with Recovery Data

Analysis of aquifer test recovery data is valuable for aquifer parameter estimation. Recovery data are not affected by irregularities and turbulence from pumping. The Cooper–Jacob method may be applied

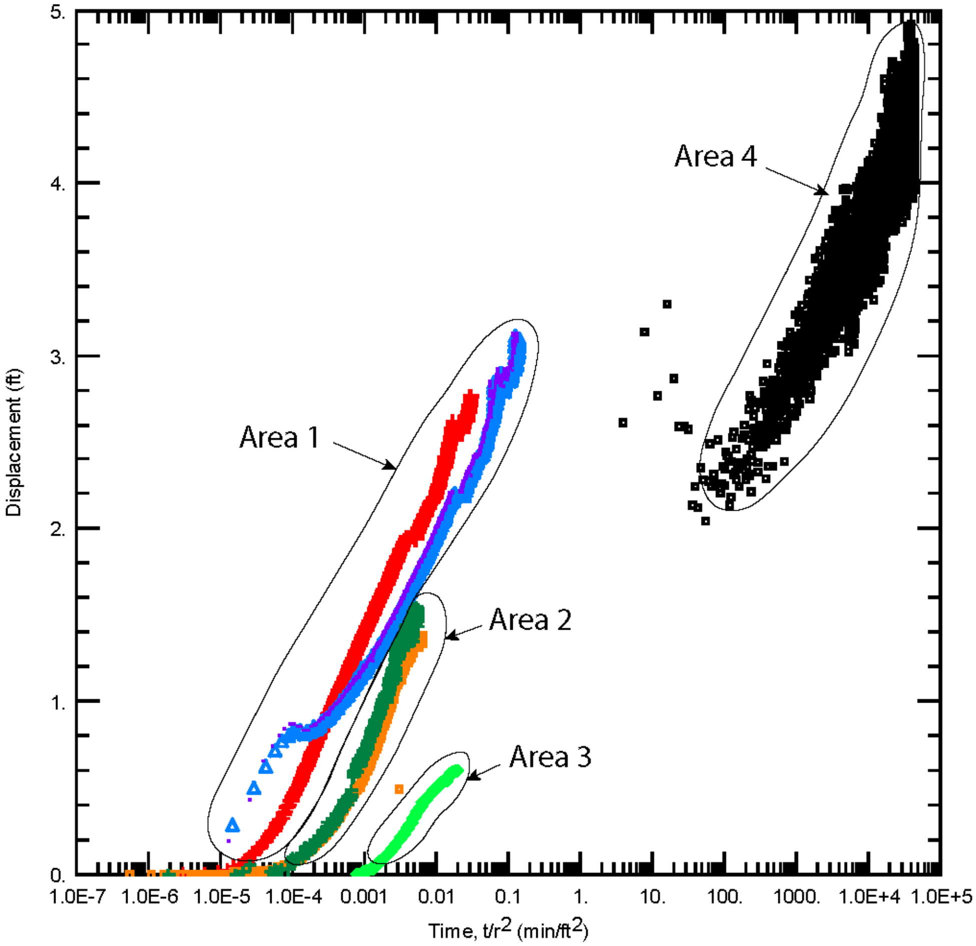


Figure 11.2. Composite plot showing four distinct responses to pumping. Multiple responses such as these indicate that the assumptions of the Theis method are violated. The aquifer may be anisotropic, or the wells may be completed in geologically dissimilar zones within a heterogeneous aquifer. Areas 1, 2, and 3 show responses at six monitoring wells. Area 4 shows the pumping well response (Abdo and others, 2013).

to recovery data. The Theis solution may be useful to analyze both pumping and recovery data.

van der Kamp Method to Enhance Recovery Data

The van der Kamp Method is a technique, founded on the theory of superposition, used to enhance recovery data. This technique is particularly useful if drawdowns during the aquifer test did not stabilize before pumping ceased. This method uses the residual drawdown (drawdown that occurs during the recovery phase of a pumping test after the pump has ceased) data to calculate drawdown that would have occurred if the pumping test continued. However, ideally, aquifer tests continue until water levels are relatively stable.

The generalized equation for residual drawdown after a constant-rate test is:

$$s_1(t) = s(t) + s_1(t - t_{off}),$$

where s is residual drawdown measured at time t; s_1 is drawdown that would have occurred at time t if pumping had continued at rate Q_1 (i.e., equivalent constant-rate drawdown); t_{off} is duration of pumping; and t is time since pumping started.

To better illustrate how to use the van der Kamp method, an example is included below. This example is taken from webinar notes (Midwest GeoSciences Group, 2011).

Residual Drawdown

Table 11.4 illustrates how to visually calculate residual drawdowns. It also shows that after an elapsed time of $2t_{off}$ the author starts to make use of s_1 that was calculated earlier in the table. Also see figure 11.3.

Table 11.4. An example of using the Van der Kamp method.

t (min)	s(t) (m)	$t-t_{off}$ (min)	$s(t-t_{off})$ (m)	s_1 (m)
0	0			0
10,380	1.75			1.75
20,760	3.02			3.02
31,140	4			4
41,520	4.7	0		4.7
51,900	3.65	10,380	1.75	5.4
62,280	3.07	20,760	3.02	6.09
72,660	2.6	31,140	4	6.6
83,040	2.26	41,520	4.7	6.96
124,560	1.52	83,040	6.96	8.48
166,080	1.18	124,560	8.48	9.66
207,600	0.95	166,080	9.66	10.61
249,120	0.76	207,600	10.61	11.37
290,640	0.68	249,120	11.37	12.05

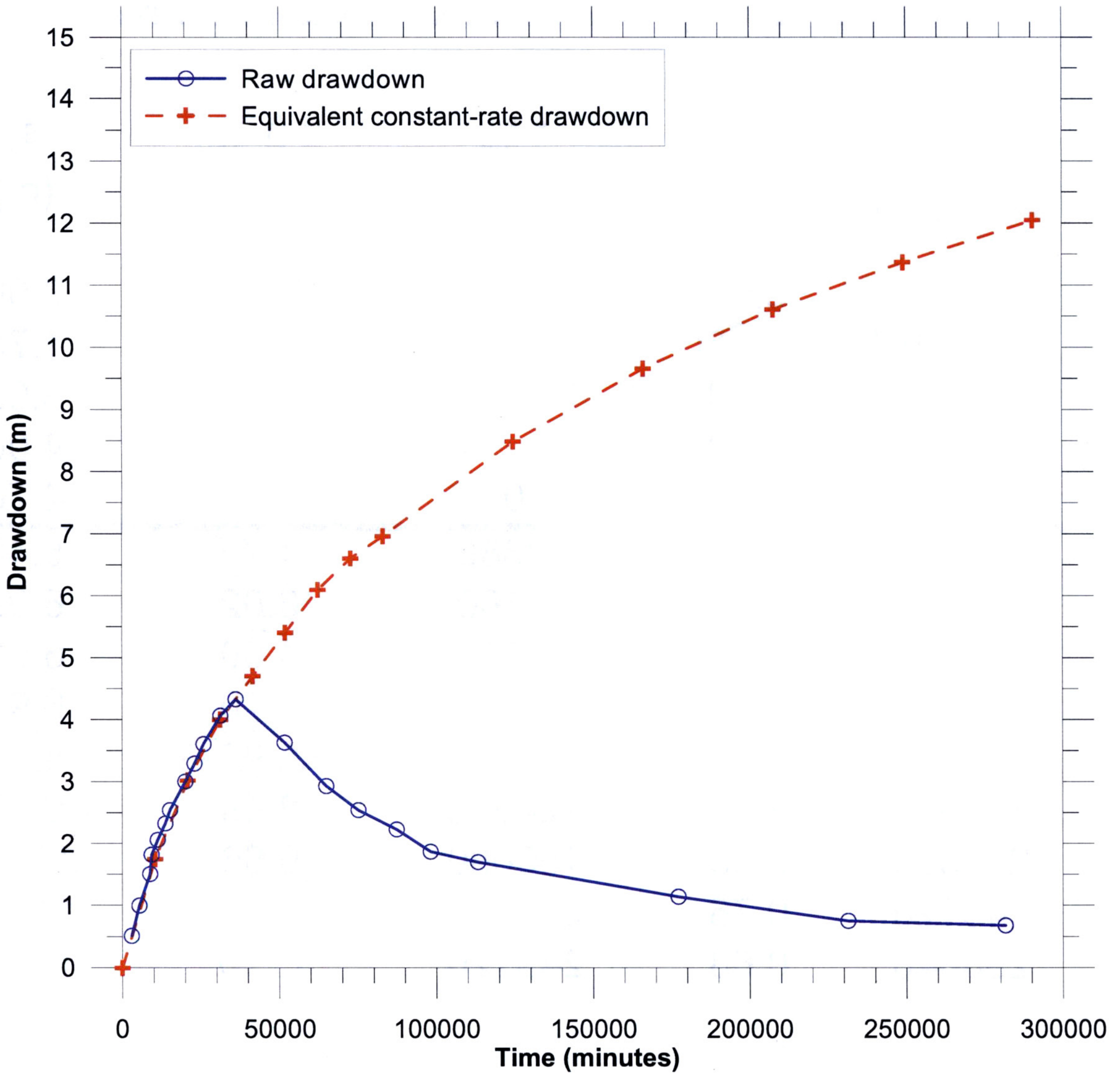


Figure 11.3. Example of the van der Kamp method. The method extends drawdown information using recovery data (table 11.4). Adapted from Midwest GeoSciences (2011).

11.9.2 Aquifer Test Data Forms

Aquifer Test Drawdown and Recovery Data

Project ____

Aquifer Test Name ____________________________________

Well Name ____

Date	**Time**	**dt**	**SWL (ft)**	**dh (ft)**	**Collected by**

Aquifer Test Discharge Data

Project ____

Aquifer Test Name __________________________________

Well Name ____

Date	Time	Totalizer (gal)	Volume (gal)	Elapsed time (min:sec)	Q(gpm)*	Collected by

*For direct read flow meters, enter the rate. If using an analog (sweeping hand) meter, select an appropriate volume (~ 1 minute) and time how long it takes the hand to cover this. For bucket and stop watch, enter the bucket volume and the time needed to fill it.

Appendix 11.9.3 Recommended Reporting on Aquifer Tests and Analysis

This recommended guidance for reporting on aquifer tests was developed by staff from the MBMG's Ground Water Investigation Program (GWIP).

Aim for a concise report, written for an audience with training in hydrogeology. The scope of GWIP aquifer test reports should include details of the particular test for which it is prepared and typically will not interpret the test results in a larger context.

A recommended outline includes the following:

I. Test Title

II. Background

A. Purpose of Test

State the purpose of the test, which might be limited to determining aquifer properties (such as *T, K, S*, anisotropy, etc.), identifying aquifer boundaries (recharge and/or barrier), or evaluating groundwater/surface-water connection.

B. Test Location

Descriptive location (for example, the aquifer test site is located in Hamilton, Montana in the floodplain about 200 ft from the Bitterroot River).

- i. Type of test (e.g., constant-rate, step-test, etc.) date, duration, average pumping rate, number of observation wells
- ii. Hydrogeologic setting/stratigraphy. Describe aquifer based on knowledge of the area, lithology reported in well records from the area, and static water levels
- iii. Note significant hydrologic features that can affect the results or should be considered (e.g., hydrologic boundaries, nearby pumping wells, irrigated fields, canals, geologic features such as faults or contacts, etc.)

III. Field Information

Provide descriptions of monitoring and pumping wells, surface-water monitoring sites, and any other monitoring features.

A. Include a figure that shows all the monitoring sites and relevant features.

B. Include a table that includes pertinent information, such as:

- Site name,
- GWIC identification number,
- Site type (pumping well, observation well, surface water site, etc.),
- Total depth,
- Screened interval and aquifer,
- Distance from the pumping well, and
- Maximum drawdown.

IV. Data Collection

A. Type of transducers, flow meter, other meters (i.e., SC, temp), frequency of measurements

B. Specify if a step-test was performed

C. Date/time pump on and off

D. Date/time start and end of data collection

E. Water-quality samples collected (if any)

F. Any issues encountered that relate to the test (equipment problems, etc.)

V. Results

A. Include general test information, such as:

- i. Pumping rate,
- ii. Apparent influences, such as other pumping wells, irrigation, precipitation, boundary conditions,
- iii. Any influences removed from the data (i.e., pre-pumping trends in water levels),
- iv. Overview of drawdown, with distance and time, affected aquifers and those not affected,
- v. Water-quality results (if any), and
- vi. Hydrograph of raw pumping well and any observation well data:
  - a. Display the pumping rate on a secondary Y-axis.
  - b. Include a date range from 1 week prior to test through 1 week after the end of recovery data collection.

        c. Keep Y-scale consistent between figures, if reasonable.
        d. If possible, plot data from multiple observation wells on one graph.

VI. Data Analysis
    A. Analysis method(s) used based on derivative plot analysis
    B. Report the range of values estimated for *T, K, S*, but do not average these values
        i. Include these values in a table format.
    C. Figures
        i. Composite Plot (if appropriate),
        ii. Derivative Plot to support analysis method,
        iii. Plot that identifies boundary conditions (if appropriate), and
        iv. AQTESOLV solution figures with curve matches or straight-line segments for selected solutions (it is not necessary to include plots that aren't used).

VII. Summary
    A. Briefly interpret results, if the purpose of the test extended beyond estimating hydrologic parameters.
    B. Report range of values, *T, K, S* (do not average *T, K*, or *S*).

12.0 USE OF PORTABLE XRF FOR ANALYSIS OF SOLID-PHASE MATERIALS

12.1 Purpose

This document provides operational and safety guidelines for analyzing the elemental composition of rock and soil samples with the portable X-ray fluorescence (XRF) analyzer. The XRF analyzer does not identify minerals, only elements. As of December 2021, the MBMG owns a Niton® XLT GOLDD+ XL3t XRF Analyzer.

The analyzer and associated equipment are contained in three field-hardy suitcases stored in Room 103A of the MBMG Analytical Laboratory in the Natural Resources Building. Laboratory personnel control access to the analyzer and perform routine maintenance.

> NOTE: Users must complete an online safety training on the Thermo Scientific website and present their certificate of completion to the laboratory before checking out the analyzer. https://www.thermofisher.com/us/en/home/industrial/spectroscopy-elemental-isotope-analysis/portable-analysis-material-id/xrf-radiation-safety-training.html
>
> Use “Niton” as the Branch Code.

12.2 Background

X-ray fluorescence is induced by irradiating atoms with a high-energy beam of X-rays. The electrons occupying the inner orbitals of the atoms (K shell, L shell, or $n = 1, 2$) absorb the X-rays and are ejected from the atom, leaving a hole or vacancy in the orbital. Electrons from the outer shells (L, M) move into the lower shell, giving up quanta of energy equal to the difference in the energy levels of the shells. The energies of X-ray emissions are distinct for individual elements. Lighter elements emit lower energies, while heavier elements emit higher energies. The uniqueness of the emission lines is the basis for distinguishing the elements. The wavelength or energy of an emission is designated according to the shell in which the vacancy occurred, and has a subscript indicating the origination of the replacing electron. For instance, Kα radiation indicates an L→K transition and Kβ radiation indicates an M→K transition.

12.3 Analyzer and Accessories

Figure 12.1 illustrates parts of the portable Thermo Niton® XL3t GOLDD XRF Analyzer. The source of incident X-rays is a vacuum tube with a rhodium anode. Electrons accelerating at a potential of over 70 keV (kiloelectron volts) strike the anode and generate the beam that exits the analyzer through a window, irradiating the sample and causing X-ray fluorescence from atoms within the sample. A safety shutter located at the exit window prevents X-rays from escaping the analyzer when it is not in the correct position for analysis.

The fluorescent X-rays generated in the sample pass through a transparent plastic window and strike the analyzer detector, where they create a voltage

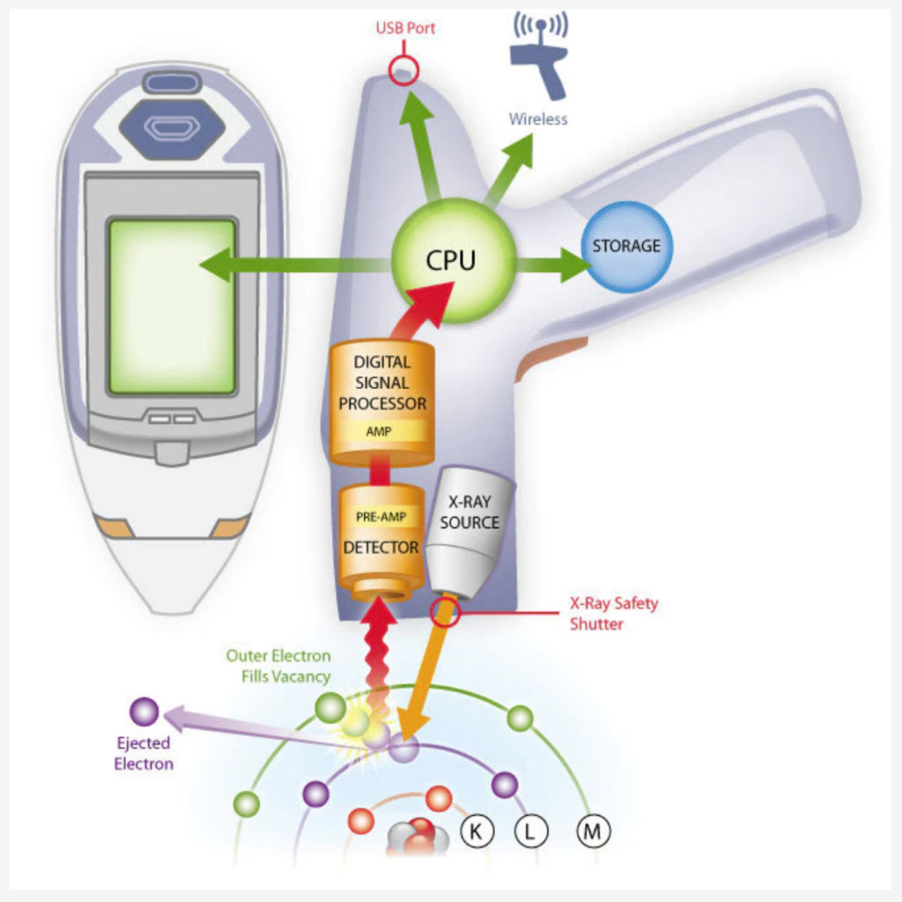


Figure 12.1. Schematic diagram of X-ray fluorescence analysis of a sample with the Thermo Niton analyzer. (Accessed October 15, 2021, from https://www.thermofisher.com/blog/mining/technology-focus-x-ray-fluorescence-xrf-in-mining/).

proportional to the energy of the X-ray. The voltage spikes are measured and counted by the digital signal processor. The counts or number of voltage spikes at particular energies accumulate during the analysis and are proportional to the concentration of an element. The magnitude of a given voltage spike is characteristic of a particular element. These two measurements are the basis for the calculated concentrations of elements in the sample. An onboard processor calculates elemental concentrations and produces a report. The spectrum (energy and peak height) of a sample is also produced and stored with the analytical report. The Niton GOLDD Analyzer can analyze stable elements from Mg to U using the TestAll Geo method in the analyzer.

Only a fraction of the X-ray energy generated during the analysis will return to the detector as a signal. The rest of the energy is scattered or absorbed by the sample's lightest elements, which do not produce X-rays energetic enough to be detected. The fraction of energy that does not contribute to the elemental analysis is reported as the balance (Bal).

A liquid crystal display (LCD) is located atop the analyzer and is the interface typically used to operate the analyzer. An RS-232 serial bus (USB) connection, located at the rear of the analyzer, is used to either control the analyzer from a computer or download analytical data to a computer. Similarly, the analyzer can be connected via a Bluetooth link.

A rechargeable lithium ion battery located in the handle powers the analyzer. A battery charge indicator on the display shows the remaining charge. Two batteries are included with the analyzer. The battery charger has three modes: (1) while operating, a red light is on if the charger is plugged into the wall; (2) an orange light indicates the battery is charging; and (3) a green light indicates the battery is fully charged. Normally MBMG's Analytical Laboratory ensures that the XRF analyzer batteries are sufficiently charged prior to checking out the instrument to a user. The battery should not be left in the charger longer than 12 h.

In addition to the portable XRF analyzer itself, a sample preparation kit is available in a separate case, including mortar and pestle, sieves, and transparent cup holders for samples. For quantitative work, samples should be ground and sieved to uniform size. Reference materials from the National Institute of Standards (NIST) are available as powdered samples for assessment of accuracy. See section 12.6, *Quality Assurance/Quality Control*.

A test stand sample holder, available in a second separate case, holds powdered samples or small specimens during data acquisition (fig. 12.2). The analyzer is inserted into the bottom of the stand and is held in place by clips. The analyzer can be operated using the trigger or through the USB interface.

12.4 Safety

X-rays are a very energetic form of electromagnetic radiation. The radiation emitted from the analyzer is similar to the exposure of a medical or dental X-ray. Therefore, a number of precautions must be taken when using the analyzer to minimize exposure.

When the analyzer has the battery inserted and is powered on, it is capable of emitting X-rays after the user logs in and selects an analytical protocol. Four flashing red lights around the analyzer signal that the analyzer is ready to produce X-rays. If the analyzer is

Figure 12.2. Stand for analyzing pulverized or small bulk samples.

not firmly in contact with the target, the X-ray Safety Shutter (fig. 12.1) will prevent X-rays from leaving the analyzer, even though they are being generated inside the analyzer. However, even this feature is not completely foolproof. When analyzing a specimen with an irregular surface, the possibility of exposure still exists.

Safety Tips:

Never point the analyzer at yourself or anyone else. Do not hold a specimen in your hand while analyzing. Use the wristband.

12.5 Procedures

12.5.1 Analyzing

12.5.1.1 Turn On and Login

Refer to figure 12.3 for screen display.

Press the ⏻ button to turn on the XRF analyzer. Press the screen to Logon.

Press Yes.

Press in 1234 and Enter.

12.5.1.2 Main Screen and Advanced Screen to Set Analysis Times

If a date and time stamp is desired on the analysis, the System menu should be accessed from the Main Screen and if the time/date is incorrect, it should be reset.

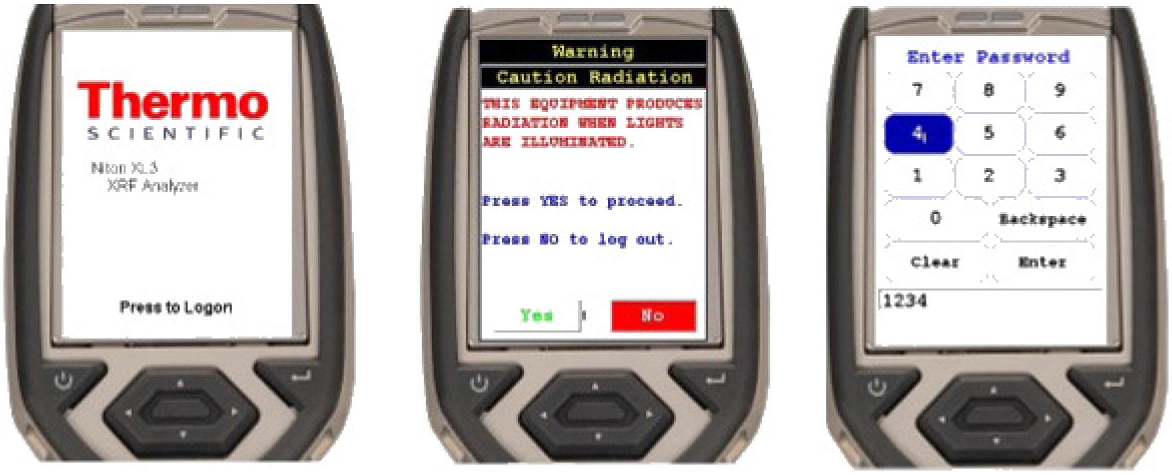
Depending on the intended purpose for the analysis, the settings on the XRF analyzer can be adjusted to provide the most efficient method of data collection. The most common use of the analyzer is semi-quantitative analysis of a hand specimen to confirm the elemental composition of the sample. In this instance, there is no need for an extended data collection period to minimize the statistical error in the reading. A result ±0.5% rather than ±0.2% is sufficient and requires much less time to hold the trigger down and to press the analyzer against the sample. Select the Advanced tab. Under the Advanced menu, several settings can be adjusted. To set the time that the analyzer collects data for the mass ranges, select Element Range (fig. 12.4).

The detector performance is enhanced by limiting the incident X-ray spectrum that excites the sample. This eliminates interferences and allows the signal from elements within a mass range to be counted with high efficiency. There are four filters that are sequentially employed during the TestAll Geo scan (fig. 12.4, right image).

Elements associated with each range are:

- Main: Mo, Zr, Sr, U, Rb, Th, Pb, Au, Se, As, Hg, Zn, W, Cu, Ni, Co, Fe, and Mn;
- Low: Cr, V, Ti, Sc, Ca, K, and S;
- High: Ba, Cs, Te, Sb, Sn, Cd, Ag, and Pd; and
- Light: Si, Al, and Mg.

The time that data are collected for each element mass range filter is adjustable. For a quick scan, program the XRF analyzer to scan each filter for as little as 20 s. This would require that the user would press the trigger for 1 min and 20 s to capture the data from all elements. For more quantitative results, a 30-s scan provides higher precision data. This would require that the user press the trigger for 2 min.



Warning

Caution Radiation

THIS EQUIPMENT PRODUCES RADIATION WHEN LIGHTS ARE ILLUMINATED.

Press YES to proceed.

Press NO to log out.

1234

Figure 12.3. The analyzer screen during login.

Mode: TestAll Geo

	Time
☑ Main Range	30.0
☑ Low Range	30.0
☑ High Range	30.0
☑ Light Range	30.0

Figure 12.4. Choosing the Advanced menu and Element Range to set analysis time.

The accuracy of percent level concentration elements is not significantly affected by analysis time, but the uncertainty in parts per million (ppm) level elements is improved by long analysis times. It is a good idea to review the settings before analysis because a previous user may have adjusted them.

A timer is sequenced to the filter settings to sound a beep. Currently, the analysis times per filter and the timer are in sequence. So, a beep is heard as the filter is changed. After four beeps, all four filters have been analyzed. Unless the user requirements are very specific, the default settings are suggested. For an in-depth discussion of options, consult the User's Guide referenced in the Technical Documents section.

At the top of the Element Range screen is a Mode setting, which indicates the analytical method to which the settings are applied. The TestAll Geo method includes the highest number of elements and is calibrated for general sample analysis (see below). After making any changes, push the Save button to exit and then Return.

12.5.1.3 Selecting a Sample Type or Method

Push Analyze or Sample Type and then select a method (fig. 12.5). TestAll Geo is sufficient for most users because it has the greatest number of elements included and it is programmed to eliminate most possible interferences.

Otherwise, from the main screen, click Sample Type. TestAll Geo, Soils, Mining Cu/Zn, and Mining Ta/Hf are the options. Two Mining options are available because the K shells of Cu/Zn overlap L shells of Ta/Hf and the interference correction is applied. These categories use different calibration routines for the different sample types. The most common option used is TestAll Geo, which uses a fundamental parameters calibration and examines the largest range of elements. The Soils method also calculates the soil bulk density by using the intensity of the Compton scattering X-ray peak. Unless the user's application is very specific for a particular matrix or elemental concentration, use

Figure 12.5. Selecting the analytical method.

TestAll Geo as the default. In a unique situation, the analyzer may require an empirical calibration to produce acceptable results. Refer to the User's Guide and several application notes cited under Technical Notes below for information on unique applications.

The sample name and other information can be entered before the sample is analyzed, but it is not necessary to do so. If desired, in the Ready to Test screen under Data Entry, press the keyboard to type the Sample Name, location, and other sample details. It is much easier to incorporate sample information into the spreadsheet after the analytical data are downloaded.

A camera in the nose of the analyzer shows where the X-rays will be focused during the analysis. If there is a mineral phase or area on the sample that is the target, the camera will facilitate placement. If the camera is not visible, but is required, exit the analysis and return to the Main Screen. Select the System menu and scroll down to the Camera setting. Make sure it is activated. Return to the analysis.

12.5.1.4 Conducting Analysis

Place the analyzer exit window firmly against a sample, then pull, and hold the trigger. As soon as the trigger is pulled, concentration data start compiling on the Results screen (fig. 12.6). The XRF will beep every 30 s.

The cumulative analytical time appears at the top and the active filter is shown at the bottom. There are up to four filters (main, low, light, and high). Filters show in the bottom of the screen in brackets: [ ]. The high filter is for high atomic weights; main, low, and light are for the remaining range of masses. It is useful to watch the filter because the analyzer will cycle through the range of filters while the trigger is pushed.

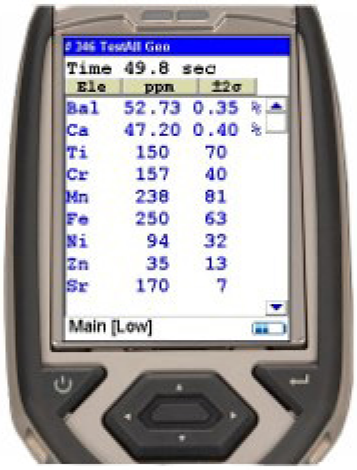
The longer the trigger is held, the better the results. To get data over the entire mass range, hold the trigger for all four filters. Even with a short counting time per filter, data can be acquired through multiple cycles of the filter ranges, as the analyzer will continue to cycle through all the filter ranges as long as the trigger is pulled. Watching the uncertainty (±2σ) can guide the user to acceptable results for their purpose. At some point, the uncertainty levels will not change with increased counting.

Results are shown as both ppm and weight percent. The percent level elements are shown with the percentage symbol (%), while the ppm level elements have no symbol (10,000 ppm is 1 weight%). As noted above, the balance (Bal) shows lighter elements, such as O, N, and C, as well as any scattered radiation from the sample that did not contribute to the elemental composition calculation. The battery life is visible on the lower right portion of the screen.

12.5.1.5 Viewing Results

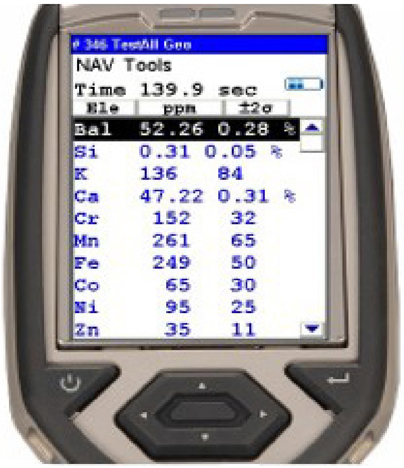
The final elemental concentration results will appear on the screen, along with additional menu options, when the trigger is released (fig. 12.7). The test number and the method used to collect data are shown at the very top of the screen. Make a note of the test number so that when samples are selected for download to a spreadsheet, the correct readings are included. The samples can be named prior to the analysis; however, exporting the results to a spreadsheet and subsequently adding the details to the file is generally much easier.

The display of results depends on the analytical



```
# 346 TestAll Geo
Time 49.8 sec
 Ele     ppm    ±2σ
Bal    52.73  0.35 %
Ca     47.20  0.40 %
Ti       150    70
Cr       157    40
Mn       238    81
Fe       250    63
Ni        94    32
Zn        35    13
Sr       170     7
Main [Low]
```

Figure 12.6. Results screen appears during analysis.



```
# 346 TestAll Geo
NAV Tools
Time 139.9 sec
 Ele     ppm    ±2σ
Bal    52.26  0.28 %
Si      0.31  0.05 %
K      136    84
Ca     47.22  0.31 %
Cr       152    32
Mn       261    65
Fe       249    50
Co        65    30
Ni        95    25
Zn        35    11
```

Figure 12.7. Post-analysis results screen.

method employed. The Soils option will only display results in ppm. The Mining option only displays results in weight percent. TestAll Geo mode displays concentrations in both ppm and weight percent. Concentrations reported in ppm can range from 0 to 10,000 ppm; concentrations exceeding 10,000 ppm are shown as percentages.

The user may view the spectrum collected during the analysis and the identified peaks. Under the Navigate (NAV) button, click Spectrum to see the spectra of a sample collected from the four filters (fig. 12.8).

The user can select a peak and identify the elements with peaks in that region. Advance by pressing the arrow indicators through all four filters in the analysis.

12.5.2 Downloading Files to a Computer

12.5.2.1 Installing the Software

The Niton XRF analyzer comes with two software applications. Niton Data Transfer (NDT) is used to download data from the analyzer. Niton Data Transfer Remote (NDTr) is used to operate the analyzer from a computer to either collect data or to download data. Administrator privileges are necessary to install the software. The software installation disks are in the case with the XRF analyzer. Make sure that the most recent version of the software is installed.

Insert the software installation disk into a computer. If the disk does not auto-load, launch Windows Explorer and open This PC. Click on the DVD/CD drive that contains the disk to see the contents. Double click on the “NDTSetup” file. This will launch the Setup Wizard. Click Next on the first two screens. Click the “I accept” radio button on the third screen and then click Next. Click Next once more and then Install. When asked to register the XRF analyzer, click Ignore. Click Finish on the final screen. Plug the analyzer into the computer using the USB cable. Turn on the analyzer. The computer will identify the new hardware.

If the drivers do not install automatically, make sure the analyzer is plugged in and proceed with the following steps. Navigate to the Control Panel on the computer. Click System and then Device Manager. Under Other Devices, right click on Unknown Device. Click Update Driver Software and then Browse My Computer for Program Files. Click Thermo Niton and then click “Install this driver software anyway.” Click Close.

12.5.2.2 Using the Software

12.5.2.2.1 Niton Data Transfer

Under the computer Start menu, navigate to Thermo Scientific and click NDT to open the software. To download data from a previous scan, click the Download button near the top of the screen. A Download Readings dialog box will open (fig. 12.9).

Click the Settings button and select the appropriate communication port. The port will display as Thermo Scientific, NITON Analyzers USB Port, or USB Serial Device (fig. 12.10). Click OK. Click Connect.

The Connection Status box in the bottom right corner will turn green. Click the Test button. A message should display that the analyzer is communicating (fig. 12.10, right image). Click OK. If the computer is not

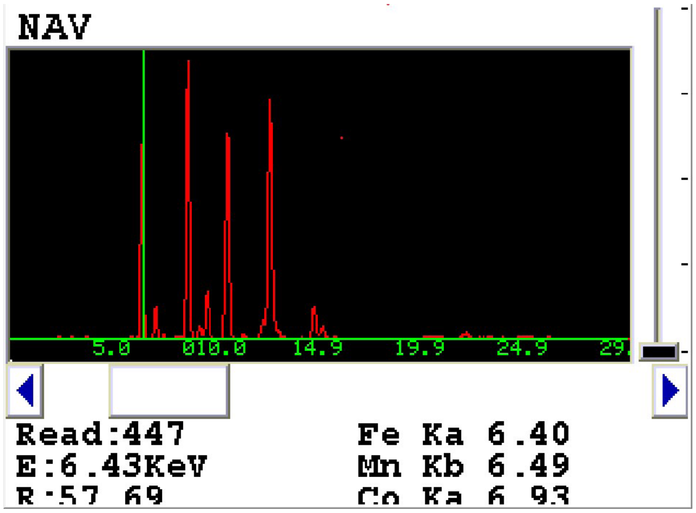
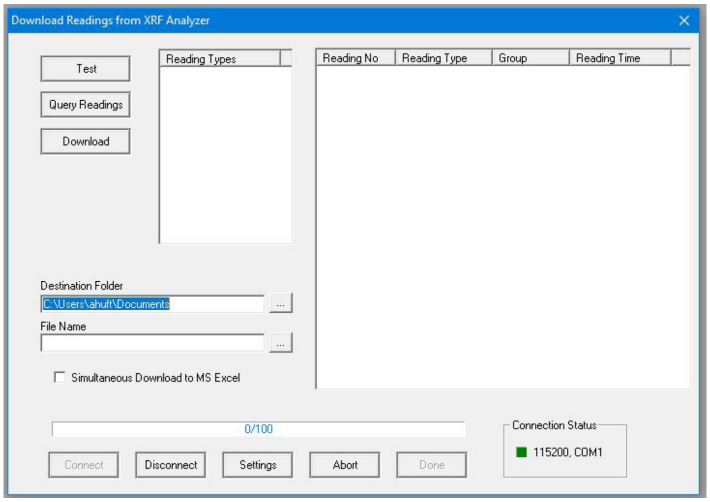


Figure 12.8. Viewing the spectrum of sample X-ray fluorescence.



Destination Folder: C:\Users\ahult\Documents

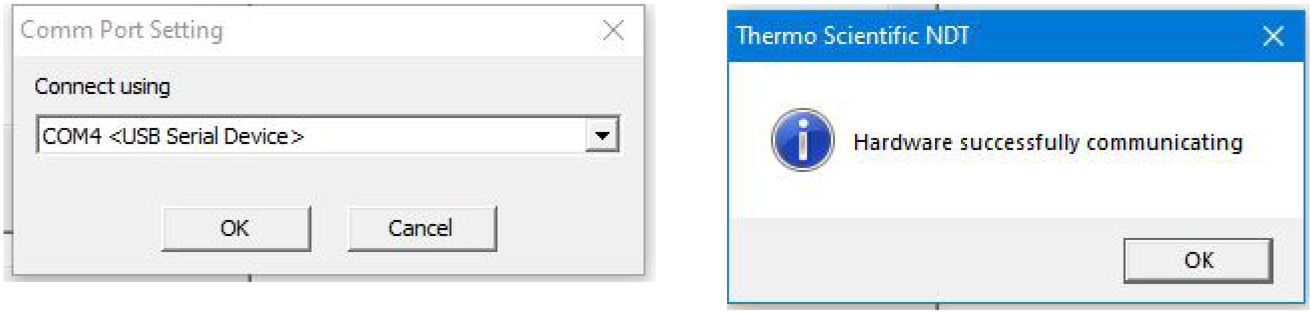
File Name:

☐ Simultaneous Download to MS Excel

0/100

Connection Status: 🟩 115200, COM1

Figure 12.9. Download screen in the NDT software.



Comm Port Setting

Connect using

COM4 <USB Serial Device>

Thermo Scientific NDT

Hardware successfully communicating

Figure 12.10. Interfaces for establishing communication from the USB connection to the computer.

successfully communicating with the analyzer, choose the bottom com port displayed and try again.

Choose a Destination Folder to save the files. To download data, click the Query Readings button; this will list the readings taken by the analyzer. The user can filter the readings shown by selecting from the Reading Types menu. Select the reading of interest and name the file (fig. 12.11). NOTE: If simultaneous data export to a spreadsheet is desired, make sure to check the appropriate box. Otherwise, only the raw .ndt file will be downloaded.

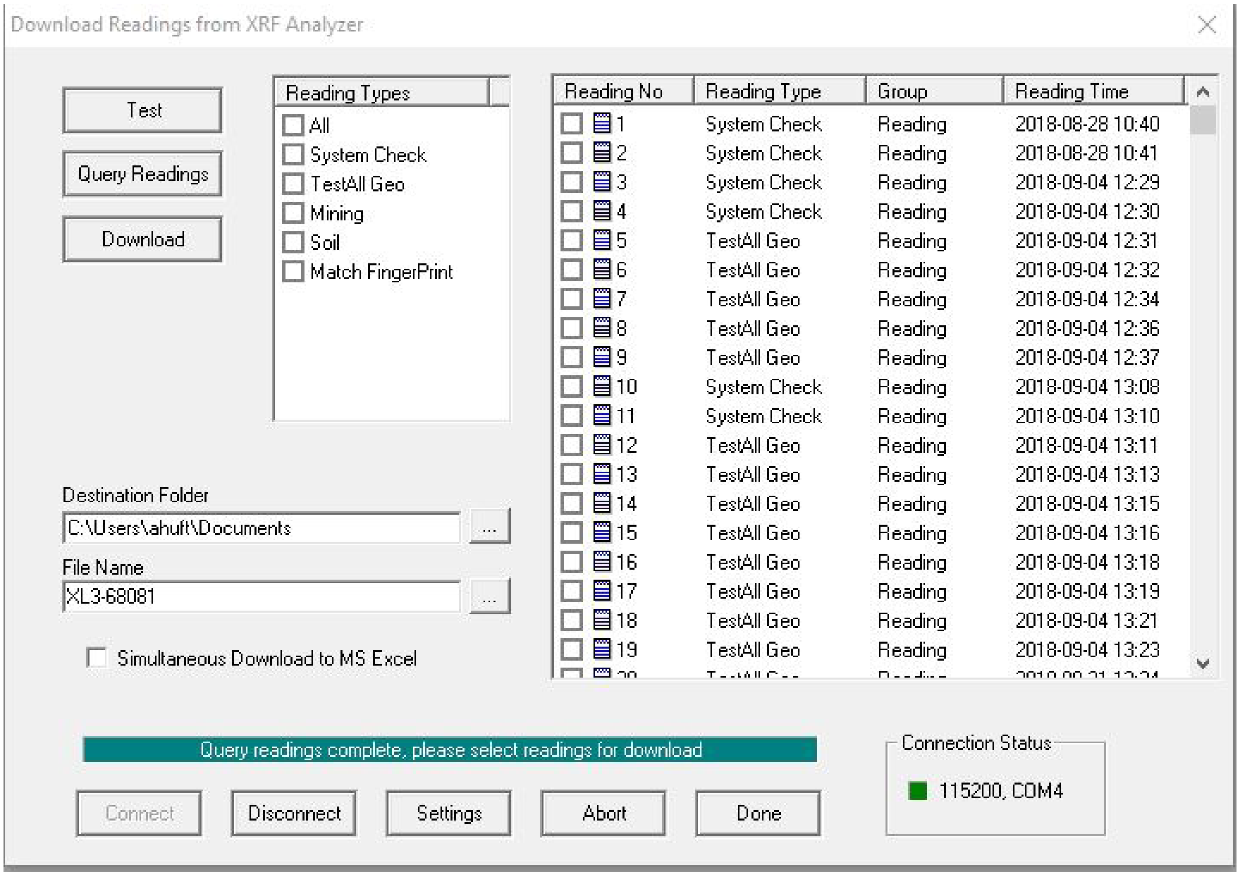
Select the readings of interest using the check boxes to the left of the readings. Click Download. The progress bar at the bottom of the dialog box will show when the download is complete (fig. 12.12).

Click Done to finish.

The data can also be exported in various formats in a separate operation. To save the data as a .csv, .xls, or .txt file, click Tools at the top of the screen and then Export Data. Select the Destination Folder, edit the File Name if desired, select the File Type, and click Start (fig. 12.13).

12.5.2.2.2 Niton Data Transfer Remote

With the analyzer turned on and plugged into a computer USB port with the cable, select Thermo Scientific from the Start menu of the computer and click NDTr. A dialog box will open where the cor-



Download Readings from XRF Analyzer

Reading No	Reading Type	Group	Reading Time
☐ 1	System Check	Reading	2018-08-28 10:40
☐ 2	System Check	Reading	2018-08-28 10:41
☐ 3	System Check	Reading	2018-09-04 12:29
☐ 4	System Check	Reading	2018-09-04 12:30
☐ 5	TestAll Geo	Reading	2018-09-04 12:31
☐ 6	TestAll Geo	Reading	2018-09-04 12:32
☐ 7	TestAll Geo	Reading	2018-09-04 12:34
☐ 8	TestAll Geo	Reading	2018-09-04 12:36
☐ 9	TestAll Geo	Reading	2018-09-04 12:37
☐ 10	System Check	Reading	2018-09-04 13:08
☐ 11	System Check	Reading	2018-09-04 13:10
☐ 12	TestAll Geo	Reading	2018-09-04 13:11
☐ 13	TestAll Geo	Reading	2018-09-04 13:13
☐ 14	TestAll Geo	Reading	2018-09-04 13:15
☐ 15	TestAll Geo	Reading	2018-09-04 13:16
☐ 16	TestAll Geo	Reading	2018-09-04 13:18
☐ 17	TestAll Geo	Reading	2018-09-04 13:19
☐ 18	TestAll Geo	Reading	2018-09-04 13:21
☐ 19	TestAll Geo	Reading	2018-09-04 13:23

Destination Folder: C:\Users\ahuft\Documents

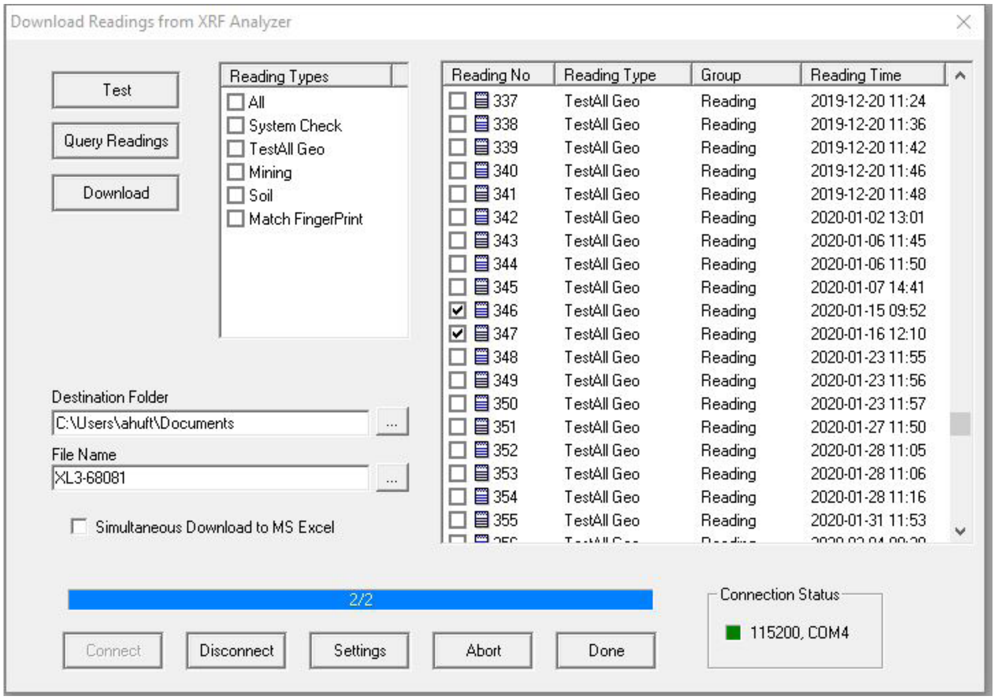
File Name: XL3-68081

☐ Simultaneous Download to MS Excel

Query readings complete, please select readings for download

Connection Status: 🟩 115200, COM4

Figure 12.11. The query readings screen.



Reading Types
- ☐ All
- ☐ System Check
- ☐ TestAll Geo
- ☐ Mining
- ☐ Soil
- ☐ Match FingerPrint

	Reading No	Reading Type	Group	Reading Time
☐	337	TestAll Geo	Reading	2019-12-20 11:24
☐	338	TestAll Geo	Reading	2019-12-20 11:36
☐	339	TestAll Geo	Reading	2019-12-20 11:42
☐	340	TestAll Geo	Reading	2019-12-20 11:46
☐	341	TestAll Geo	Reading	2019-12-20 11:48
☐	342	TestAll Geo	Reading	2020-01-02 13:01
☐	343	TestAll Geo	Reading	2020-01-06 11:45
☐	344	TestAll Geo	Reading	2020-01-06 11:50
☐	345	TestAll Geo	Reading	2020-01-07 14:41
☑	346	TestAll Geo	Reading	2020-01-15 09:52
☑	347	TestAll Geo	Reading	2020-01-16 12:10
☐	348	TestAll Geo	Reading	2020-01-23 11:55
☐	349	TestAll Geo	Reading	2020-01-23 11:56
☐	350	TestAll Geo	Reading	2020-01-23 11:57
☐	351	TestAll Geo	Reading	2020-01-27 11:50
☐	352	TestAll Geo	Reading	2020-01-28 11:05
☐	353	TestAll Geo	Reading	2020-01-28 11:06
☐	354	TestAll Geo	Reading	2020-01-28 11:16
☐	355	TestAll Geo	Reading	2020-01-31 11:53

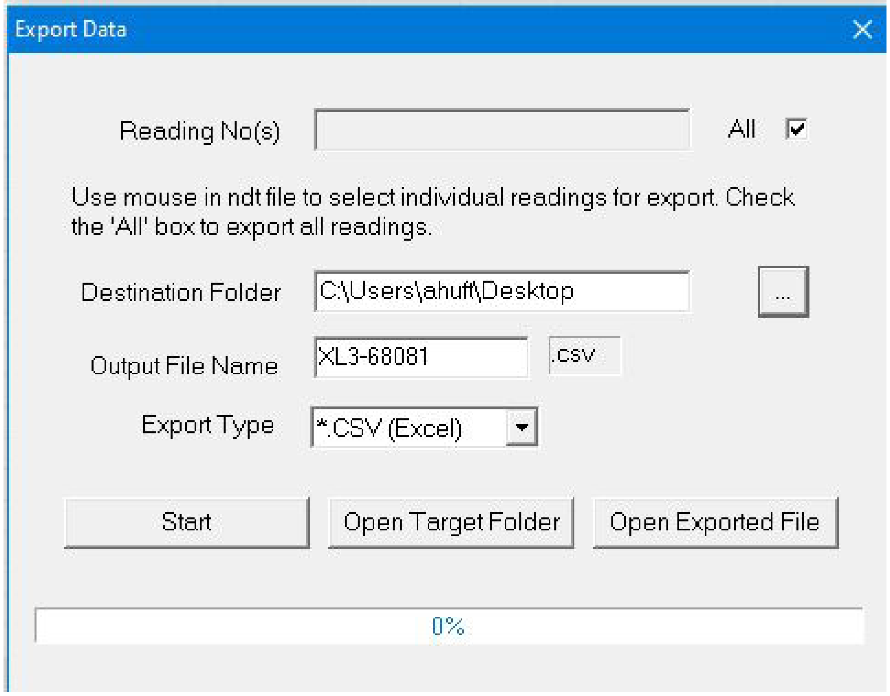
Destination Folder: C:\Users\ahuft\Documents

File Name: XL3-68081

☐ Simultaneous Download to MS Excel

Connection Status: 🟩 115200, COM4

Figure 12.12. A completed download of .ndt files of two sample readings.



Reading No(s): All ☑

Use mouse in ndt file to select individual readings for export. Check the 'All' box to export all readings.

Destination Folder: C:\Users\ahuft\Desktop

Output File Name: XL3-68081 .csv

Export Type: *.CSV (Excel)

Figure 12.13. Export data interface.

rect communication port must be selected (typically at the bottom of the list of ports). Once connected, the computer display resembles the LCD display of the analyzer (fig. 12.14). Clicking on the areas of the computer display with the mouse causes the analyzer to respond as if the LCD itself was used.

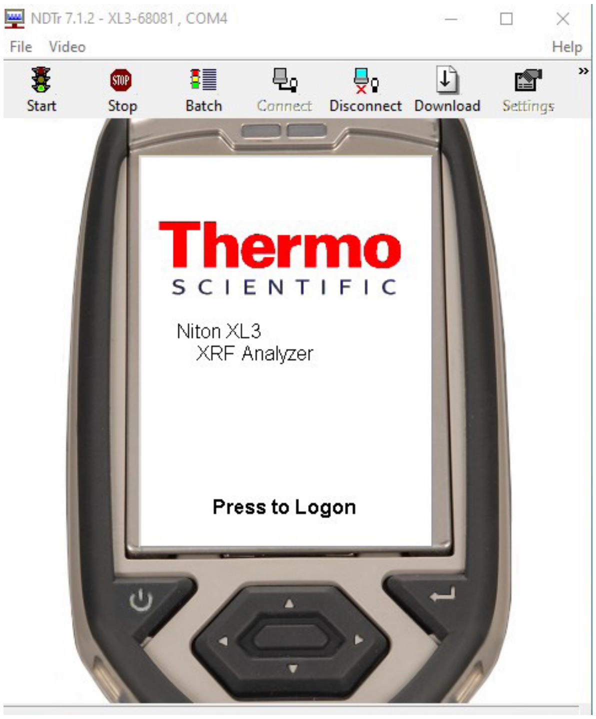


Figure 12.14. Computer display in NDTr.

The menu bar at the top of the display allows data collection using the Start and Stop icons instead of using the instrument trigger.

It is generally convenient to use this remote mode of operation with the analysis stand (fig. 12.2). For instructions on use of the stand, refer to the Technical Notes section in the User's Guide. Samples analyzed in the stand must be relatively uniform particulate, and typically requires grinding and sieving of solid materials. The user should consider how to best obtain a representative test portion from bulk materials; this often depends on the purpose of the analysis.

12.6 Quality Assurance/Quality Control

A Sampling and Analysis Plan (SAP) should be prepared for projects that involve acquiring quantitative data from the XRF, prior to collecting and analyzing samples. Users should contact the MBMG Analytical Laboratory in advance of instrument use to determine if preventive maintenance and recalibration is required. Maintenance is typically performed at the factory, and there could be a month or more delay before the analyzer is certified to collect accurate data.

Each day of use prior to analyzing samples, the System Check routine should be run (fig. 12.4, image on left). Two check routines are executed to verify the tube and detector are within specification.

The SAP should include a protocol for obtaining a sub-sample for testing from bulk samples collected in the field. A significant amount of the total sample error is associated with this step. While beyond the scope of this SOP, users are referred to Ryan and others (2017), which describes use of a portable XRF for quantitative geochemical analysis of rock and sediment.

Overall data quality can be ensured by including samples that document accuracy and precision. Accuracy can be addressed by analyzing NIST reference materials included in the analyzer equipment cases or USGS reference samples (USGS, 2007). Precision can be addressed by including collection and analysis of duplicate samples. As discussed above, sub-sampling procedures for obtaining test portions from bulk samples should be considered.

12.7 References

The Niton User's Guide and other relevant materials are archived at: \\MBMGS1A\Bureau\Publications Public\XRF Technical Documents. These include manufacturer's descriptions of use of the portable XRF to assess rare earth elements, porphyry deposits, and platinum group elements.

Ryan, J.G., Shervais, J.W., Li, Y., Reagan, M.K., Li, H.Y., Heaton, D., Godard, M., Kirchenbaur, M., Whattam, S.A., Pearce, J.A., Chapman, T., Nelson, W., Prytulak, J., Shimizu, K., and Petronotis, K., 2017,Application of a handheld X-ray fluorescence spectrometer for real-time, high-density quantitative analysis of drilled igneous rocks and sediments during IODP Expedition 352: Chemical Geology, v. 451, p. 55–66, doi: https://doi.org/10.1016/j.chemgeo.2017.01.007.

U.S. Geological Survey, 2007, USGS Reference Materials Program. USGS Fact Sheet 2007-3056 August, 2007.

Additional information is available from Thermo Niton:

https://www.thermofisher.com/us/en/home/industrial/spectroscopy-elemental-isotope-analysis/portable-analysis-material-id/.html

CHAPTER 13.0 SAMPLING ROCKS AND SEDIMENT FOR ANALYSIS AND ARCHIVING

13.1 Purpose

This document provides standard procedures for collecting rock and sediment samples that will be prepared for chemical or other analyses and subsequently archived at MBMG facilities.

13.2 Background

MBMG staff routinely visit sites to collect samples of rocks and other geologic materials (sediment, for example). Although not all samples collected by field geologists need to be archived, MBMG staff may have samples of significance deserving of preservation. For example, geologists may want to archive hand samples collected for the purposes of rock description or collected to characterize spatial variability within a formation. In general, sample splits from all samples that will be subject to any type of laboratory analysis should be archived.

These procedures establish guidance for these field sampling efforts, standardize routine tasks, and support staff training. The procedures aid in maintaining quality and consistency in field-based collection efforts, subsequent sample analyses, and sample archiving. This document supports adequate and consistent training of personnel new to collecting rock and sediment samples, personnel new to the MBMG, and students hired on an *ad hoc* basis.

Compiling these procedures establishes a standard of practice and provides a basis for quality control for rock and soil sampling across various MBMG program areas and office locations. While desired analyses may vary by the program or project for which the sample was collected, all samples should be collected and handled by the same or largely similar standards.

This document may be periodically reviewed, updated, and reissued to remain in line with evolving procedures and equipment.

13.3 Scope

These guidelines address recording field data, recommended sample volume and/or mass, and sample storage. It also describes procedures for submitting data and samples to the MBMG Mineral Separation Laboratory and Sample Repository.

The MBMG Mineral Separation Laboratory currently provides sample preparation for geochemical analysis, cosmogenic nuclide dating, U/Pb geochronology, He dating, Fission track (FT) dating, and Ar^{40}/Ar^{39} dating. Laboratory personnel may be able to prepare samples for other analyses or techniques. Principal Investigators should discuss project-specific or customized needs with the Laboratory Manager, including requirements for the volume, mass, or dimensions of sample material and preparation services needed.

13.4 Equipment and Supplies

- Rock hammer
- Chisel and handheld rock saw
- Heavy-duty plastic (recommended) or cloth sample bags
- Sharpie or other weatherproof writing implement
- Ties for bags
- Field notebook and/or tablet or other electronic data recorder
- Handheld GPS or equivalent

13.5 Field Procedures

Plan to collect enough sample material to perform all desired analyses and for cutting billets and thin sections. Also collect a representative hand sample for archiving. The amount of material needed for each analytical technique varies depending on rock type, target mineral, and other techniques that will be performed on the same sample. In general, collecting 1–2 kilogram (kg) of rock is sufficient for most analyses. If unsure, err on the side of collecting too much material rather than too little.

Sample requirements and laboratory processing for specific techniques are as follows:

- Geochemical analysis—100 grams of unweathered rock chips
- Cosmogenic nuclide dating—roughly 1 kg of rock crushed, milled, and sieved to between 250 and 500 micrometers (µm; target yield 500 grams) and magnetic separation (target mineral: quartz)
- U/Pb geochronology—roughly 2 kg of rock

crushed, milled, and sieved to less than 355 µm, Wilfley table separation, magnetic separation, and heavy liquid separation (target mineral: zircon)

- He and fission track (FT) dating—roughly 2 kg of rock crushed, milled, and sieved to less than 355 µm, Wilfley table separation, magnetic separation, and heavy liquid separation (target minerals: apatite and zircon)
- Ar^{40}/Ar^{39} dating—roughly 2 kg of rock crushed, milled, and sieved to 100 to 500 µm, depending on the geologic material type

Rock and sediment samples should be collected to match the needs of their intended analysis. For example, geochemical analysis requires fresh (unweathered) rock. In contrast, samples collected for cosmogenic nuclide dating should be from the rock surface or sediment surface exposed to weathering. Sample collectors should consult with project Principal Investigators before going into the field if they are uncertain about preferred sampling conditions.

Break up samples in the field to facilitate transport and additional processing at the laboratory. Break up the sample on the outcrop if possible, to avoid cross-contamination from other nearby rocks. Alternatively, samples may be brought to the lab where they can be broken up on a steel plate. This may incur additional lab processing charges.

Rock pieces that will be processed through crushing and milling must have all sides less than 9 cm in length, to fit into the chute of the jaw crusher. A piece larger than processing size may be retained as the representative hand sample.

Place the rock pieces in a heavyweight plastic sample bag. Include a piece of paper with the sample name, and tie the bag closed to prevent cross-contamination. Plastic bags are preferred to maintain cleanliness, although cloth bags may also be used. Using a Sharpie (or other weatherproof writing implement), write the sample name directly on the bag or on a label attached to the bag. If this were to become illegible, the label in the bag serves as a duplicate. If multiple bags are needed for a single sample, number each. For example, “Bag 1/2" and “Bag 2/2.”

Each sample will receive a unique database identifier when entered into the MBMG’s Natural Resources Archive Data System (NRADS) database as well as an International Generic Sample Number (IGSN). However, the sample name assigned in the field by the sample collector may consist of any combination of letters and numbers that meet the needs of that project. The sample name should follow a meaningful structure devised by the Principal Investigator or other project staff. For example, samples collected for the MBMG’s State Map Program are named according to the format XAAyyXBB0##, where

XAA is collector’s initials with a leading “X” if using only two initials;

yy is last two digits of year;

XBB is USGS 1:24,000-scale topographic map (7.5-minute quadrangle) name abbreviation with a leading “X” if abbreviation is two letters; and

0## is sample number by this collector within the 1:24,000 topo map, with a leading “0” or “00” if the sample number is one or two digits.

The sample name *XJM21BLM001* indicates the first sample collected by geologist JM in 2021 from the area within the Black Mountain 24k USGS topographic map.

13.6 Upon Return from the Field

Submit sample information into the NRADS web-based submission form prior to delivering samples to the lab. Submitting a group of samples via a spreadsheet format may be coordinated with the laboratory manager. The webform is available here: (https://data2.mbmg.mtech.edu/NRADS/login.asp).

The following minimum information is required for each sample submitted to the lab:

- Sample name assigned by collector
- Latitude and longitude, reported in decimal degrees, using the World Geodetic System 1984 (WGS84) datum and collected by navigational GPS (NAV-GPS)
- Date of sample collection
- Collector

Additional information related to a sample may be recorded in the submission form. However, field personnel may not be familiar with some of this information or geologic interpretation. For example, the stratigraphic unit or formation that was sampled may not be known with certainty. These fields may be completed following sample submission, for example after consultation with the project Principal Investigator. Additional information may include:

- Intended collection (example: STATEMAP, CORE CM, or other project name)
- Sample Type (example: rock, sediment, well cuttings, etc.)
- Sample Origin (examples: outcrop, mine tailings, streambed, etc.)
- Stratigraphic age
- Supergroup/group/formation/member/unit
- Rock type (igneous, metamorphic, sedimentary, etc.)
- Notes about the sample deemed important by the collecting geologist

Lab requests may also be entered at the time of sample submission, or can be completed later. After the initial NRADS sample information form is submitted, the Lab Manager will contact the sample collector to discuss the requests and coordinate sample delivery to the lab. Samples will generally be processed in the order they were received. Principal Investigators are encouraged to discuss laboratory scheduling with respect to project deadlines or other considerations with the Lab Manager.