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Quality-Assurance Plan for Ground-Water Activities, U.S. Geological Survey, Washington Water Science Center

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U.S. Department of the Interior
U.S. Geological Survey

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Compiled by Brian W. Drost

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Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

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Conversion Factors

Multiply	By	To obtain
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
quart (qt)	0.9464	liter

Quality-Assurance Plan for Ground-Water Activities, U.S. Geological Survey, Washington Water Science Center

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Abstract

This quality-assurance plan documents the standards, policies, and procedures used by the U.S. Geological Survey's Washington Water Science Center, for activities related to the collection, processing, storage, analysis, and publication of ground-water data. This plan serves as a guide to all Washington Water Science Center personnel involved in ground-water activities, and changes as the needs and requirements of the Washington Water Science Center and Discipline change. Regular updates to this plan represent an integral part of the quality-assurance process.

1.0—Introduction

This quality-assurance plan provides formal procedures for documentation and review of policies, practices, and activities that are used by the U.S. Geological Survey (USGS), Washington Water Science Center (WWSC), to assure the technical quality and reliability of WWSC ground-water products. The plan is based on the following principles:

- WWSC ground-water programs and projects will be planned efficiently and effectively to provide information needed to evaluate local, State, and National water resources.
- Technical and scientific activities will be performed in accordance with applicable Water Resources Discipline (WRD) practices and policies.
- Ground-water activities will be performed by technically qualified personnel performing at a level commensurate with their training and experience.
- All such activities and projects will receive appropriate and timely review for completeness, reliability, and credibility.
- Remedial actions will be taken to correct any observed technical or project deficiency.
- Safety procedures, training, and equipment will be provided to minimize hazards and protect field personnel.

The intent of this quality-assurance plan for ground-water activities does not differ in any substantial way from similar plans addressing water-quality and surface-water activities. However, because of the greater emphasis on data synthesis and interpretation in ground-water studies, and because of the limited number of formal standards established to govern the conduct of such studies, this plan focuses on the technical review process. For example, there is no single established technique for selecting "correct" values of storage coefficient or transmissivity for use in a ground-water flow model or other publication. The formal training, breadth of experience and technical judgment of the project leader, the Chief of the Hydrologic Studies Program, the appropriate section or unit chief, and the WWSC Ground-Water Specialist are all factors in determining the standards against which interpretive products are judged.

This plan generally conforms to the guidelines presented in the report, "A Quality-Assurance Plan for District Ground-Water Activities of the U.S. Geological Survey" (Brunett and others, 1997).

2.0—Organization and Responsibilities

Organization and responsibilities for conduct and review of district ground-water projects, data collection, and other activities are outlined in the USGS ground-water quality-assurance plan (Brunett and others, 1997).

3.0—Training and Safety

The qualifications of project personnel relative to the technical demands of the work will be determined by the project leader, WWSC managers, and discipline specialists, and training to remedy deficiencies will be recommended. Personnel will receive training to ensure technical competence or to rectify inadequacies. The appropriate section or unit chief will develop and document a specific plan to provide the required training. This plan will be approved by the Chief of the Hydrologic Studies Program. The WWSC will perform all quality-assurance activities related to training as documented in Brunett and others (1997, p. 5).

Performing work activities in a manner that ensures the safety of personnel and others remains the highest priority for the USGS and the WWSC. Beyond the obvious negative impact unsafe conditions can have on personnel, such as increasing the potential for accidents and personal injuries, they also can have a direct effect on the quality of ground-water data and data analysis. For example, errors may be made if an individual's attention to detail is compromised when dangerous conditions create distractions. So that personnel are aware of and follow established procedures and policies that promote all aspects of safety, the WWSC communicates information and directives related to safety to all personnel through in-house and out-of-office training classes, memoranda, and video-tape sessions.

In the WWSC, a designated Safety Officer heads the WWSC Safety Committee, identifies and provides direction on safety issues, manages the safety budget, coordinates safety training, prepares safety reports for the Regional Office, and deals with new and ongoing safety issues. Currently, the WRD provides policy and guidelines for safety-related issues in the WWSC. The Safety Committee, which meets periodically, consists of nine members: the WWSC Safety Officer, the WWSC Chief, one member from each of the three Field Offices, one member representing administration and management, and one specialist each in aviation, hazardous waste, and boat safety.

Job Hazard Analyses (JHAs) list the basic tasks of a job, identify the potential hazards associated with the tasks, and help develop safety procedures to avoid the hazards. WWSC personnel who have questions or concerns pertaining to safety, or who have suggestions for improving some aspect of safety, should direct those questions, concerns, and suggestions to their supervisor or the Safety Officer.

4.0—Project Planning and Review

Project planning includes project staffing and preparation of a project work plan. The Hydrologic Studies Program Chief is responsible for the selection of the project leader, but the selection will be made in consultation with the WWSC Chief, discipline specialists, and Section Chief, as appropriate. All projects will receive technical review at established times during the life of the project. Responsibility for scheduling technical reviews rests with the Ground-Water Specialist and the Hydrologic Studies Program Chief.

4.1—Development of Work Plan

The development of a project work plan typically begins in discussions, either with a cooperator or within the WWSC staff, regarding a ground-water problem or information need. At this point, the project chief, in consultation with the appropriate WWSC discipline specialists, program, section or unit chiefs, and experienced ground-water personnel, develops a project proposal. Generally, the proposal will indicate the overall purpose, scope, objectives, strategy, duration, general personnel requirements, funding, and expected products of the study.

Following project approval by the Western Region Office of the Regional Hydrologist, the proposal will be developed into a detailed work plan. This generally involves a literature search of applicable reports, and some limited field reconnaissance. The work plan summarizes data needs and technical approaches, identifies work elements, itemizes costs, defines personnel needs, and provides deadlines for each work element. Requirements for work by the Technical Communications and the Computer Applications Sections, by the cooperator, or by contractors will be clearly identified and scheduled.

A report-planning document may be developed as an integral part of the project work plan. The planning document will identify the type, scope, intended audience, and planned reports; and will provide a preliminary outline of each report, including a description of major illustrations and tables. Preparation of the work plan and report-planning documents is to be accomplished in the first 10 percent of the project duration. To achieve this end, the project leader confers with the Hydrologic Studies Program Chief, the WWSC Ground-Water Specialist, and any other persons, USGS or non-USGS, who may offer guidance or insight into the problem being investigated.

The work plan and report-planning document will meet the financial and temporal limits already placed on the study in the approved project proposal, and will schedule the submission of the final report(s) so that the report(s) will be published prior to the conclusion of project funding. The work plan will include a completed Report Processing Schedule. The work plan will be reviewed by the Hydrologic Studies Program Chief, appropriate section or unit chief, other discipline specialists, as appropriate, Reports Specialist, and the WWSC Chief. Review also may be sought from Regional or Headquarters personnel, or from the cooperating agency. The project chief will develop a final work plan and report plan in response to the review comments.

If, during development of the work plan (or at any other time during the life of the project), it becomes clear that the technology, funding, personnel, or time indicated in the original project description are inadequate to meet project objectives, the Project Chief will so inform the Hydrologic Studies Program Chief. The Hydrologic Studies Program Chief may then direct the Project Chief to complete two modified versions of the work plan. In one of these versions, the objectives will be reduced to fit the originally estimated resources; in the other version, the resources will be increased to meet the original objectives. These two plans, after appropriate internal review, will form the basis for further negotiations between the cooperating agency and the WWSC staff on modifications to the originally approved proposal. A final plan will be developed from the results of these negotiations. If at any time the scope of the project must be modified from that described in the approved proposal and work plan, these modifications must be agreed upon by both the WWSC and the cooperating agency and must be documented by the Project Chief.

The general project personnel requirements will be determined during the proposal process. Personnel assignments become more specific as the work plan is developed. As the need for each position on the project staff is established, selection procedures will be initiated and the staff assembled. This process will normally overlap the process of developing the work plan.

4.2—Project Review

All projects will receive technical review at established times during the life of the project. The project type and complexity will determine the frequency and scope of the review, but all ground-water projects will be reviewed by the Ground-Water Specialist and the Hydrologic Studies Program Chief at approximately 10, 40, and 70 percent of project duration.

For projects with no set termination dates (e.g., ground-water-monitoring networks or ground-water data base management), technical reviews will be held at least annually. In addition, ongoing and frequent, informal reviews are conducted during team meetings, and during discussions among project staff, Hydrologic Studies Program Chief, section and unit chiefs, discipline specialists, and others, as appropriate. In some instances, technical advisory groups may be established to oversee and monitor project activities. A file of project reviews is maintained by the WWSC Administrative Services Section.

WWSC projects also receive administrative reviews (budget and timelines) quarterly. If during these reviews it is determined that additional technical review is needed (beyond the 10-40-70 technical review schedule), the Hydrologic Studies Program Chief and the Ground-Water Specialist will schedule and conduct the additional review.

5.0—Data Collection

The types of data collected, the standards governing the precision and accuracy of the data, and the frequency with which data are collected may differ among the various ground-water projects, according to the objectives of the individual studies. The project chief must clearly document and provide to the project personnel, in sufficient detail, instructions regarding data collection so the project's data needs are satisfied. Routine and non-routine data-collection activities and procedures are documented by project or support personnel and recorded in appropriate field notebooks. These notes are to be kept with project files and archived upon project completion.

Supervision of field procedures and activities is an essential responsibility of the project chief, who must assure, through personal observation or with the assistance of the Ground-Water Specialist, that field personnel are fully qualified. The Ground-Water Specialist will review the data-gathering activities of all ground-water projects as part of project reviews (see Section 4.2). Project personnel will be trained to ensure technical competence or to rectify inadequacies.

Individual field practices are spot-checked by the Ground-Water Specialist or designated representative. The frequency and intensity of these checks generally are matched with each field person's individual capabilities and experience. However, even the practices of the most experienced and capable field personnel are checked on at least a biennial basis, with more frequent checks required for personnel of lesser experience.

5.1—Documentation of Technical Procedures

Procedures used for the collection of ground-water data are derived from a series of technical procedures documents, technical memoranda, Techniques of Water-Resources Investigations (TWRIs) reports, and a number of other publications. The primary documentation of technical procedures is discussed in WWSC ground-water procedure documents (GWPD 8.1). Technical procedures for which a WWSC technical procedure document is not available generally can be found in the techniques of data collection, which contains discussions of all the major types of ground-water data collection, together with extensive bibliographies relevant to each activity (U.S. Geological Survey, 1977). Standards for ground-water data collection will be based on the methods outlined in that chapter, or in the selected references contained therein. Technical procedures not documented in any of the above should be discussed and planned with the WWSC Ground-Water Specialist and documented in the project files.

Techniques for the collection of ground-water samples are given in U.S. Geological Survey, variously dated, in other TWRIs, in memoranda issued by the Office of Water Quality, and in publications with technical guidance provided by the WWSC Water-Quality Specialist. The WWSC Ground-Water Specialist will ensure that full coordination is arranged, and when applicable, that suitable cross training in water-quality procedures is provided.)

5.2—Instrumentation

Quality-assurance procedures involving instrumentation will be conducted as described in Brunett and others (1997, p. 11-13).

6.0—Data Processing, Review, Storage, and Archiving

All ground-water data will be processed, reviewed, stored, and archived in accordance with Washington Water Science Center Instructional Memoranda.

7.0—References Cited

Brunett, J.O., Barber, N.L., Burns, A.W., Fogelman, R.P., Gillies, D.C., Lidwin, R.A., and Mack, T.J., 1997, A quality-assurance plan for district ground-water activities of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 97-11, accessed March 2004, at URL: http://water.usgs.gov/ogw/pubs/OFR9711/index.html

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at URL: http://pubs.water.usgs.gov/twri9A.

8.0—Appendixes: Washington Water Science Center Ground Water Procedure Documents

8.1—Ground Water Procedure Documents (GWPD)

GWPD 8.1a—Ground-Water Site Inventory (GWSI)

Purpose

To specify procedures for well and spring site inventory (location) and the minimum amount of information that should be collected during the initial reconnaissance of an individual ground-water site.

Materials and Instruments

1. A state highway map, county road map, a USGS 7.5-minute topographic quadrangle map, and a quarter-quarter section grid overlay. When required, an aerial photograph, or a town plat/lot number map also may be used. A Global Positioning System (GPS) instrument should be used to establish an accurate well location (see GWPD 8.1b).
2. Well schedule form 9-1904-A (http://wwwnwis.er.usgs.gov/forms/GW-site-form.pdf) and water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf), or other forms approved by the WWSC Ground-Water Specialist.
3. Orienteering (transparent base) compass (optional).
4. Equipment for water-level measurements (see GWPD 8.1c-g).
5. Pen or pencil.
6. Camera and film and whiteboard and marker (optional).
7. Washington Department of Ecology (WDOE) Water Well Report or other documents pertaining to the well being inventoried (optional).

Data Accuracy and Limitations

1. Latitude and longitude values determined using a GPS instrument can be read to the nearest tenth of a second and generally are accurate to at least one-half second.
2. Well construction information obtained from the well driller or from geophysical logs generally should be considered as more reliable than information obtained verbally from the well owner.
3. Altitudes determined from topographic maps are considered to be accurate to within one-half of the map contour interval.

Assumptions

1. A ground-water site is a single point, not a geographic area or property.
2. A GPS instrument is used to determine the latitude and longitude.
3. A USGS 7.5-minute topographic quadrangle map with 1:24,000-scale will be used to plot the well location and determine land-surface altitude. The person locating the well can accurately plot the location on the 7.5-minute topographic quadrangle map.
4. Site information is recorded on form 9-1904-A or other forms approved by the WWSC Ground-Water Specialist, as it is collected and never documented from memory.
5. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

Note: *The minimum data requirements for GWSI change frequently as the software is updated. Consult GWSI Database Administrator for updates to minimum requirements.*

1. By examining available data files and interviewing the well owner and (or) driller, compile the following ground-water site data in the field using form 9-1904-A or other forms approved by the WWSC Ground-Water Specialist.

   Note: *It is critical to determine that the well visited is indeed a match for the driller's log or other data taken into the field (i.e., use the WDOE well tag number, the log data [e.g., casing type and diameter, well depth, date drilled, owner's name, site address, etc.], reported information, and your observations to establish a reasonable certainty that there is a match).*

   a) Source of information—Date of site visit and name of person conducting site visit.

   Note: *All field-recorded information should come from observation/measurement or be reported by owner, renter, neighbor, etc. Information from the driller's log should NOT be copied to the field form.*

b) Geographic location—see GWPD 8.1b.

c) Political regimes—State and county or town identification and land-net location.

d) Source identifiers—Owner's name and address.

e) Individual site characteristics—Topographic setting, use of site, use of water.

f) Well construction—Driller's name, date drilled, type of well (drilled, bored, or dug), total depth, casing (type, depth, and diameter), finish (screen, open hole). It is important to note which data are from observations and which are reported (e.g., was well depth measured or reported?).

g) Any reported information on well yield, dependability, amount of water use, water quality, or any other pertinent items should be recorded on the field well schedule (C185).

h) WDOE "Unique Well No.": If a WDOE tag is present, the number should be recorded on the field schedule (C190). This number should be compared to the number on the driller's log to verify a match between the log and well being visited.

Note: *Some well drillers attach information on well depth, casing depth, water levels, etc., to the well casing (or in concrete pads around wells, etc.). Also, some well owners record information (water levels, water usage, etc.) on walls of well houses. This type of information should be recorded on the field schedule (C185) and the source of the information indicated.*

2. Locate and plot the ground-water site (see GWPD 8.1b).
3. Prepare a detailed sketch map of the site location (see GWPD 8.1b).
4. Record water-level measurements and date and time measured on water-level measurement field form 9-194 or other forms approved by the WWSC Ground-Water Specialist. See technical procedure documents for making water-level measurements using a graduated steel tape (8.1d), an electric sounding tape (8.1e), or an air line (8.1f). See 8.1g for making water-level measurements in a flowing well.
5. OPTIONAL—Take photographs of the well location (indicating on the photograph the direction of view) and the measuring point (MP). Include in the photograph a whiteboard with the well number or other identifying information indicated. File photographs with the other site data.

Data Recording

Data are recorded in the field on well schedule form 9-1904-A or other forms approved by the WWSC Ground-Water Specialist. Water levels are recorded on the water-level measurements form 9-194 or other forms approved by the WWSC Ground-Water Specialist. All field forms, the sketch map, photographs, and a copy of the field topographic map showing the plotted location are to be filed together in the WWSC's permanent ground-water records.

Selected References

American Society for Testing and Materials, 1994, ASTM standards on ground water and vadose zone investigations (2d ed.): Philadelphia, Pa., American Society for Testing and Materials, p. 300-304.

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

U.S. Geological Survey, 1990, National water information system user's manual, ground-water site inventory system: U.S. Geological Survey Open-File Report 89-587, v. 2, chap. 4, (variously paged).

GWPD 8.1b—Locating a Well

Purpose

To specify procedures for characterizing the location of a well.

Materials and Instruments

1. A Global Positioning System (GPS) instrument.
2. A state highway map.
3. USGS 7.5-minute topographic quadrangle map, 1:24,000-scale and quarter-quarter section grid overlay.
4. Well schedule form 9-1904-A (http://wwwnwis.er.usgs.gov/forms/GW-site-form.pdf) and water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf), or other forms approved by the WWSC Ground-Water Specialist.
5. Pen or pencil.
6. Orienteering (transparent base) compass (optional).
7. Town or county plat map (optional).
8. Aerial photograph (optional).

Data Accuracy and Limitations

1. Latitude and longitude values determined using a GPS instrument can be read to the nearest tenth of a second and generally are accurate to at least one-half second.

Assumption

1. The person locating the well has been trained to use a GPS instrument to determine the latitude and longitude of a point on the ground.

Instructions

1. The GPS unit should be placed as close as possible to the well while also being positioned to allow the maximum number of satellites to be used (avoid interference from metal buildings, power lines, etc.). The position of the GPS unit relative to the well should be recorded (e.g., 40 ft southwest of well – to avoid metal well house) (adjustments to the recorded latitude/longitude should be made to account for the positioning of the GPS instrument). After the GPS instrument has obtained a steady reading, record the latitude, longitude, number of satellites, estimated position error, and datum used. Latitude and longitude should be recorded in degrees, minutes, and seconds. The GPS instrument model and identification number should be recorded.

   Note: *When visiting a well that has a latitude/longitude determined from a previous single GPS measurement, repeat the GPS measurement and compare to the previous values.*

2. Prepare a detailed sketch map of the site location. The sketch map should include a North arrow. The sketch map should contain enough detail so that a person who has never visited the site can find the well again. Include distances (in feet) from permanent landmarks, such as buildings, bridges, culverts, and road center lines. These distances should be measured by pacing where possible (if distances are estimated, so indicate). Distances from road intersections may be measured using a vehicle odometer and recorded to the nearest 0.1 mi. The "topographic setting" should be noted and recorded (see C19 of form 9-1904-A). In addition, detailed sketches of the well including the measuring point (MP), access ports for water-level measurements, and sampling points should be drawn on the back of the field form with the date recorded. This information is updated during each future site visit.
3. The ground-water site should be plotted on the topographic map while at the site. The sketch map and topographic map plot should be compared for consistency while in the field.
4. In the office, the latitude and longitude determined with the GPS instrument should be used to plot (digitally) the well locations as accurately as possible on a 7.5-minute topographic map. The land-surface altitude should then be determined from this plotted location and coded into GWSI. The digital plot should be compared to the field topographic map plot. The local site number (Township/Range-Section-Quarter-Quarter Section) generated from the field plot should be checked versus the digital plot and reassigned if necessary. If available, use LIDAR data to determine a more accurate land-surface altitude than is possible from the topographic map.
5. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Data Recording

Data are recorded in the field on well schedule form 9-1904-A or other forms approved by the WWSC Ground-Water Specialist. All field forms, the sketch map, and a copy of the field topographic map showing the plotted location are to be filed with the WWSC's permanent ground-water records.

Selected References

American Society for Testing and Materials, 1994, ASTM standards on ground water and vadose zone investigations (2d ed.): Philadelphia, Pa., American Society for Testing and Materials, p. 300-304.

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

U.S. Geological Survey, 1990, National water information system user's manual, ground-water site inventory system: U.S. Geological Survey Open-File Report 89-587, v. 2, chap. 4, (variously paged).

GWPD 8.1c—Well-Depth Measurement Using a Graduated Steel Tape

Purpose

To measure the total depth of a well below land-surface datum using a graduated steel tape. This method is recommended for wells less than 200-ft deep.

Materials and Instruments

1. Steel tape graduated in feet, tenths and hundredths of feet. A break-away weight should be attached to the end of the tape, strongly enough to hold the weight, but not as strong as the tape, so that if the weight becomes lodged in the well the tape still can be pulled free. The weight should be brass, stainless steel, or iron.
2. Clean rag.
3. Diluted household chlorine bleach (20:1 dilution with tap water), single-use towels, and latex gloves (optional).
4. Tool box (see "Ground-Water Tool Box; Recommended Contents").
5. Pen or pencil.
6. Water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf) or other forms approved by WWSC Ground-Water Specialist.
7. Gloves, of leather or other protective material (optional).

Data Accuracy and Limitations

1. A graduated steel tape commonly is accurate to 0.01 ft.
2. The steel tape should be calibrated against another acceptable steel tape. An acceptable steel tape is one that is maintained, in the office, for use only for calibrating steel tapes.
3. When measuring well depth in deep wells, tape expansion and stretch is an additional consideration (Garber and Koopman, 1968).
4. If the well casing is angled instead of vertical, the well depth will have to be corrected.

Advantages

1. The graduated steel tape is considered to be the most accurate method of measuring well depth.
2. Easy to use.
3. Small diameter allows entry to wells with openings too small for probes on electrical tapes.

Disadvantages

1. Not recommended for measuring wells with installed pumps (definitely not in pumping wells).
2. Difficult to get accurate results for wells in excess of 200-ft deep.

Assumptions

1. An established measuring point (MP) exists. See GWPD 8.1h for technical procedure document on establishing an MP.
2. The MP is clearly described so that a person who has not measured the well will know where to measure from.
3. The well is free of obstructions. Well obstructions, if present, could cause errors in the measurement if the obstructions affect the plumbness of the steel tape.
4. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

1. Before making the well-depth measurement in a well used for drinking-water supply, disinfect the weights and that portion of the tape that will pass below the water level in the well with dilute bleach solution.

   ***Note**: Preferred method of disinfection is to submerge the end of the tape and weights in the bleach solution (5-gal plastic containers with small diameter screw-on caps are included for this purpose with the WWSC ground-water field equipment). However, generally only the first 5–10 ft of the tape can be disinfected by submergence. The remainder can be disinfected by running the tape over a clean cloth soaked in the bleach solution as the tape is lowered into the well.*

   ***Note**: Latex gloves are recommended for this procedure (to increase sanitary condition of tape as well as to protect the individual from bleach solution). When possible, the recommended procedure is to use the latex gloves for both the disinfecting procedure and the measurement itself (this may not be possible when measuring deep water levels—leather gloves may be required to avoid cutting your hand with the edge of the tape).*

2. Measure from the zero point on the tape to the bottom of the weight. Record this number as the length of the weight interval.
3. Lower the weight and tape into the well until the weight reaches the bottom of the well and the tape slackens. The tape should be lowered by sliding it over the palm of one hand, which is held as directly above the well as possible while the other hand holds the handle of the tape reel and swings it in a pendulum motion (allowing the weight of the tape to be felt continuously, thereby reducing the chance of the tape hanging up and becoming tangled).

   Note: *Gloves are recommended for this procedure.*

4. Partially withdraw the tape from the well until the weight is standing in a vertical position, but still touching the bottom of the well. A slight jerking motion will be felt as the weight moves from the horizontal to the vertical position.
5. Repeat step 3 several times by lowering and withdrawing the tape to obtain a consistent reading.
6. Record the tape reading held at the MP.
7. Withdraw the tape from the well 1–2 ft, so that the weight will hang freely above the bottom of the well. Repeat steps 2 through 4 until two consistent depth readings are obtained.
8. Calculate total well depth below land-surface datum (LSD) as follows:

(Tape reading held at the MP) + (Length of the weight interval) +/– (MP correction) =

Total well depth below LSD.

Data Recording

Data are recorded in the field on water-level measurement form 9-194 or other forms approved by the WWSC Ground-Water Specialist. The original field form is to be filed with the WWSC's permanent ground-water records. Well-depth data also should be recorded in the ground-water site data section, on the second page of the GWSI ground-water site schedule (form 9-1904-A). All data are recorded to the nearest 0.01 ft.

Selected References

Garber, M.S., and Koopman, F.C., 1968, Methods of measuring water levels in deep wells: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chap. A1, 23 p.

U.S. Geological Survey, 1989, Yucca Mountain Project—Use of hand-held steel tapes in vertical boreholes, U.S. Geological Survey Technical Procedure HP-61, p. 2.

GWPD 8.1d—Water-Level Measurement Using a Graduated Steel Tape

Purpose

To measure the depth to water surface below a measuring point using the graduated steel tape (wetted-tape) method.

Materials and Instruments

1. A steel tape graduated in feet, tenths and hundredths of feet. A break-away weight should be attached to the end of the tape, strong enough to hold the weight, but not as strong as the tape, so that if the weight becomes lodged in the well the tape can still be pulled free. The weight should be brass, stainless steel, or iron. The most commonly used weights in the Washington WWSC are "sausage weights" (alternating several-inch long segments of surgical tubing and stainless steel or brass rods). It is permissible to use an unweighted tape where conditions do not allow access for a weighted tape – in these circumstances; the tape should be carefully inspected to make sure it is free of any kinks or bends that would decrease the accuracy of the measurement.
2. Blue carpenters chalk.
3. Clean rag.
4. Pen or pencil.
5. Water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf) or other forms approved by WWSC Ground-Water Specialist.
6. Tool box (see Ground-Water Tool Box; Recommended Contents).
7. Diluted household chlorine bleach (20:1 dilution with tap water), single-use towels, and latex gloves (optional).
8. Gloves, of leather or other protective material (optional).

Data Accuracy and Limitations

1. A graduated steel tape is commonly accurate to 0.01 ft.
2. The steel tape should be calibrated against another acceptable steel tape. An acceptable steel tape is one that is maintained, in the office, for use only for calibrating steel tapes.
3. When measuring deep water levels, tape expansion and stretch is an additional consideration (Garber and Koopman, 1968).

Advantages

1. The graduated steel tape method is considered to be the most accurate methods for measuring the water level in nonflowing wells of moderate depth.
2. Easy to use.

Disadvantages

1. May be impossible to get reliable results if water is dripping or cascading into the well or condensing on the well casing. Cascading water is common in open-hole basalt wells in eastern Washington.
2. Potentially hazardous (to pumps and people) in pumping wells. Pumping levels should be measured only if there is reliable information as to the intake depth of the pump (tapes should not be lowered to any closer than 5 ft of the intake depth).
3. Difficult to get reliable results if an oil layer is present.
4. Because there is generally no indication of when the water level has been reached, it is possible to lower the tape into the water past the point to which the tape has been disinfected.

Assumptions

1. An established measuring point (MP) exists or will be established as part of measurement. See GWPD 8.1h for technical procedure document on establishing an MP.
2. The MP is clearly described so that a person who has not measured the well will know where to measure from.
3. A water-level measurement taken during the last field visit or from the driller's log is available to estimate the length of tape that should be lowered into the well. If no previous measurement information is available, first measurement may be done more efficiently by using an electric sounding tape.
4. The well is free of obstructions. Well obstructions, if present, could cause errors in the measurement if the obstructions affect the plumbness of the steel tape.
5. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

1. Before making the water-level measurement in a well used for drinking-water supply, disinfect with diluted bleach solution and dry with single-use towels (e.g., techwipes) the first 5 to 10 ft of the tape, including weights.

   Note: *Preferred method of disinfection is to submerge the end of the tape and weights in the bleach solution (5-gal plastic containers with small diameter screw-on caps are included for this purpose with the WWSC ground-water field equipment).*

   Note: *Latex gloves are recommended for this procedure (to increase sanitary condition of tape as well as to protect the individual from bleach solution). When possible, the recommended procedure is to use the latex gloves for both the disinfecting procedure and the measurement itself (this may not be possible when measuring deep water levels—leather gloves may be required to avoid cutting your hand with the edge of the tape).*

2. Chalk the lower few feet of the tape by pulling the tape across a piece of blue carpenter's chalk. The wetted chalk mark will identify that part of the tape that was submerged.

3. Lower the tape and weight into the well until the lower end of the tape is submerged below the water. The tape should be lowered by sliding it over the palm of one hand which is held as directly above the well as possible while the other hand holds the handle of the tape reel and swings it in a pendulum motion (allowing the weight of the tape to be felt continuously, thereby reducing the chance that the tape will hang up and become tangled). Slowly lower the tape and weight into the water to prevent splashing. Continue to lower the end of the tape into the well until the tape has reached several feet past the assumed water-level depth. Hold the tape against the MP and record the value on the tape in the `MP HOLD' column of the water-level measurements field form 9-1905-A or other form approved by the WWSC Ground-Water Specialist.

   Note*: Gloves are recommended for this procedure.*

4. Rapidly bring the tape to the surface before the wetted chalk mark dries and becomes difficult to read. Record the number of the wetted chalk mark (referred to as the cut) in the `WETTED CHALK MARK' column of the water-level measurements field form, 9-1905-A or other forms approved by the WWSC Ground-Water Specialist.

   Note: *In extremely cold conditions, freezing of the water on the tape sometimes distorts the wetted chalk mark and may also make drying and rechalking the tape very difficult. If so, use an electric sounding tape.*

5. Subtract the wetted chalk mark number from the number held to the MP, and record this number in the `DEPTH TO WATER FROM MP' column of the water-level measurements field form, 9-1905-A or other forms approved by the WWSC Ground-Water Specialist. The difference between these two readings is the depth to water below the MP. Record depth to water, date and time of measurement, and initials of party making the measurement.

6. Apply the MP correction to get the depth to water below or above land-surface datum. If the MP is above land surface, the distance between the MP and land-surface datum is subtracted from the depth to water from the MP to obtain the depth to water below land surface. If the MP is below land surface, precede the MP correction value with a minus (–) sign and subtract the distance between the MP and land surface datum from the depth to water from the MP to obtain the depth to water below land surface (this is the same as adding the MP to the depth of water below the MP). Record this number in the `DEPTH TO WATER FROM LSD' column of the water-level measurements field form, 9-1905-A or other forms approved by the WWSC Ground-Water Specialist. If the water level is above LSD, record the depth to water in feet above land surface as a negative number.

7. Make a check measurement by repeating steps 1 through 5. The check measurement should be made using a different hold value than that used for the original measurement. The difference between hold values should not be an integer number of feet. For example, if the first hold is 91.00 ft, then the second should not be 92.00 ft, but could be 92.20 ft. If the check measurement does not agree with the original measurement within 0.02 ft,

continue to make check measurements until the reason for the lack of agreement is determined or until the results are shown to be reliable. If more than two readings are taken, record the average of all readings (exception: if several readings agree within 0.02 ft, while another differs by more 0.02 ft, then the outlier can be ignored. It is common in wells with pump columns, wiring, etc. down the hole to have the tape travel in a multitude of pathways as it is lowered into the well; this sometimes results in what appear to be valid measurements, but which cannot be easily repeated. If repeated measurements indicate a non-static condition (e.g., the water level is rising due to recovery from recent pumping, or the water level is declining due to pumping of a nearby well), indicate the appropriate status of the water level on the field form. To determine if the water level measured is truly static, repeat measurements should be at least 3 minutes apart. Wells in Washington commonly have slowly rising or declining water levels, which differ greatly from static conditions. If only non-static water levels are recorded, then the highest level should be coded into GWSI.

8. Maintain the tape in good working condition by periodically checking the tape for breaks, kinks and possible stretch due to the suspended weight of the tape and the tape weight.

9. In some pumped wells (typically those with turbine pumps), a layer of oil may float on the water surface. If the oil layer is thin (generally a foot thick or less), read the tape at the top of the oil mark and use this data for the water-level measurement instead of the wetted chalk mark. The measurement will differ slightly from the water level that would be indicated were the oil not present. However, if more than a foot of oil is present in the well, or if it is necessary to know the thickness of the oil layer, a commercially available water-detector paste can be used that will detect the presence of water in the oil. The paste is applied to the lower end of the tape and will show the top of the oil as a wet line, and the top of the water will show as a distinct color change. Because oil density is about three-quarters that of water, the water level can be estimated by adding the thickness of the oil layer times its density to the oil-water interface elevation. The status of the water level should be recorded as “V” (foreign substance) and noted in remarks.

Data Recording

All water-level data are recorded on the water-level measurement form 9-194 or other forms approved by the WWSC Ground-Water Specialist, to the nearest 0.01 ft. All original field forms are filed with the well records.

Selected References

Garber, M.S., and Koopman, F.C., 1968, Methods of measuring water levels in deep wells: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chap. A1, 23 p.

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

GWPD 8.1e—Water-Level Measurements Using an Electric Sounding Tape

Purpose

To measure the depth to the water surface below a measuring point using the electric-tape method.

Materials and Instruments

1. Electric water-level measurement device. Electric sounding tapes commonly are mounted on a hand-cranked supply reel that contains space for batteries and some device for signaling when the circuit is closed. To be acceptable, electric sounding tapes must be stretch-resistant and graduated in 0.01-ft intervals.

   Note: *"old-style" electric sounding tapes graduated in 5-ft intervals and (or) without embedded stretch-resistant cables, should no longer be used in the WWSC.*

2. Pen or pencil.
3. Water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf) or other forms approved by the WWSC Ground-Water Specialist.
4. Tool box (see Ground-Water Tool Box; recommended contents).
5. Diluted household chlorine bleach (20:1 dilution with tap water), single-use towels, and latex gloves (optional).
6. Gloves, of leather or other protective material (optional).

Data Accuracy and Limitations

1. Independent electric sounding tape measurements of static water levels using the same tape should agree within + or - 0.02 ft for depths of less than about 250 ft.
2. For depths in excess of 250 ft, the maximum difference of independent measurements using the same tape should agree within ±0.04 ft.
3. For depths in excess of about 1,000 ft, the repeatability of measurements using the same tape should agree within ±0.1 ft.

Advantages

1. Superior to steel tape method when water is dripping or cascading into the well or condensing on the inside casing walls, which may make it impossible to get a good water mark on a chalked steel tape.
2. Superior to steel tape method in wells that are being pumped, particularly with large-discharge pumps, where the splashing of the water surface makes consistent results by the wetted-tape method impossible.
3. Superior to steel tape method when a series of measurements are needed in quick succession, such as during aquifer tests, because the electric sounding tape does not have to be removed from the well for each reading.
4. Superior to steel tape when making measurements in the rain.
5. Safer to use in pumping wells than steel tape method because the water is sensed as soon as the probe reaches the water surface and there is less danger of lowering the tape into the pump impellers.
6. May be easier to use for deep water levels or in cramped conditions due to lighter weight.
7. Much easier and faster water-level measurements than with steel tape method, particularly when no estimate of the water level is available before measurement is made.
8. Much less likely to extend tape into water past the point to which the tape has been disinfected.

Disadvantages

1. Harder to keep calibrated than a steel tape. Electric connections need to be maintained in good order.
2. Probes are of greater diameter than steel tapes and therefore will not fit into some well openings accessible to steel tapes.

Assumptions

1. An established measuring point (MP) exists or will be established as part of the measurement. See GWPD 8.1h for the technical procedure document on establishing an MP.
2. The MP is clearly described so that a person who has not measured the well will know where to measure from.
3. The well is free of obstructions. Well obstructions, if present, could cause errors in the measurement if the obstructions affect the plumbness of the electric sounding tape.
4. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

1. Before making the water-level measurement in a well used for drinking-water supply, disinfect with diluted bleach solution and dry with single-use towels (e.g., chemwipes) the first 5–10 ft of the tape, including weights.

   Note: *Preferred method of disinfection is to submerge the end of the tape and weights in the bleach solution (5-gal plastic containers with small diameter screw-on caps are included for this purpose with the WWSC ground-water field equipment: use 1-qt household bleach and tap water to fill 5-gal container).*

Note: *Latex gloves are recommended for this procedure (to increase sanitary condition of tape as well as to protect individual from bleach solution). When possible, the recommended procedure is to use the latex gloves for both the disinfecting procedure and the measurement itself (this may not be possible when measuring deep water levels—leather gloves may be required to avoid blistering your hand from the friction of the tape passing over it).*

2. Check the circuitry of the electric sounding tape before lowering the probe into the well, either by turning the control to test mode, or placing the probe in water.

   Note: *Most newer tapes have a sensitivity setting. Start with the setting in mid-range and adjust as necessary.*

3. Lower the tape (and weight, if needed) into the well. The tape should be lowered by sliding it over the palm of one hand which is held as directly above the well as possible while the other hand holds the handle of the tape reel and swings it in a pendulum motion (allowing the weight of the tape to be felt continuously, thereby reducing the chance of the tape hanging up and becoming tangled). The tape and weight should be lowered slowly into the water to prevent splashing. Continue to lower the end of the tape into the well until contact with the water surface closes the circuit activating the indicator (light, buzzer, etc.). The tape should be raised and lowered a few inches at a time to best locate the point where the indicator is activated. Hold the tape against the MP and record the value on the tape in the `MP HOLD' column of the water-level measurements field form 9-1905-A or other forms approved by the WWSC Ground-Water Specialist.

   Note: *Gloves are recommended for this procedure.*

4. Apply the MP correction to get the depth to water below or above land-surface datum. If the MP is above land surface, the distance between the MP and land surface datum is subtracted from the depth to water from the MP to obtain the depth to water below land surface. If the MP is below land surface precede the MP correction value with a minus (–) sign and subtract the distance between the MP and land surface datum from the depth to water from the MP to obtain the depth to water below land surface (this is the same as adding the MP to the depth of water below the MP). Record this number in the `DEPTH TO WATER FROM LSD' column of the water-level measurements field form, 9-1905-A or other forms approved by the WWSC Ground-Water Specialist. If the water level is above LSD, record the depth to water in feet above land surface as a negative number.

5. Make a check measurement by repeating steps 2 and 3. If the check measurement does not agree with the original measurement within the accuracy given under data accuracy, continue to make check measurements until the reason for the lack of agreement is determined or until the results are shown to be reliable. If repeated measurements indicate a non-static condition (e.g., the water level is rising due to recovery from recent pumping, or the water level is declining due to pumping of a nearby well), indicate the appropriate status of the water level on the field form. Repeat measurements should be at least 3 minutes apart (in order to determine if the water level measured is truly static—wells in Washington commonly have slowly rising or declining water levels, which differ greatly from static conditions).

   Note: *Record the identification number of the electric sounding tape on the field form.*

6. Maintain the tape in good working condition by periodically checking the tape for breaks, kinks, and possible stretch due to the suspended weight of the tape and the tape weight. Do not let the tape rub across the top of the casing because the insulating sheathing could be breached, resulting in shorting of the circuit.

   Note*: At least once during each field trip (minimum of once a week during prolonged trips), measure a water level using both an electric sounding tape and a steel tape. These check measurements should be reported to the WWSC Ground-Water Specialist for inclusion in an electrical tape versus steel tape comparison file.*

Data Recording

All data are recorded on the water-level measurement form 9-194 or other forms approved by the WWSC Ground-Water Specialist, to the appropriate accuracy for the depth being measured. See data accuracy and limitations. All original field forms are filed with the well records.

Selected References

Garber, M.S., and Koopman, F.C., 1968, Methods of measuring water levels in deep wells: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chap. A1, 23 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water Supply Paper 2220, p. 72-73.

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

GWPD 8.1f—Water-Level Measurement Using an Existing Air Line

Purpose

To measure the depth to the water surface below a measuring point using the submerged air line method in an existing air line. Use this method only if wetted-steel tape or electric sounding tape methods are not applicable (e.g., no access for tape).

Materials and Instruments

1. Calibrated pressure gage with tee connector (one end with a tire valve stem [to connect to bicycle pump or air tank regulator] and one end with tire valve stem connector [to connect to air line]).
2. Bicycle pump or compressed air tank with regulator.
3. Pen or pencil.
4. Water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf) or other forms approved by the WWSC Ground-Water Specialist.

Data Accuracy and Limitations

1. Water-level measurements using an existing air line should be accurate to 1 ft.
2. When measuring deep water levels, corrections for fluid temperatures and vertical differences in air density are additional considerations (Garber and Koopman, 1968).

Advantages

1. Especially useful in pumped wells where water turbulence may preclude using a more precise method.
2. Method can be used while the well is being pumped, when splashing of water makes accurate measurements with the wetted steel tape method impossible.
3. In many eastern Washington wells, existing air lines (owner- or driller-installed) are the only means of measuring water levels. Either no other access into the well casing is available, or other conditions, such as high rates of cascading water, render other methods ineffective.

Disadvantages

1. Less accurate than the wetted steel tape or the electric sounding tape methods.
2. Requires information on the air-line length (accuracy of this reported information generally is unknown).

Assumptions

1. An established measuring point (MP) exists. See GWPD 8.1h for technical procedures on establishing an MP.
2. The MP is clearly described so that a person who has not measured the well will know where to measure from.
3. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

1. Attach pressure gage to air line (use tire valve stem connector end of tee connector).
2. Attach bicycle pump or regulator from air tank to tire valve end of tee connector.
3. Expel all water from air line by forcing compressed air into the air line using bicycle pump or air tank. A maximum pressure reading will be attained when all water is expelled (at this point, continued pumping or induction of compressed air from the air tank does not induce an increased pressure reading). Record the pressure reading (psi). If possible, use a pressure gage for which the reading will fall within the middle one-third of the gage's range (for best accuracy).
4. Multiply the pressure reading (psi) times 2.31 (ft/psi) to determine the length of the water column that was expelled from the air line.
5. Subtract the length of the water column expelled from the depth of the bottom of the air line to obtain the depth to water below the MP.
6. Apply the MP correction to get the depth to water below land-surface datum.
7. Record the water-level data on field form to an accuracy of 1 ft.

Data Recording

All data are recorded on the water-level measurement form 9-194 or other forms approved by the WWSC Ground-Water Specialist. All original filed forms are filed with the well records.

Selected References

Garber, M.S., and Koopman, F.C., 1968, Methods of measuring water levels in deep wells: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chap. A1, 23 p.

Johnson, E.E., 1975, Ground water and wells—A reference book for the water-well industry (1st ed., 4th printing): Saint Paul, Minn, Johnson Division, Universal Oil Products, Inc., p. 90-91.

Loman, S.W., 1953, Measurement of ground-water levels by air-line method: U.S. Geological Survey Open-File Report 53-159, 5 p.

GWPD 8.1g—Water-Level Measurement in a Flowing Well

Purpose

To measure low-pressure or high-pressure water-level heads in flowing wells.

Materials and Instruments

1. Low-pressure head measurement.
   a) Short length of transparent plastic tubing.
   b) Hose clamps.
   c) Measuring scale (steel tape or pocket tape with 0.01-ft graduations).
2. High-pressure head measurement.
   a) Flexible hose with a 3-way valve.
   b) Hose clamps.
   c) Pressure gage.
   d) Tool box (see Ground-Water Tool Box; Recommended Contents).
3. Pen or pencil.
4. Water-level measurement form 9-194 (http://wwwnwis.er.usgs.gov/forms/GW-wl-9-194.pdf) or other forms approved by the WWSC Ground-Water Specialist.

Data Accuracy and Limitations

1. With care and experience, low-pressure head measurements can be measured to an accuracy of 0.1 ft.
2. High-pressure head measurements using a pressure gage probably are accurate to about 0.5 ft (report to nearest 1 ft).
3. When a flowing well is closed or opened by a valve or test plug, it should be done gradually. If pressure is applied or released suddenly, the well could be permanently damaged by the "water-hammer effect" by caving of the aquifer material, breakage of the well casing, or damage to the distribution lines or gages.
4. Ideally, all flow from the well should be shut down so a static water level can be measured. However, because of well owner objections or system leaks, this is not always possible. If the leak is very small relative to the pressure reading, the water level can be recorded with an indicated status of "other" (this should be explained in the field notes and in the "water-level status," C238, and "remarks," C150, elements in GWSI).
5. If a well has to be shut down, the time required to reach static pressure may range from hours to days. Because it may be impractical or impossible to reach true static conditions, record the shut-in time (amount of time since well stopped flowing or being pumped) for each gage reading and record water-level status as "E" (recently flowing). During return visits to a particular well, it is best to duplicate the previously used shut-in time before making a pressure gage reading.

Advantages

1. Low-pressure head measurements: Relatively simple and fast to perform and more accurate than high-pressure head measurements.
2. High-pressure head measurements: Can be used with water levels that are sufficiently above land surface to preclude easy low-pressure head method.

Disadvantages

1. Low-pressure head measurements: Generally impractical for water levels more than 5 or 6 ft above ground level.
2. High-pressure head measurements: Can be less accurate than low-pressure method. Pressure gages can be subject to erroneous readings if not properly handled and calibrated.

Assumptions

1. An established measuring point (MP) exists. See GWPD 8.1h for technical procedures on establishing an MP.
2. Pressure gages have been calibrated.
3. A logbook containing all calibration and maintenance records is available for each recording device.
4. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

1. Low-pressure head measurement (direct measurement).
   a) Connect a short length of transparent plastic tubing tightly to the well with hose clamps (or other appropriate hardware, depending on individual well plumbing, etc.).
   b) Raise the free end of the tubing until the flow stops.
   c) Rest the end of the measuring scale (graduated in 0.01-ft increments) on the measuring point (MP), as level as possible.
   d) Read the water level directly, by placing the hose against the measuring scale.
   e) Apply the MP correction to get the depth to water above land-surface datum (LSD).
   f) Take a second reading at least 3 minutes after first reading.

   Note: *The tubing should remain in the same upright position between measurements.*

g) To make sure that the well is not being used, check that there are no pressure fluctuations.

2. High-pressure head measurement (indirect measurement).

a) Make sure that all well valves are closed except the one to the pressure gage. This should be done gradually to prevent water hammer effect. This will prevent use of the well during the measurement period and assure an accurate water-level reading. Record the original position of each valve that is closed (full open, half open, closed, etc.), so the well can be restored to its original operating condition.

b) Connect a flexible hose with a 3-way valve to the well with hose clamps (or other appropriate hardware, depending on individual well plumbing, etc.).

c) If possible, use a pressure gage for which the reading will fall within the middle one-third of the gage's range (for best accuracy).

d) Attach the pressure gage to one of the two "open" valve positions using a wrench. Never tighten or loosen the gage by twisting the case because the strain will disturb the calibration and give erroneous readings.

e) Bleed air from the hose, using the other "open" valve position.

f) Open the pressure gage valve slowly to reduce the risk of damage by the water-hammer effect to the well, distribution lines and gages. Once the needle stops moving, tap the glass face lightly to make sure the needle is not stuck.

g) To make sure that the well is not being used, check that there are no pressure fluctuations.

h) If using a flexible hose with 3-way valve, hold the pressure gage in a vertical position with the center of the gage at the exact height of the MP. If an alternative method is used to attach the pressure gage to the well, a new MP may need to be used (and documented). Read the pressure gage to the smallest increment (of pounds per square inch) possible and multiply this value by 2.31 to convert to feet (report value to nearest 1 ft).

i) Apply the MP correction to get the depth to water above LSD.

j) Take a second reading at least 3 minutes after the first reading.

k) Record the identification number of the altitude/pressure gage with each water-level measurement so that the reading can be back referenced to the calibration record, if necessary.

Data Recording

All calibration and maintenance data for the gage are recorded in the logbook. All water-level data are recorded on the water-level measurement form 9-194 or other forms approved by the WWSC Ground-Water Specialist.

> ***Note**: The identification number of the pressure gage should be recorded on the field form.*

Selected References:

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

GWPD 8.1h—Establishing a Measuring Point

Purpose

To establish a reference point from which all water levels are measured in a particular well.

Materials and Instruments

1. Well schedule form 9-1904-A (http://wwwnwis.er.usgs.gov/forms/GW-site-form.pdf) or other forms approved by the WWSC Ground-Water Specialist.
2. Steel tape graduated in feet, tenths, and hundredths of feet.
3. Pen or pencil.
4. Pocket tape measure graduated in feet, tenths, and hundredths of feet.
5. Tool box (see Ground-Water Tool Box; Recommended Contents).
6. Paintstick, bright color (optional).
7. Field note book.

Data Accuracy and Limitations

Land surface datum (LSD) at a well is a somewhat arbitrary plane chosen to be approximately equivalent to the average altitude of the ground around the well. Therefore, great precision is not useful for establishing a measuring point (MP). MPs generally are established to the nearest 0.1 ft using a pocket tape to measure the distance from the MP to the LSD. Measuring points change from time to time, especially on private wells. In such instances, it is important to measure as accurately as possible the relative differences between MPs. With multiple MPs, after the first MP is established all additional MPs should be measured to a precision of 0.01 ft, relative to the first MP. For example, if an MP has been established on a well at the top of casing and recorded as being 1.2 ft above LSD, and then a 0.52-ft piece of casing is added to the top of the well, the new MP should be recorded as 1.72 ft above LSD (1.2 + 0.52).

Assumption

For comparability, water-level measurements must be referenced to the same datum (altitude).

Instructions

1. Upon installation of a monitoring well, or when an existing well is inventoried, establish an MP. The MP must be as permanent as possible, clearly defined, and easily located.
2. The measuring point is measured with respect to LSD and should be the most convenient place from which to measure the water level in a well.
3. The top of the casing (or other relatively permanent point) should be designated as the MP if at all possible. MPs that are subject to change (e.g., the top of a breather pipe that is threaded into the sanitary seal may shift position if it is tightened or loosened, and this change would not be readily identifiable by the next person measuring the well) should be avoided, if possible.
4. If possible, position the MP at a particular point on the casing where a leveling rod could be set on it directly over the well and where the water-level measuring tape can hang freely when it is in contact with the MP.
5. If possible, clearly mark the MP. This may be done using a bright colored paintstick. However, make sure to have approval from well owner before doing so.
6. The height of the MP is measured in feet above or below LSD and is recorded on the site schedule form 9-1905 or other forms approved by the WWSC Ground-Water Specialist. Values for MPs below land surface should be preceded by a minus sign (–). Also record the date the MP was established and a detailed description of the MP. Depending on the purpose of a study, it may be desirable to "survey-in" the LSD and the MP. See GWPD 8.1a, which includes description of the minimum set of data elements needed to identify a ground-water site.
7. Make a detailed sketch of the MP on the back of the site schedule form 9-1905 or ohter forms approved by the WWSC Ground-Water Specialist. Optional: also take a photograph (mark the MP and draw an arrow to it). Date all sketches and photographs.

Data Recording

MP data are recorded on water-level form 9-194 or other forms approved by the WWSC Ground-Water Specialist, and on the GWSI well schedule (form 9-1904-A). All original field notes and photos are placed with the WWSC's permanent ground-water records.

Selected References

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition: U.S. Geological Survey Handbook, chap. 2, p. 1-149.

U.S. Geological Survey, 1990, National water information system user's manual, ground-water site inventory system: U.S. Geological Survey Open-File Report 89-587, v. 2, chap. 4. (variously paged).

GWPD 8.1i—Entry of Site Data into the GWSI Database

Purpose

To assure accurate entry of field site information into the Ground-Water Site Inventory (GWSI) database. The Project Chief, WWSC Ground-Water Database Manager, and the WWSC Ground-Water Specialist are responsible for the entry and quality control of all ground-water data input to the GWSI database. When a project needs to input large quantities of data into GWSI, the Ground-Water Database Manager offers assistance to project personnel. To assure compliance with established standards, several stages of checking are required before and after data are entered into the system.

Materials and Instruments

1. Well schedule form 9-1904-A (http://wwwnwis.er.usgs.gov/forms/GW-site-form.pdf) or other forms approved by the WWSC Ground-Water Specialist and the location plotted on a 7.5-minute topographic map.
2. USGS 7.5-minute latitude-longitude scale and quarter-quarter section grid overlay.
3. GWSI system, ground-water site schedule form 9-1904-A or other forms approved by the WWSC Ground-Water Specialist.

Data Accuracy and Limitations

1. Latitude and longitude values determined with a USGS 7.5-minute latitude-longitude scale can be read to the nearest 0.5 second. Latitude and longitude values determined with a GPS instrument can be read to the nearest 0.1 second and generally are accurate to at least 0.5 second.
2. Well construction information obtained from the well driller or from geophysical logs generally should be considered as more reliable than information obtained verbally from the well owner.
3. Altitudes determined from topographic maps are considered to be accurate to within one-half the map contour interval.

Instructions

A. General procedures for entering ground-water site data into local data base:

1. As each step of checking is completed, the person who completed the check will initial and date the appropriate section of the coding form.
2. Prior to entering data in GWSI, the field data will undergo the following checks (in addition, see data checks in instruction number 4 of Appendix 8.1b):
   a) Comparison of measured and reported data from field form to driller's log or previous field forms to verify match of paper records with site visited (e. g., casing type and diameter, well depth, Washington Department of Ecology (WDOE) Unique Well No., etc.).
   b) Sketch map vs. topographic map plot—All elements required to precisely locate the well should be present in the sketch (i.e., North arrow, prominent features, and all distances from readily identifiable features). Using information from sketch map, check that site location agrees with topographic map plot.
   c) Altitude—Check altitude reported on field form vs. topographic map plot. Verify accuracy indicated (generally one-half contour interval).
   d) Water levels—Verify water levels (check math), reporting precision, water-level status, and that measuring point (MP) correction was properly applied.
   e) Local Site Number—Check topographic map plot to verify that Local Site Number indicates proper Township, Range, Section, and Quarter-Quarter Section.
3. Each well or spring entered into GWSI will be assigned a Local Well Number based on the official public-land survey (Township, Range, Section, Quarter-Quarter Section, and well sequence number; e.g., 09N/27E-12F02). Additional characters and numbers may be added at the end of the well sequence number to indicate deepened or reconstructed wells ("e.g., D1, D2…), nested piezometers (e.g., P1, P2…), or springs (S1, S2…). The Local Well Number will be entered into data element C012. In addition, WDOE Unique Well ID No., if available, should be entered into data element C190. The aforementioned identification numbers will enable the files of the USGS to be more easily cross-referenced to other State and Federal agencies and their databases.
4. Geohydrologic unit designations for individual wells should be coded (minimum requirement is coding Primary Aquifer – C714). Code assignment is the responsibility of the Project Chief, WWSC Ground-Water Database Manager, and the WWSC Ground-Water Specialist.

B. Recording site data on coding form

1. In addition to the mandatory data elements in GWSI, the following data elements (if known) comprise the minimum amount of information to be entered into GWSI for a Washington WWSC ground-water site. If any of these elements are unknown, the site may still be entered. Ideally, ALL available information for which data elements exist should be entered (later projects generally are unaware of uncoded information that resides only as hard copy in the well records). The GWSI component number (C#) is shown for each data element.
   a) Geographic location—latitude-longitude accuracy (C11), sketch map of site location (not in GWSI but filed with well record), altitude (C16), altitude method (C17), altitude accuracy (C18), altitude datum (C22), hydrologic unit code (C20), Water-Resource Inventory Area (C801), map name (C14), map scale (C15), and topographic setting (C19).
   b) Source identifiers—project (C5), owner's name (C161), date of ownership (C159), date inventoried (C711), date of site visit (C187), and name of person conducting site visit (C188).
   c) Individual site characteristics—use of water (C24), MP beginning date (C321), MP height (C323), MP remarks (C324), water level (C237), time water level measured (C709), date water level measured (C235), method water level measured (239), status of water level (C238), source of water-level data (C244), party making water-level measurement (C246), date of construction (C21), hole depth (C27), well depth (C28), source of depth information (C29), top of open interval (C83), bottom of open interval (C84), type of logs available (C199), discharge (C150), drawdown (C239), and pumping period (C157).
   d) Geohydrologic units—As a minimum, code primary aquifer (C714) in general site data. Preferred method is to code all geohydrologic unit identification numbers (C93), tops (C91), bottoms (C92), lithologies (C96), lithologic modifiers (C97), and contributing unit information (C304). If geohydrologic units are not identified, primary aquifer (C714) should be coded as unconsolidated sediments (000OVBD) or bedrock (BEDROCK, BASEMENT), as appropriate.
   e) Safety—any safety-related information (e.g., animal hazards, bare wiring, etc.) should be entered in remarks (C806).
2. If a GPS unit was not used in the field, then transfer the site location from the field map to a flat, unfolded USGS 7.5-minute topographic quadrangle map. Determine the ground-water site latitude (C9) and longitude (C10) to the nearest second using a USGS 7.5-minute latitude-longitude scale or a digitizer. Record the latitude and longitude method (C35), accuracy (C11), and datum (C36) based on information from the field form (generally one second for field visited sites). See GWPD 8.1a for the technical procedures on locating a ground-water site.
3. After all data have been coded, the person doing the coding will initial and date the "Coded by" line on the coding form.
4. The completed coding form will be checked by a second party, who will initial and date the "Checked by" line on the coding form.

C. Entering, Retrieving and Verifying Data Entered into GWSI

The person entering the data into GWSI initial and date the "Entered by" line on the coding form. After data entry, the data should be retrieved and verified versus the coding form. Also, the site should be plotted using the latitude/longitude data in GWSI and this plot compared to the field topographic map plot.

To assure consistency and accuracy of data entered into the system, the standards and guidelines set forth in U.S. Geological Survey (1990) will be strictly followed.

Selected References

U.S. Geological Survey, 1990, National water information system user's manual, ground-water site inventory system: U.S. Geological Survey Open-File Report 89-587, v. 2, chap. 4. (variously paged).

GWPD 8.1j—Measuring Water Levels in Wells and Piezometers Using a Submersible Pressure Transducer

Purpose

To measure water levels to help determine hydraulic gradients and rates and directions of ground-water flow and to aid interpretation of water-quality data from wells.

Materials and Instruments

1. Transducer (only gauge or differential should be used; with vent tube), data logger, cables, suspension system, and power supply.
2. Data readout device (i.e. laptop computer loaded with correct software) and data storage modules or diskettes.
3. Well cover or recorder shelter with key.
4. Water-level indicator graduated in hundredths of feet (electric sounding tape or steel tape with blue carpenter's chalk and a clean rag).
5. Forms including:
   a) Well completion form,
   b) Log book with records of previous measurements for comparison,
   c) Transducer calibration worksheet (fig. 1),
   d) Water-level measurements field form or ground-water inspection sheet (fig. 2),
6. Pen or pencil.
7. Calculator and watch.
8. Spare desiccant, replacement batteries.
9. Tools, including high-impedance (digital) multimeter, connectors, crimping tool, and contact-burnishing tool or artist's eraser.
10. Camera and film.
11. GPS instrument.

Data Accuracy and Limitations

1. Water levels should be measured to 0.01 ft, where possible.
2. Tape measurements for the in-place calibration of pressure transducers should be made to the nearest 0.01 ft.
3. Pressure transducers are subject to drift, offset and slippage of the suspension system. For this reason, the transducer readings should be checked against the water level measured with electric sounding tape or steel tape in the well on every visit, and the transducer should be recalibrated periodically and at the completion of monitoring.

Advantages

1. Small size allows water levels to be measured in wells or piezometers that are narrow, crooked, or contain pumps or other equipment.
2. Measurements can be read directly in the field.
3. Data logger can be left unattended for prolonged periods until data can be downloaded to a portable computer in the field.
4. Some data loggers are small enough to be placed inside the protective well casing and do not require a separate shelter.
5. Downloaded data can be imported directly into spreadsheet or database.

Disadvantages

1. It may be necessary to correct the data for instrument drift, hysteresis, temperature effects, and offsets. Most transducers have temperature compensation built-in.
2. Transducers operate only in a limited depth range. The unit must be installed in a well in which the water level will not fluctuate outside the operable depth range for the specific transducer selected. Wells with widely fluctuating water levels may be monitored with reduced resolution or may require frequent resetting of the depth of the transducer.
3. Materials in the transducer and cable may react with substances present in the water, causing damage or failure of the instrument.
4. Rapid water-level fluctuations may be missed if they occur between the programmed water-level measurement times.
5. With some data loggers, previous water-level measurements may be lost if the power fails.

Assumptions

1. A clearly marked measuring point (MP) exists, as described in GWPD 8.1h.
2. The user is familiar with the transducer specifications and limitations, and has evaluated the required accuracy of the measurements in accordance with the study objectives. The transducer's range is appropriate for the range of water levels expected in the observation well (operating range will not be exceeded).
3. The transducer has been calibrated, either by the manufacturer or by the user, for the conditions expected in the field installation.

4. If the user is visiting an existing installation, the vent tube is unobstructed, the desiccant is in place, and the well is free of obstructions.

5. All field notes should be neat, legible, and leave no doubt about interpretation. Errors/modifications should be indicated by a single line drawn through them (no erasures or blackouts).

Instructions

Pressure transducers are used in a variety of applications including installations on soil tensiometers, direct burial, and for short-term aquifer tests. The scope of this document, however, is limited to the installation of pressure transducers in observation wells and piezometers for long-term monitoring of water levels. For additional information, and for other applications (see Freeman and others, 2002).

1. If preparing a new installation:
   a) Check that the well is unobstructed and open to the aquifer (i.e., perform a slug test).
   b) Keep the transducer packaged in its original shipping container until it is installed. Avoid dropping the transducer or permitting sharp contacts with the sides of the well casing. Do not allow the transducer to free fall into the well.
   c) Conduct a field calibration of the transducer by raising and lowering it over the anticipated range of water-level fluctuations. Take three readings at each of a minimum of five intervals, during both the raising and lowering of the transducer. Record the data on a calibration worksheet (fig. 1).
   d) Lower the transducer to the desired depth below the water level (caution: do not exceed the depth range of the transducer).
   e) Fasten the cable or suspension system to the well head using tie wraps or a weatherproof strain-relief system. If the vent tube is incorporated in the cable, make sure not to pinch the cable too tightly or the vent tube may be obstructed.
   f) Make a permanent mark on the cable at the hanging point, so future slippage, if any, can be determined.
   g) Measure the total depth and the static water level in the monitor well with a steel tape or electric sounding tape. Repeat if measurements are not consistent within 0.02 ft.
   h) Record the well and MP configuration, with a sketch. Include the MP height above the land surface, the hanging point and the hanging depth (fig. 3).
   i) Connect the data logger, power supply, and ancillary equipment. Configure the data logger to ensure the channel, scan intervals, etc., selected are correct. Activate the data logger. Most loggers will require a negative slope in order to invert water levels for ground-water applications.
   j) Take photographs of the site/installation and take a GPS reading.
2. If visiting an existing installation:
   a) Record the well number and location, measuring point, and whether the well was being pumped when measured, was pumped recently, or whether a nearby well was pumping during the measurement, together with any other changes at or near the site that may affect the measurements.
   b) Retrieve ground-water data using instrument or data logger software.
   c) Measure the water level with a steel tape or electric sounder and compare the reading with the value recorded by the transducer and data logger.
   d) If the tape and transducer readings differ, raise the transducer out of the water and take a reading to determine if the cable has slipped, or whether the difference is due to drift.
   e) If drift is significant, recalibrate the transducer as described in GWPD 8.1c.
   f) Use the multimeter to check the charge on the battery, and the charging current supply to the battery. Check connections to the data logger, and tighten as necessary. Burnish contacts if corrosion is occurring.
   g) Replace the desiccant, battery (if necessary), and data module. Verify the logger channel and scan intervals, document any changes to the data logger program and activate the data logger.
   h) If possible, wait until logger has logged a value, and then check for reasonableness of data.

Data Recording

All data times of measurement are recorded in the field notebook or trip log and on the ground-water inspection sheet or water-level field measurements form. Depending on the type of data logger used, data from the data logger are transferred to the office computer in a data module, downloader, or diskette.

Selected References

Freeman, L.A., Carpenter, M.C., Rosenberry, D.O., Rousseau, J.P., and Unger, R., 2002, Use of submersible pressure transducers in water-resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chapter A3.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program: selection, installation, and documentation of wells, and collection of related data: U.S. Geological Survey Open-File Report 95-398, 69 p.

U.S. GEOLOGICAL SURVEY – WATER RESOURCES DIVISION
CALIBRATION WORKSHEET FOR SUBMERSIBLE TRANSDUCERS

Data Processing No._____
Page _____ of _____

Site Name: Official USGS site name _____ Site ID and Number: 8 or 15 digit USGS Site ID_____

M.P. used: Nested piezometers often have multiple measuring points. Party:_____

Date (mm/dd/yy): ___/___/___ Julian:_____ Watch time: _____ EST CST MST PST Daylight Atomic (circle)

Measuring Device: i.e. Calibrated steel tape, calibrated electric tape.

Transducer Information.
Date:_____ Type:_____ Length:_____ Serial No._____ Output:_____

Units of reading: mv, psi, ma Range: i.e 0-5 psi_____ Conversion to feet: 2.3067 x psi = range of 0 to 11.534 ft.

Calibration marks: Describe what was used to mark the transducer cable for measuring distance moved during the calibration process.

_____

Out-of-water reading: _____/_____ Set Point reading: _____/_____ Scan Rate:_____ Reset? Yes No

Time	Water Level	Cal. Mark	Dist. btwn. Marks	Total Dist.	Readings	Avg.	Remarks
1014	2235 DBLS		1.00		0.4334 psi		
1015		1		1.00	0.4337		
1016	22.35		1.50		0.4332		
1022	22.35				1.0838 psi		
1023		2		2.50	1.0841		
1024	22.35		1.50		1.0840		
1030	22.34				1.7341 psi		
1031		3		4.00	1.7337		
1032	22.34		1.50		1.7339		
1039	22.33				2.3843		
1040		4		5.50	2.3846		
1041	22.33		1.50		2.3844		
1047	22.33				3.0346		
1048		5		7.00	3.0342		
1049	22.33		1.00		3.0351		
1058	22.32				3.4682		
1059		6		8.00	3.4685		
1100	22.32		1.00		3.4678		
1106	22.32				3.0392		
1107		5		7.00	3.0388		
1108	22.32		1.50		3.0390		
1114	22.32				2.3887		
1115		4		5.50	2.3889		
1116	22.32		1.50		2.3891		
1120	22.31				1.7514		
1121		3		4.00	1.7516		
1122			1.50		1.7517		
1126	22.31				1.1011		
1127		2		2.50	1.1013		
1128	22.31		1.50		1.1010		
1134	22.31				0.4509		
1135		1		1.00	0.4507		WL rise of 0.04
1136	22.31 DBLS		1.00		0.4507		ft. during calib.

Figure 1. Calibration worksheet for submersible transducers.

U.S. GEOLOGICAL SURVEY – WATER RESOURCES DIVISION

GROUND WATER INSPECTION SHEET

Site Name: _____ Station ID Number:_____

State/Local Well Numbers: _____ Party:_____

Date (mm/dd/yy): ____/____/____ Julian:_____ Watch time: _____ EST CST MST PST Daylight Atomic (circle)

Data Logger Information:

Date (mm/dd/yy): ____/____/____ Julian:_____ Time: _____ EST CST MST PST Daylight Atomic (circle)

Data Logger Type:_____ Serial No._____

Temporary Storage Values: Time: _____ EST CST MST PST Daylight Atomic (circle)

CH 1 _____ CH 2 _____ CH 3 _____ CH 4 _____ CH 5 _____ CH 6 _____ CH 7 _____

CH 8 _____ CH 9 _____ CH 10 _____ CH 11_____ CH 12_____ CH 13_____ CH 14_____

CH 15_____ CH 16_____ CH 17_____ CH 18_____ CH 19_____ CH 20_____ CH 21_____

CH 22_____CH 23 _____ CH 24_____ CH 25_____ CH 26_____ CH 27_____ CH 28_____

Permanent Storage Values: Time: _____ EST CST MST PST Daylight Atomic (circle) Data Block No. _____

CH 1 _____ CH 2 _____ CH 3 _____ CH 4 _____ CH 5 _____ CH 6 _____ CH 7 _____

CH 8 _____ CH 9 _____ CH 10 _____ CH 11_____ CH 12_____ CH 13_____ CH 14_____

CH 15_____ CH 16_____ CH 17_____ CH 18_____ CH 19_____ CH 20_____ CH 21_____

CH 22_____CH 23 _____ CH 24_____ CH 25_____ CH 26_____ CH 27_____ CH 28_____

Channel • •	CH #	CH #	CH #	CH #	CH #	CH #	CH #	CH #
Well No. • •	Well	Well	Well	Well	Well	Well	Well	Well
M.P. used								
Hold								
Cut								
Water Level below M.P.								
M.P. to Land Surface								
Water Level to Land Surface								
Meas. Time (watch)								
Logger Value								
Converted Logger Value								
Parameter Shift								

Remarks: _____

Figure 2. Ground-water inspections sheet.

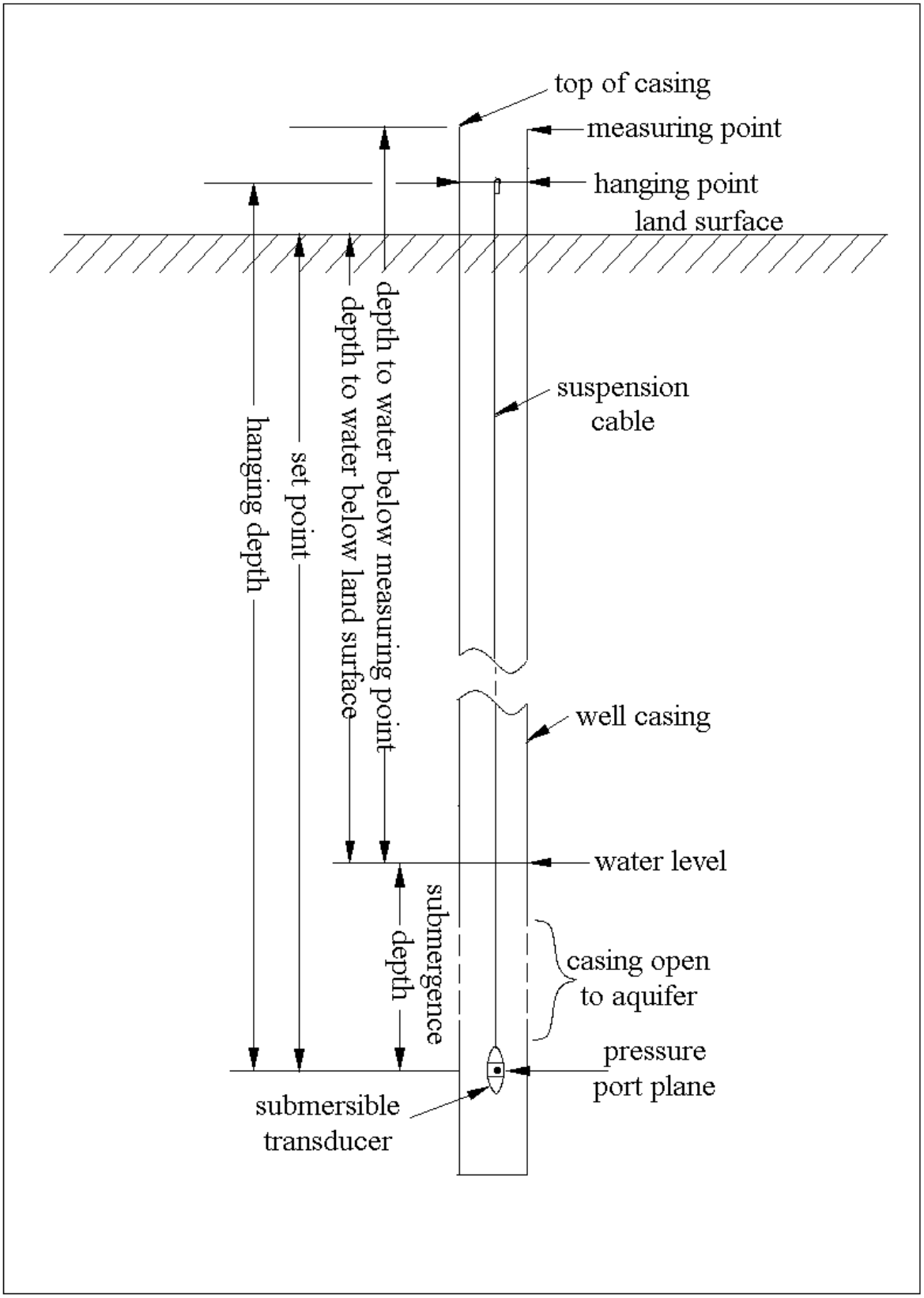

Figure 3. Submersible transducer in an observation well.

8.2—Ground-Water Tool Box; Recommended Contents

The WWSC maintains several sets of ground-water field equipment. An example of the equipment contained in a set is listed below:

Measuring Equipment:

- Steel measuring tapes; 100, 300, and 500 ft
- Electric sounding tape; Waterline 300 ft, Waterline 1,000 ft
- Pocket measuring tape (engineering scale)
- Air tank (and tie-downs)
- Pressure gage and regulator
- Bicycle pump
- Rags
- Carpenter's chalk
- Measuring tape weights and spares (sausage-style; brass, copper, or stainless steel)
- Sounding weight and attaching wire
- Field instruction manual
- Paintstick (for marking measuring point)

Disinfecting equipment:

- Bleach container, 5 gal
- Household bleach
- Tech and Chem-wipes
- Latex gloves

Safety Equipment:

- Vest, USGS, orange (size 42)
- Safety glasses
- Hantavirus kit:
  - Half-mask respirators (small and large) and replacement filters
  - Latex gloves
  - Protective goggles
  - Alcohol wipes
  - Spray bottle for bleach solution

Office Supplies:

- Calculator
- Clipboard
- Pencils, pens, etc.
- Well-location map overlay and scale

Miscellaneous Equipment:

- GPS unit
- Plastic garbage bags
- Paper towels
- Raincoat (x-large)
- Bucket, 5-gal, plastic
- Hand cleaner

Tools:

- WD-40
- Set of screwdrivers
- Gloves
- Well plugs (assorted sizes)
- Bolts and nuts (assorted sizes)
- Set of Allen wrenches (standard)
- Set of Allen wrenches (metric)
- Socket wrenches (standard)
- Socket wrenches (metric)
- Machete
- Pipe wrenches (8-, 10-, 14-, 18-, and 24-in.)
- Crescent wrenches (6-, 8-, 10-, and 12-in.)
- Crow bar
- Batteries (spares for GPS [4 AA], flashlight [2 C], and e-tape [1 9V])
- File
- Shovel
- Pry bar
- Hack saw
- Whiskbroom
- Duct tape
- Electrical tape
- Flashlight
- Wire brush
- Hammer
- Pliers
- Chisel
- Misc. additional tools

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