Washington State Department of Ecology

Environmental Assessment Program

Standard Operating Procedure for the use of Submersible Pressure Transducers During Groundwater Studies

Version 1.1

Authors – Kirk Sinclair and Charles Pitz
Date-

Reviewer - Martha Maggi, Groundwater/Forests & Fish Unit Supervisor
Date -

QA Approval - William R. Kammin, Ecology Quality Assurance Officer
Date – 02/25/2015

EAP074

APPROVED: 10/20/2010
RECERTIFIED: 02/25/2015

Signatures on file

The Washington State Department of Ecology's Standard Operating Procedures (SOPs) are adapted from published methods, or developed by in-house technical and administrative experts. Their primary purpose is for internal Ecology use, although sampling and administrative SOPs may have a wider utility. Our SOPs do not supplant official published methods. Distribution of these SOPs does not constitute an endorsement of a particular procedure or method.

Any reference to specific equipment, manufacturer, or supplies is for descriptive purposes only and does not constitute an endorsement of a particular product or service by the author or by the Department of Ecology.

Although Ecology follows this SOP in most cases, there may be situations where an alternative methodology, procedure, or process is used to meet specific project objectives. In such cases the project manager is responsible for documenting deviations from these procedures in the field notes and formal study report.

Revision History

Date	Revision number	Summary of change(s)	Revised section(s)	Reviser(s)
02/25/2015	1	Minor edits, formatting changes, and reference updates for other cited SOPs	All	K. Sinclair

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CONVERSION FACTORS

1 mm Hg = 0.01934 psi @ 0°C
1 inch Hg = 0.491154 psi @ 0°C
1 mbar = 0.01450377 psi
1 bar = 14.50377 psi
1 ft of pure water at 4°C = 0.43353 psi
1 psi = 2.30666 ft of pure water at 4°C (see appendix E for additional information)
1 inch = 25.4 mm

ABBREVIATIONS

DD	Decimal degrees (of latitude or longitude)
DQO	Data quality objective(s)
EAP	Environmental Assessment Program
GW	Groundwater
GWL	Groundwater level
Hg	symbol for the element Mercury
lbs/in^2	pounds per square inch (psi)
mbar	millibar
mm	millimeter
MP	Measuring point
PDT	Pacific daylight (savings) time
psi	pounds per square inch
PST	Pacific standard time
QA	Quality assurance
QAPP	Quality assurance project plan
SOP	Standard operating procedure
WL	Water level

Environmental Assessment Program

Standard Operating Procedure for the use of Submersible Pressure Transducers During Groundwater Studies

1.0 Purpose and Scope

1.1 The Environmental Assessment Program (EAP) is responsible for measuring, assessing, and reporting information about the environmental condition and health of Washington's land and water resources. This information is used by resource managers, policymakers, and others to help protect and manage Washington's environment. As such there is a need to document and ensure that consistent and scientifically defensible practices, procedures, and techniques are used by EAP staff, and that the data and information they provide are of consistent and high quality.

1.2 This SOP summarizes the procedures and practices that EAP groundwater staff uses to deploy and evaluate the results from submersible pressure transducers. This document is one of several that record the field and analytical procedures EAP uses to perform its work. Digital versions of this and other EAP SOP's can be found on Ecology's website at: http://www.ecy.wa.gov/programs/eap/quality.html.

2.0 Applicability and Background

2.1 Submersible pressure transducers are a convenient and cost effective tool for measuring groundwater levels. They can be programmed to measure and record water levels (in terms of pressure head) at a variety of time scales ranging from nearly-continuous measurements to less frequent user-defined intervals. Transducers are increasingly being used by EAP and other Ecology programs to monitor water levels during ambient groundwater investigations, surface water/groundwater interaction studies, and other projects. Like all monitoring equipment however, transducers must be appropriately maintained and their data properly evaluated, to realize the full potential these instruments afford.

2.2 This SOP provides general information and examples to help guide users through the various aspects of transducer use including:

2.2.1 pre-project planning activities,
2.2.2 transducer selection and verification,
2.2.3 common transducer deployment techniques,
2.2.4 data recovery, verification, post processing, and archiving procedures.

2.3 This document is intended to complement the instrument-specific instructions and software tools provided by transducer manufacturers.

3.0 Definitions

3.1 Absolute pressure – the pressure measured relative to absolute zero pressure (i.e. a total vacuum). Absolute pressure is equal to the sum of gauge pressure and local atmospheric pressure (see gauge pressure).

3.2 Absolute pressure transducer – a transducer whose internal reference chamber is sealed at or close to 0 psi (at or near a perfect vacuum). These instruments are used to measure the absolute pressure exerted by the atmosphere plus the pressure exerted by fluid (typically water) that overlies the instrument sensor (see Figure 1).

3.3 Atmospheric pressure – the force per unit area exerted against a surface by the weight of air above that surface. In mountainous regions, atmospheric pressure can vary widely from location to location due to variations in air pressure with elevation. Also known as barometric pressure. See also station pressure.

3.4 Barometric efficiency – a measure of the water level change in a well due to variations in atmospheric pressure. Barometric efficiency is expressed as a ratio and represents the change in a well's hydraulic head (water-level) relative to the corresponding change in atmospheric pressure that produced the change. The barometric efficiency of wells typically ranges from 0.2 to 0.75 (Freeze and Cherry, 1979).

3.5 Barometric pressure transducer (baro-transducer) – an absolute pressure transducer deployed specifically to measure and log atmospheric pressure. Baro-transducers are deployed above the water column (typically in a monitored well) to allow barometric effects to be subtracted from the water levels logged by absolute transducer(s) (see Figure 1).

3.6 Cable grip – A mechanical device used to secure a transducer vent/communication cable at a fixed point within a well (see Figure 6).

3.7 Data Quality Objectives (DQO's) - Data Quality Objectives are qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions (USEPA, 2006).

3.8 Drift – a change in output over time that is not a function of the measured property. Total drift is comprised of two independent components; a change in a transducer's zero value (zero drift) over time, and a change in a transducer's sensitivity (sensitivity drift) over time (Freeman et al., 2004).

3.9 Dry calibration test – an air-only calibration test of a transducer used to determine the amount of electronic noise in the instrument.

3.10 EAP – Environmental Assessment Program

3.11 Ecology – The Washington State Department of Ecology

3.12 EIM – Environmental Information Management System. Ecology's database of environmental data and information.

3.13 Electronic noise – random fluctuation of an electronic signal

3.14 Fluid Pressure – the force per unit area exerted at a specific point within a body of static non-moving fluid (typically water) due to the weight of the fluid lying above that point (also called hydrostatic pressure) (see Figure 1).

3.15 Gauge pressure – the pressure exerted at a point exclusive of atmospheric pressure. Gauge pressure is zero referenced to local ambient air pressure, so it is equal to the absolute pressure minus atmospheric pressure (see absolute pressure).

3.16 Gauged pressure transducer – A transducer that is zero referenced to local atmospheric pressure (i.e. vented to the atmosphere, thereby eliminating the affect of atmospheric pressure on the pressure measurement) (see Figure 1).

3.17 Hanging point offset – The vertical distance between the transducer hanging point and the water level measuring point (see Figure 5).

3.18 Land surface datum (LSD) – an imaginary plane that is approximately at land surface at each well. If known, the elevation of the land surface datum relative to a standard geodetic reference datum (such as NAVD 88) is given in the well description.

3.19 Measurement-check error – the arithmetic difference between a transducer measured water level and a corresponding measurement made by alternative means such as a properly calibrated e-tape or steel tape.

3.20 Pressure transducer – An electronic instrument that can be programmed to measure and record pressure over time. Changes in pressure are recorded by a pressure transducer as changes in the intensity of an electrical signal.

3.21 Quality assurance project plan (QAPP) – A written plan that describes how a study will be conducted and its results assessed.

3.22 Static water level (SWL) – The level to which water in a well naturally rises in the absence of external stresses (such as the withdrawal or injection of water within the well or other nearby wells).

3.23 Station (atmospheric) pressure – The atmospheric air pressure at a specific monitoring station or point. The station pressure is equal to the combined weight of air in a column of atmosphere projected vertically above the station or point.

3.24 Transducer hanging point – The fixed point on a well from which a pressure transducer is suspended (see Figure 5).

3.25 Water level measuring point (MP) – The point on a well from which manual depth-to-water measurements are made (see Figure 5).

3.26 Wet calibration test – an instrument calibration test conducted by submerging a transducer under a known water column height and assessing its response to the imposed stress.

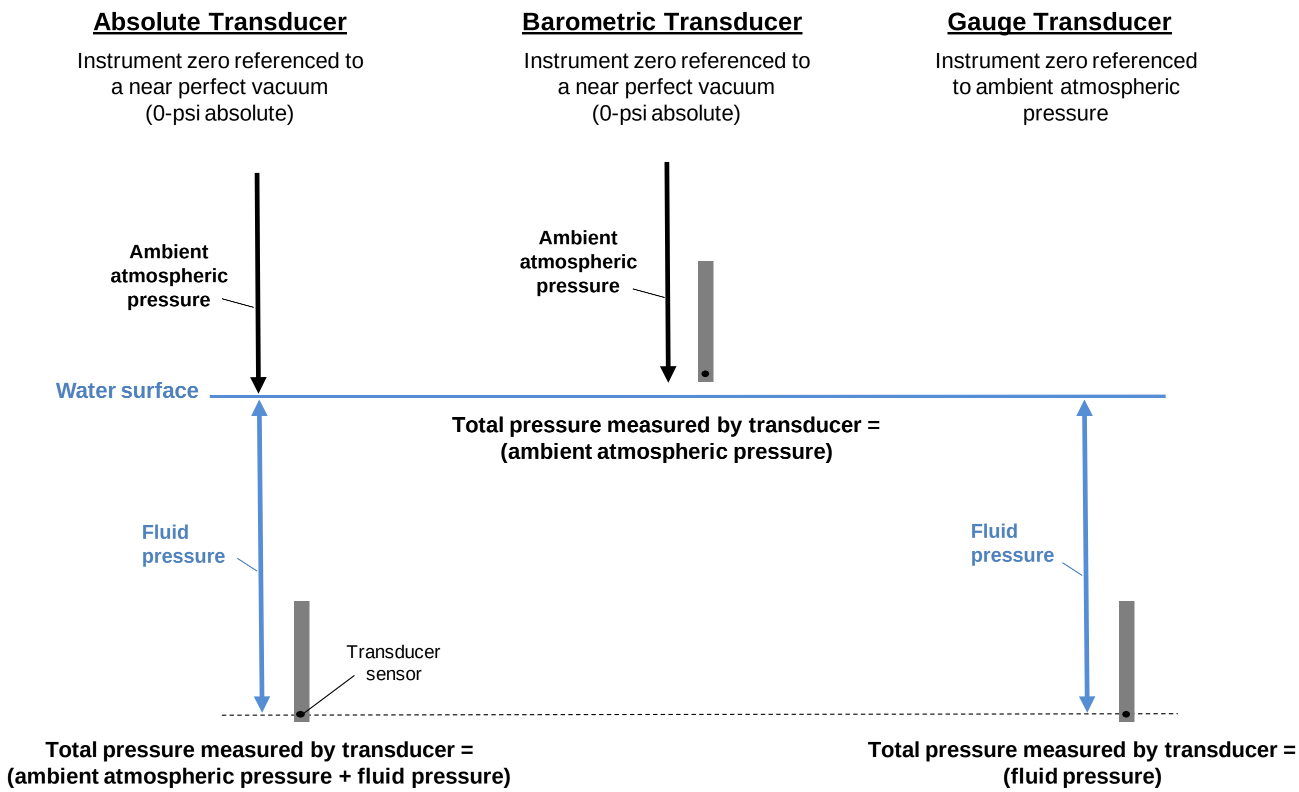


Figure 1 – Transducer Types and Associated Pressure Measurements

4.0 Personnel Qualifications and Responsibilities

4.1 EAP staff who deploy or maintain submersible pressure transducers during groundwater studies are responsible for complying with this SOP and the requirements of the EAP safety manual - particularly Chapter 1 "General Field Work" and the following sections of Chapter 2: "Groundwater Sampling and Water-Level Measurements" and "Using Hand or Power Tools" (Ecology EAP, 2012).

4.2 Staff deploying or servicing transducers for the first time should review Freeman and others, 2004, for useful background information prior to preparing a project QAPP or beginning field work. All field staff are responsible for reading the user's manual(s) for the specific transducers being deployed or serviced. (Note: when working with new or unfamiliar transducer model(s) conduct a practice "dry run" of the instrument setup, launch, and download procedures before heading to the field. Doing so will help minimize the potential for user error and data loss).

4.3 The field lead is expected to have detailed working knowledge of the project Quality Assurance Project Plan (QAPP) and is responsible for ensuring that other field staff adhere to the project's prescribed sampling and measurement procedures.

5.0 **Summary of Procedures**

5.1 Modern transducers can be programmed to log and record pressure in a variety of measurement units. In addition, the supporting transducer software typically enables one to reference reported pressure values to a user-defined reference point such as the transducer hanging point or the water level measuring point.

5.2 Each transducer manufacturer approaches instrument programming and setup in slightly different ways. To accommodate these differences EAP has adopted a standardized approach for transducer deployment and programming. When programming transducers for a project, water temperature is always recorded as °C. In addition, water level and barometric pressure are always recorded using a consistent unit of measure (e.g. ft of water, psi, etc.). This approach minimizes potential confusion and data collection issues for field staff. It also promotes the use and development of standardized field forms, data collection protocols, and post-processing procedures.

5.3 EAP's typical workflow for transducer based projects is shown schematically in Figure 2 and described by primary subject area in the following sections.

5.4 Project Planning

5.4.1 Ecology staff are required to prepare a Quality Assurance Project Plan (QAPP) for any environmental studies or monitoring they undertake (see Ecology's quality assurance web page for guidance: http://aww.ecology.ecy.wa.gov/programs/eap/qa/qa.html). The project plan serves two primary purposes. First, it formally documents the study objectives, and the procedures that will be followed or employed to achieve them. Second, the plan serves as a communication focal point by providing detailed guidance and direction for project staff. This helps to ensure consistency over time - particularly during subsequent staffing changes.

5.4.2 A QA plan is typically prepared by the field or project lead during the initial planning phase of a project. In addition to the usual QAPP elements all QA plans that include the use of transducers should specify the project acceptance limits for measurement-check errors (i.e. the acceptable difference between a transducer measurement (submersible or barometric) and a corresponding manual confirmation measurement (GWL and barometric). This will help ensure that the selected transducer(s) and WL confirmation methods are accurate enough to achieve the project goals. The QAPP should specify criteria for when transducer data will be corrected for drift, zero offset problems, or other issues; and for replacing instruments that fail or are not producing acceptable results.

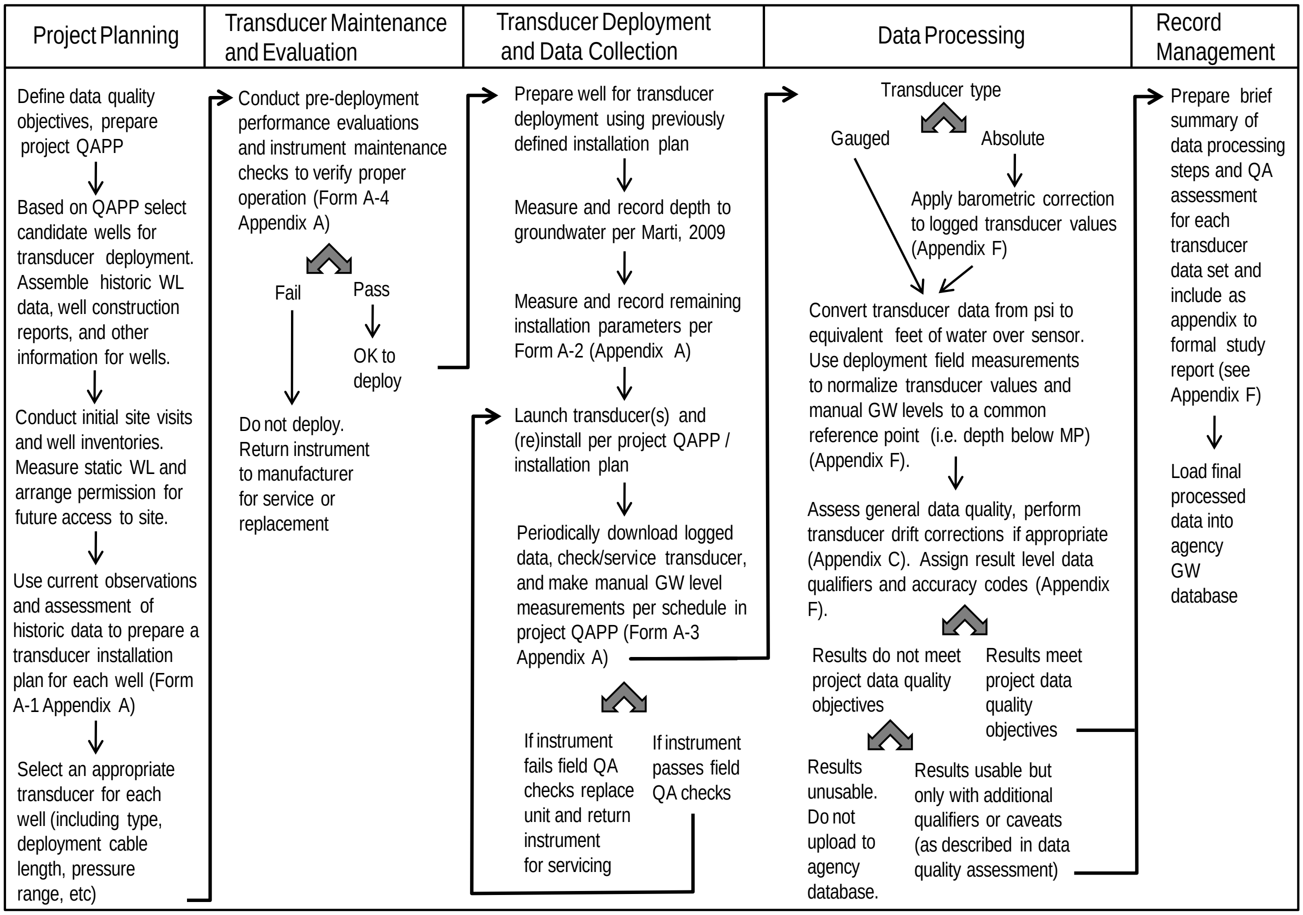


Figure 2 – Generalized workflow for deploying and assessing the results from submersible pressure transducers

5.4.3 During QAPP development staff should locate and compile well construction log(s), static-water-level histories, and other relevant information about the well(s) that will be evaluated for transducer deployment. Compile the above information in a project file along with preliminary site maps, driving directions, well-owner contact information, and orthophotos for each perspective well site.

5.4.4 Conduct preliminary site visits for each candidate well to evaluate its adequacy for transducer deployment. Confirm the well can be safely monitored and accessed for transducer installation, maintenance, and removal. For those wells meeting project requirements, arrange for ongoing site access with the well and property owner(s) and confirm that periodic manual groundwater measurements can be made while a transducer is installed. Document any necessary modifications to vent the well to the atmosphere, hang or secure transducer(s), or to perform confirmatory manual depth to groundwater measurements while the transducer is deployed (Form A-1, Appendix A). Discuss proposed modifications with the well owner(s) and obtain their approval to perform the work.

5.4.5 If the well hasn't been previously inventoried, use a GPS receiver to initially define its latitude and longitude coordinates (see Janisch, 2006). Record the coordinate values, the coordinate accuracy estimate (in feet), the horizontal reference datum, and the number of satellites used to define the location on the well inventory form (Form A-1, Appendix A). Clearly mark the well location and ID on the digital ortho-photo and retain for later GIS refinement of the well site coordinates.

5.4.6 Establish and document a permanent water level measuring point for each selected well (see Marti, 2009). Describe the measuring point and its height above or below land surface datum on the inventory form. (Note: By convention the heights for measuring points that lie above ground surface are recorded as positive values while those below ground surface are reported as negative values). Assign the measuring point an ID number (e.g. MP1) and document the date and time of first use. Clearly mark the measuring point with black indelible ink or by another permanent means so that it can be easily identified and used during subsequent field visits.

5.4.7 Measure the depth to groundwater with a properly disinfected and calibrated e-tape or steel tape (see Marti, 2009). Record the measuring point ID, the measurement date and time, the time datum (PST/PDT) and the measured values (hold and cut) on the field form.

5.4.8 If the well was not previously assigned a Department of Ecology unique well ID tag, then tag it now (see Pitz, 2011for additional guidance). (Note: Remember to complete a tagging form for any wells you tag. Submit the completed form(s) and a copy of the driller well construction report(s) to Ecology's Water Resources Program).

5.4.9 Take one or more digital photographs of the well head and immediate surroundings. Record the photo sequence number(s) on the well inventory form, so they can later be paired to create a visual site reference for others who may service the well. (Note: remember to document and load important site photos into Ecology's photo information management system - PIMS).

5.4.10 Use the information collected during the site inventory to select appropriate transducer(s) for each well. Where possible choose a transducer that meets project accuracy requirements and whose maximum pressure range can accommodate the wells expected annual water level fluctuation (Table 1).

Table 1 – Example transducer specifications and accuracy ranges[1]

Instrument manufacturer	Transducer model	Pressure range (psi)	Water level range (ft)	Performance accuracy (% of full scale)	Effective performance accuracy (ft)	Temperature range	Temperature accuracy	Instrument use
Insitu	BAROTroll	0-16.5	NA	± 0.1%	± 0.0381	-5°C to 50°C	± 0.25°C	Barometric pressure monitoring
Insitu	Mini-Troll 100 (15 psi)	0-15	0-35	± 0.2%	± 0.0693	-5°C to 50°C	± 0.25°C	WL/barometirc monitoring
Insitu	Mini-Troll 100 (30 psi)	0-30	0-69	± 0.1%	± 0.0693	-5°C to 50°C	± 0.25°C	WL/barometirc monitoring
Onset	Hobo U20 (21 psi)	0-21	0-13	± 0.075%	± 0.01	-20°C to 50°C	± 0.37°C	WL/barometirc monitoring
Onset	Hobo U20 (30 psi)	0-30	0-30	± 0.05%	± 0.015	-20°C to 50°C	± 0.37°C	WL/barometirc monitoring

5.4.11 For many EAP studies absolute transducers are favored over gauged transducers due to their generally lower initial cost (Figure 3). However, unless dedicated communication cables are used for deployment, absolute transducers must be periodically removed from the well to perform battery checks and download data. Therefore one must use care to ensure instrument(s) are correctly repositioned in the well following servicing or data downloads. This can be challenging when pump-riser pipes, centralizers, electrical wiring, or other obstructions present potential “snag points” for the transducer and hanging cable. In these situations consider deploying instruments on a dedicated communication cable which enables users to download instruments in place, thereby minimizing the need to remove and redeploy transducers.

5.4.12 Absolute transducers generally require a separate baro-transducer (or equivalent) to enable barometric corrections to be applied to the logged water pressures. In low-relief terrain, a single barometric transducer can generally be used to compensate absolute transducers lying within a few mile radius of the barometric monitoring site. However, when working in areas where elevation differences between wells may be large, a dedicated baro-transducer may be required at each well to achieve optimal results. (Note: For each 10 meter increase in elevation above sea level there is a corresponding reduction in atmospheric pressure equal to approximately 1 cm of water. This elevation/barometric pressure effect is most pronounced near sea level and gradually diminishes with increasing elevation. The above relationship generally holds at elevations up to about 2000 meters (6560 ft) and can be used to help determine where additional or well specific baro-transducers are needed to achieve project data quality objectives. See Rasmussen and Crawford, 1997; Spane, 1999 for additional discussion).

5.4.13 Using two instruments to obtain the final water pressure reading adds an additional data processing step that is not required for gauged transducers and doubles the potential for transducer drift or failure.

[1] Note: The values shown here are for example purposes only. When selecting transducers for deployment check manufacturer websites for current instrument specifications.

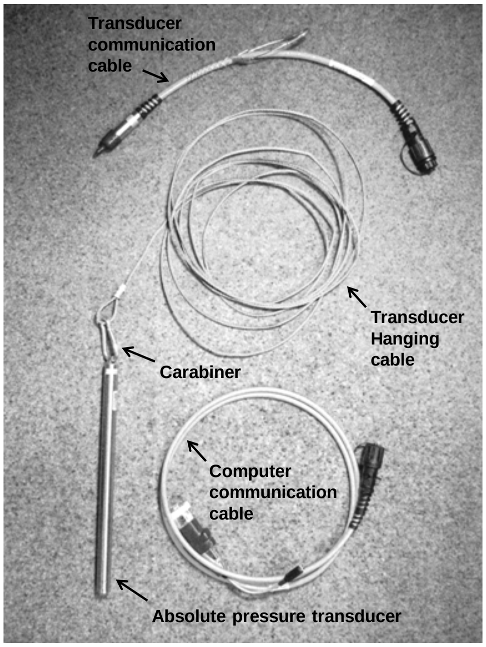


Figure 3 – Typical components for installing an absolute pressure transducer on a stainless steel hanging cable or equivalent.

5.4.14 Gauged transducers (unlike absolute instruments) do not require barometric compensation. They can also be downloaded in place, reducing the potential error associated with repeated instrument removal and redeployment. However, the vent cables used to deploy gauged transducer are prone to physical degradation or damage, can add significantly to equipment costs, and require rigorous maintenance protocols to ensure the vent cable interior remains dry and obstruction free (Figure 4). Excess cable that can't be secured inside the well casing can also necessitate the installation of an external lock box to protect the cable from vandalism or other damage.

5.4.15 Gauged transducers are perhaps most appropriate for secure long-term installations where an auxiliary above-ground-battery pack, solar charger, and telemetry system are used to perform routine data downloads and system operational checks.

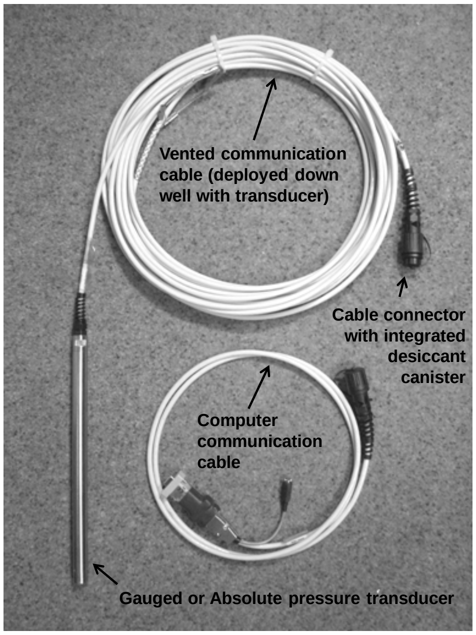


Figure 4 – Typical components for deploying a gauged/absolute pressure transducer on a vented communication cable

5.4.16 With transducer selection completed, proceed with developing a transducer installation plan for each well (Form A-1, Appendix A). Use the inventory information to calculate a preliminary transducer hanging depth for each well based on the measured depth to groundwater and the well's known or estimated annual water level fluctuation[2]. An optimal hanging depth places the transducer deep enough that the sensor port remains below the water surface at all times but not so deep that the instrument's pressure rating is exceeded when groundwater levels rise to seasonal high values.

5.4.17 When installing gauged transducers (or absolute transducers on communication cables) select an appropriate length communication cable for each well. The cable should be long enough to position the transducer at the target hanging depth defined above but not so long that there is an excessive length of extra cable (since the cable must be secured and protected either within the well casing or in an external protective housing).

[2] For those wells that don't have a known water level history search Ecology's groundwater database or the USGS GWSI system for comparable nearby wells that have a good measurement history. Use this information to estimate the probable annual range in groundwater levels at the current site. (Note: In some cases the transducer hanging depth may have to be adjusted based on the results of subsequent manual check measurements).

5.4.18 For standard cabled deployment of absolute transducers it's generally easiest to fabricate the hanging cable at the field operations center (OC) where one has access to a smooth flat working surface and the appropriate tools. To do this use a steel or other non-stretch reference tape to measure a length of light-gage stainless steel cable approximately 8-10 feet longer than the target deployment depth [3]. Cut the cable and add a secure-closed loop to one end using an appropriately sized cable eye and swage. Attach the transducer to the cable loop with a stainless carabineer (Figure 3). Lay the cable out in a flat safe area on the OC parking lot and stretch it tight. Starting at the transducer sensor port measure along the cable to locate the target deployment depth. Temporarily mark the deployment depth position on the cable with a piece of tape or an indelible ink pen. Form a second closed loop at this point on the cable using a second cable eye and a screw tightened (removable) clamp.

5.4.19 If a baro-transducer will also be installed at the well, it can be attached to the submersible transducer hanging cable at a point close to the water surface, yet high enough on the cable that it will not be submerged when the water level rises to seasonal high values. This is most securely done by swaging a small loop of cable to the primary hanging cable (Figure 5). For shallow deployments it may be more convenient to fabricate a separate hanging cable for the baro-transducer.

5.5 Pre-deployment maintenance and evaluation of transducer performance

5.5.1 All transducers should be visually inspected and tested before field deployment to confirm proper operation. For previously used transducers, begin the inspection by first wiping the instrument exterior with a clean-water-moistened cloth or paper towel to remove silt or other accumulated residue. Make sure the transducer serial number and pressure rating stamped on the instrument exterior are legible (retag as necessary). Visually inspect the transducer pressure port(s) to ensure they are free of foreign material. Use a low pressure squirt bottle and fresh tap-water to gently flush the port(s) of submersible transducers to remove silt or other accumulated material.

5.5.2 Check the o-ring seals of all transducer caps and cable connectors for cracks or other signs of wear. Replace cracked or stiff o-rings. Install new batteries, if applicable, and inspect the electronic contacts and leads on both the transducer and communication cables for damage or wear.

5.5.3 Carefully inspect the entire length of vent cables for excessive wear or cracks. Also check for loose fittings or connectors that might compromise cable integrity. Check and replace the cable desiccant canister(s) if necessary. Defective cables should be clearly marked and set aside until they can be returned to the manufacturer for repair or replacement.

[3] This extra length of cable enables the transducer to be repositioned (lowered) in the well if necessary based on subsequent water level measurements made at the time of deployment. If materials other than stainless steel are used to construct the hanging cable they must be non-stretching, non-corroding, and sufficiently strong to easily support the transducer assembly - including any supplemental weights or instruments added to complete the installation.

5.5.4 After inspection and instrument cleaning is complete, a “dry” calibration test is performed on all transducers prior to deployment to determine the amount of electronic noise present in the instrument. A more rigorous “wet” calibration test procedure is also run on transducers that have not been factory calibrated within the past 6 months. When both “dry” and “wet” calibration tests are required, they can be scheduled and run sequentially for greater efficiency. See Appendix B for guidance on conducting and evaluating the results of these tests.

5.5.5 Instruments that fail pre-deployment calibration checks should be returned to the manufacturer for recalibration prior to further use.

5.5.6 Most modern transducers also measure and log water temperature. Follow the procedures outlined in Bilhimer and Stohr, 2009, to verify thermistor operation and accuracy prior to field deployment.

5.6 Transducer Deployment

5.6.1 (Note: This discussion assumes that the well being instrumented was previously inventoried and the transducers operation verified. If not, complete the steps outlined in sections 5.4 and 5.5 before proceeding.

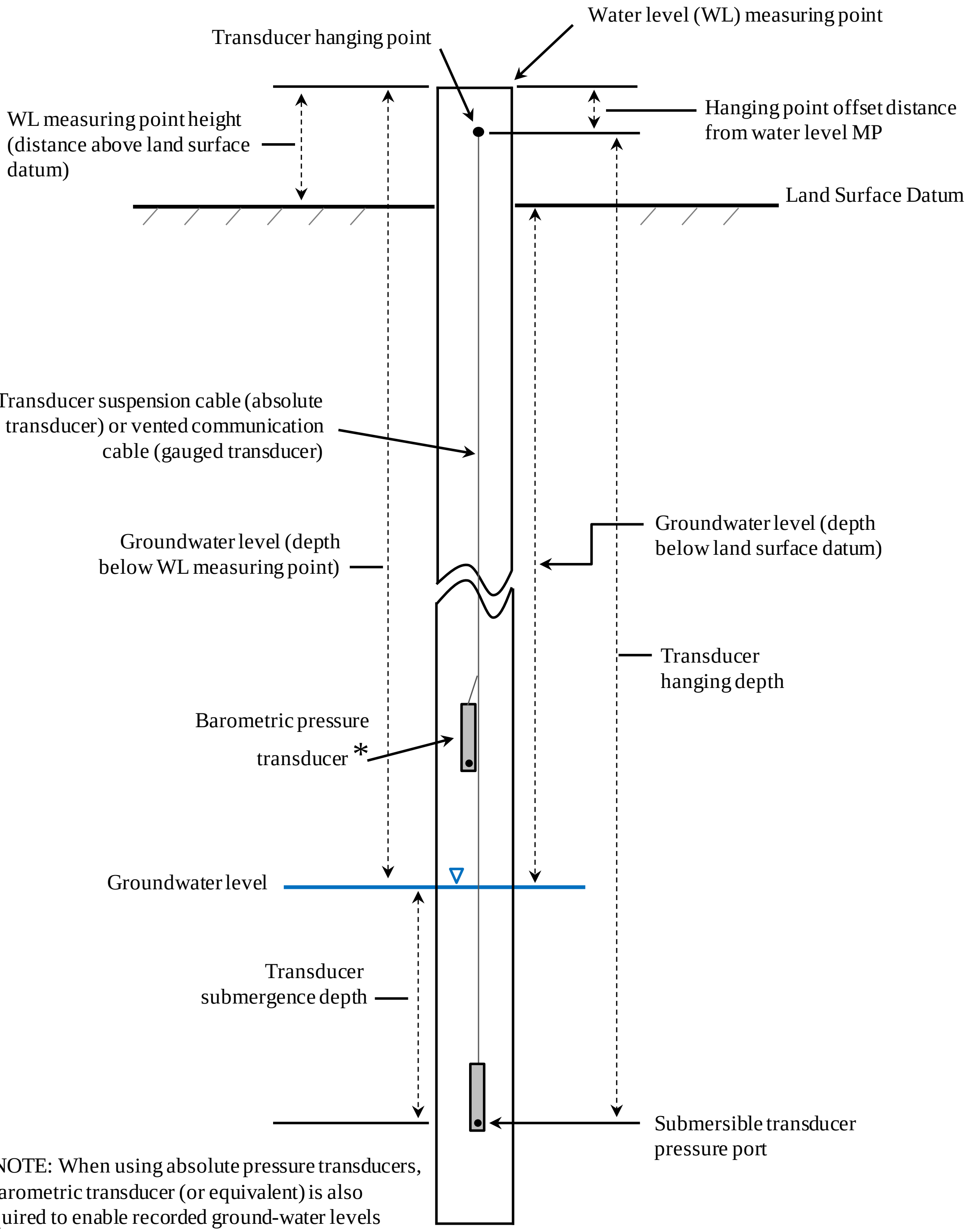
5.7 Installing absolute pressure transducers using a stainless steel hanging cable or equivalent

5.7.1 At the field operations center assemble the materials and tools needed to complete the installation(s) (Appendix D). Connect the field laptop to the Ecology network and start the computer. This will synchronize the laptop’s internal clock with the official US time. If you wear a wrist watch synchronize it as well.

5.7.2 After arriving at the well site enter the site location information on the transducer installation from (Appendix A, Form A-2).

5.7.3 Prepare the well for instrument deployment. Begin by creating a fixed hanging point for the transducer and baro-transducer (if used). This is often done by installing an eye bolt (or equivalent) in the well casing or cap. For air-tight wells, provide atmospheric access to the well by replacing the access-port plug with a screened-breather pipe or by drilling a small vent hole in the well casing or cap (Note: When in doubt, confirm that you have the well owner’s permission to perform such modifications before proceeding. Also remember to seal any installed breather holes and/or replace the solid access-port plug at the completion of project monitoring activities).

5.7.4 Measure the hanging point offset distance from the water level measuring point (see Figure 5), and record the value on the transducer installation form. Note whether the hanging point is higher (+) or lower (-) than the water level measuring point with regard to the land surface datum.



* NOTE: When using absolute pressure transducers, a barometric transducer (or equivalent) is also required to enable recorded ground-water levels to be corrected for local barometric pressure effects. In lowland areas with little topographic relief, a single barometric transducer can generally be used to correct several nearby absolute transducers. In mountainous areas where elevation differences between wells are often significant, it may be necessary to deploy well-specific barometric transducers.

Figure 5 – Schematic of a typical transducer deployment and associated field measurements (Adapted from Freeman et al., 2004).

5.7.5 Use a calibrated water-level meter (E-tape) or steel tape to make a manual groundwater level measurement using the measuring point established during well inventory (see Marti, 2009). Wait a few minutes and then make a second measurement to confirm static conditions. Record the static groundwater level hold and cut values, the measurement method and accuracy, the measuring point ID, and the measurement time on the installation form (Appendix A, Form A-2). Use an Engineers hand tape to measure and record the measuring point height ("casing stickup"). (Note: If possible, use the same water-level meter or steel tape for all subsequent measurements at the well. This will help eliminate the potential error associated with using different instruments).

5.7.6 Based on the above water level measurement adjust the hanging cable length (if necessary) to arrive at the "final" deployment depth for the transducer (referenced as feet below the hanging point) (see Figure 5). Do this by repositioning the upper cable eye and clamp assembly. Complete required adjustments (if any) for the baro-transducer hanging cable at this time too. If there is a significant amount of extra cable remaining after the final hanging cable length is defined, it can either be removed or lowered into the well with the remainder of the assembly. (Note: For low-yield wells that experience significant drawdown during pumping it may not be possible to capture the well's entire range of potential water levels – particularly with smaller range transducers. In these cases one must anticipate and accept data loss during pumping periods, or install a larger pressure range transducer).

5.7.7 After completing any required hanging cable length adjustments, attach a small locking carabineer to the upper cable eye and carefully re-measure the distance from the transducer sensor port to the inside apex of the carabineer. Record this value as the transducer hanging depth on the installation form (Appendix A, Form A-2).

5.7.8 Remove the transducer cap and connect the transducer to the field lap-top using the instrument communication cable. Confirm communication and then synchronize the transducer date and time with the laptop. [Note: Be sure to note the time datum in effect (PDT or PST) when initially launching a transducer. This is also important during subsequent instrument servicing/downloads, and when making manual water level measurements. ALL measurement times (both transducer and manual) must be normalized to a consistent time datum in order to properly process and validate transducer results]. Check the transducer battery voltage and installation date. Replace user-serviceable batteries as necessary. Record the transducer's serial number, battery percent remaining, and storage information on the installation form.

5.7.9 Follow the directions in the instrument user manual to program the transducer to log at the frequency and measurement units specified in the project work plan. Record the instrument serial number, launch time, and logging interval on the installation form. (Note: Some older model transducers do not report temperature values. One can add this capability to the monitoring program by attaching a recording thermistor to the hanging cable with a zip tie. Set the thermistor to start and log at the same time and frequency as the transducer).

5.7.10 Disconnect the launched transducer from the computer communication cable. Confirm the O-ring is in place then re-secure the cap making sure it seats securely against the transducer body.

5.7.11 If a baro-transducer will be installed at the site complete step 5.7.8 for this instrument as well. Follow the directions in the instrument instruction manual to program the transducer to log barometric pressure and temperature using the same units employed for the submersible transducer. At a minimum, the period of barometric data collection should span the planned period of transducer water level monitoring. In addition, the logging interval should be frequent enough (e.g. hourly) to provide sufficient data for later barometric compensation of the submersible transducer data (Spane, 1999). Record the instrument launch time, logging interval, and other observations/measurements on the installation form.

5.7.12 Connect the upper end(s) of the submersible transducer cable and baro-transducer cable (if used) to the instrument hanger with a small carabineer or equivalent.

5.7.13 To help prevent the spread of iron bacteria, carefully clean and disinfect all cables and transducers by wiping them with a clean cloth moistened with a 10% bleach solution. (Note: For vented communication cables confirm that the cable end cap(s) are secure and water tight before cleaning. Be careful to not submerge the cable desiccant chamber while cleaning or rinsing). After cleaning, thoroughly rinse the cable and transducer exterior with fresh water to remove residual bleach.

5.7.14 Slowly lower the submersible transducer and cable assembly into the well. Do not let the transducer “free fall” while lowering, since contacting the water at a high-rate-of-speed can damage the pressure sensor. (Note: For smaller light-weight transducers, it may be necessary to add additional weight (such as stainless steel nuts or tubing) to the transducer and cable assembly to make sure the instrument reaches the proper depth and hangs vertically in the well. If nuts or other weights are added to the assembly, slide them onto the cable prior to attaching the upper cable eye and clamp).

5.7.15 If a baro-transducer is being deployed at the site (but on a separate hanging cable) position the instrument at a point close to the water surface yet high enough in the well that it won’t be submerged when the water level rises to seasonal high values.

5.7.16 Record the instrument deployment time(s) on the installation form.

5.7.17 Review the installation form. Confirm that all measurements required to document the installation have been made and recorded in the appropriate location. Complete and record any missing measurements or observations.

5.7.18 Secure the well. (Note: Do not use an air-tight locking cap unless the casing itself is vented to allow free air exchange with the atmosphere).

5.7.19 For new installations recheck instruments within a few days or weeks if possible to verify proper operation. Correct any identified problems.

5.8 Installing gauged or absolute pressure transducers using a dedicated communication cable

5.8.1 (Note: This discussion assumes the well was previously inventoried and that transducer/cable operation has been verified. If not, complete the steps outlined in sections 5.4 and 5.5 before proceeding. Also, assemble the materials and tools needed to complete the installation(s) (Appendix D).

5.8.2 Before leaving the operation center, connect the field laptop to the Ecology network and start the computer. This will synchronize the laptops internal clock with the official US time. If you wear a wrist watch synchronize it as well.

5.8.3 At the well site, begin transducer installation by completing the preparatory work described in sections 5.7.2 through 5.7.5 (i.e. install the instrument hanger, collect a manual water level, and measure the offset distance between the transducer hanger and the water level measuring point). Document the hanger installation and other measurements on the installation form.

5.8.4 Record the total manufactured cable length and ID on the transducer installation form.

5.8.5 Connect the transducer to the vent/communication cable. Confirm the twist-lock connection is secure.

5.8.6 Connect the vent/communication cable to the field lap-top computer. Confirm proper communication with the transducer and then follow the procedures in the software instruction manual to synchronize the transducer clock and date to the laptop. Check the transducer battery voltage and replace as necessary (if user serviceable). Record the transducer's serial number, battery percent remaining, and memory information on the installation form.

5.8.7 If a baro-transducer will be installed at the site complete step 5.7.8 for this instrument as well. Follow the directions in the instrument instruction manual to program the transducer to log barometric pressure using the same measurement units that were employed for other instruments. The logging interval should be frequent enough (e.g. hourly) to provide sufficient data for later barometric compensation of the submersible transducer data (Spane, 1999). Record the instrument launch time, logging interval, and other observations/measurements on the installation form.

5.8.8 Use the water level measurement made in section 5.8.3 to define the transducer deployment depth in feet below the hanging point. An optimal deployment places the transducer deep enough that the sensor port remains below the water surface at all times but not so deep that the instrument's pressure rating is exceeded when groundwater levels rise to seasonal high values. The baro-transducer (if used) should be suspended near the groundwater surface yet high enough in the well that it won't be submerged as water levels rise to seasonal high values. (Note: For low-yield wells that experience significant drawdown during pumping it may not be possible to capture the well's entire range of potential water levels – particularly with small range transducers. In these cases one must anticipate and accept data loss during pumping periods, or install a larger-pressure range (but generally less accurate) transducer.

5.8.9 Locate the target deployment position (distance) along the communication cable by careful measurement with a calibrated steel tape or non-stretch cloth tape starting at the transducer sensor port. Temporarily mark the deployment position on the cable with a piece of tape. Slide the cable grip and attached carabineer from its current location along the cable until the upper inside loop of the carabineer abuts the tape. (Note: the grip can be repositioned along the cable by compressing it from both ends and sliding it to the desired position (Figure 6). Once in position, re-stretch the grip to secure it in place). With the grip secured carefully re-measure the hanging point distance (to the nearest 0.01 foot) to confirm correct placement.

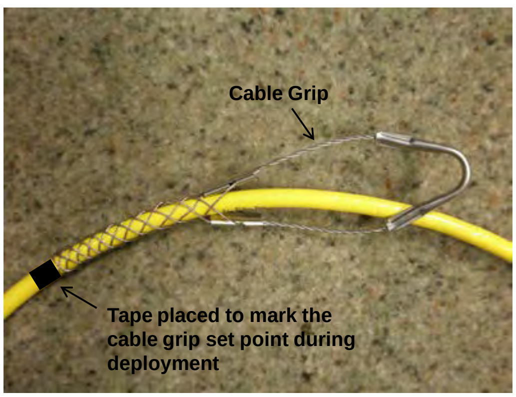


Figure 6 – Cable grip detail

5.8.10 Wrap a piece of black electrical tape around the communication cable to mark the bottom of the cable grip (Figure 6). The tape serves as a quick visual reference of grip placement and can be used to reposition the grip to its original position should that be necessary in the future.

5.8.11 Clip the cable-grip and carabineer to the transducer hanging point and then slowly begin lowering the transducer into the well. Be careful not to let the transducer "free fall" since contacting the water at a high speed can damage the pressure sensor. When installing transducers in actively used supply wells, work carefully to prevent instrument entanglement with installed pumps, centralizers, or electrical wiring. Also avoid abrading the cable on the casing side or other sharp objects. Continue lowering the instrument assembly until its weight rests firmly on the transducer hanger.

5.8.12 With the instrument assembly secured in place connect the communication cable to the laptop to view real-time pressure readings from the transducer. Use the field form to calculate the transducer hanging depth within the well by adding the manual depth to water value to the real-time pressure value (normalized as feet) reported by the transducer. (Note: For absolute transducers remember to compensate for ambient barometric pressure by subtracting the initial air-only barometric pressure value (also normalized as feet) from the submersible transducer pressure value)[4.] Correct for the hanging point offset distance and then compare the final result to the target deployment depth to confirm the transducer is resting at the correct depth (Figure 7). If it is not, the transducer or cable may be hung up within the well and need repositioning to achieve the desired depth.

5.8.13 Allow the transducer to stabilize to in-well conditions. This can be as much as an hour or more in some cases. During this period collect periodic manual water levels until static equilibrium is reached. Record the final water-level hold and cut values on the installation form along with the exact measurement time.

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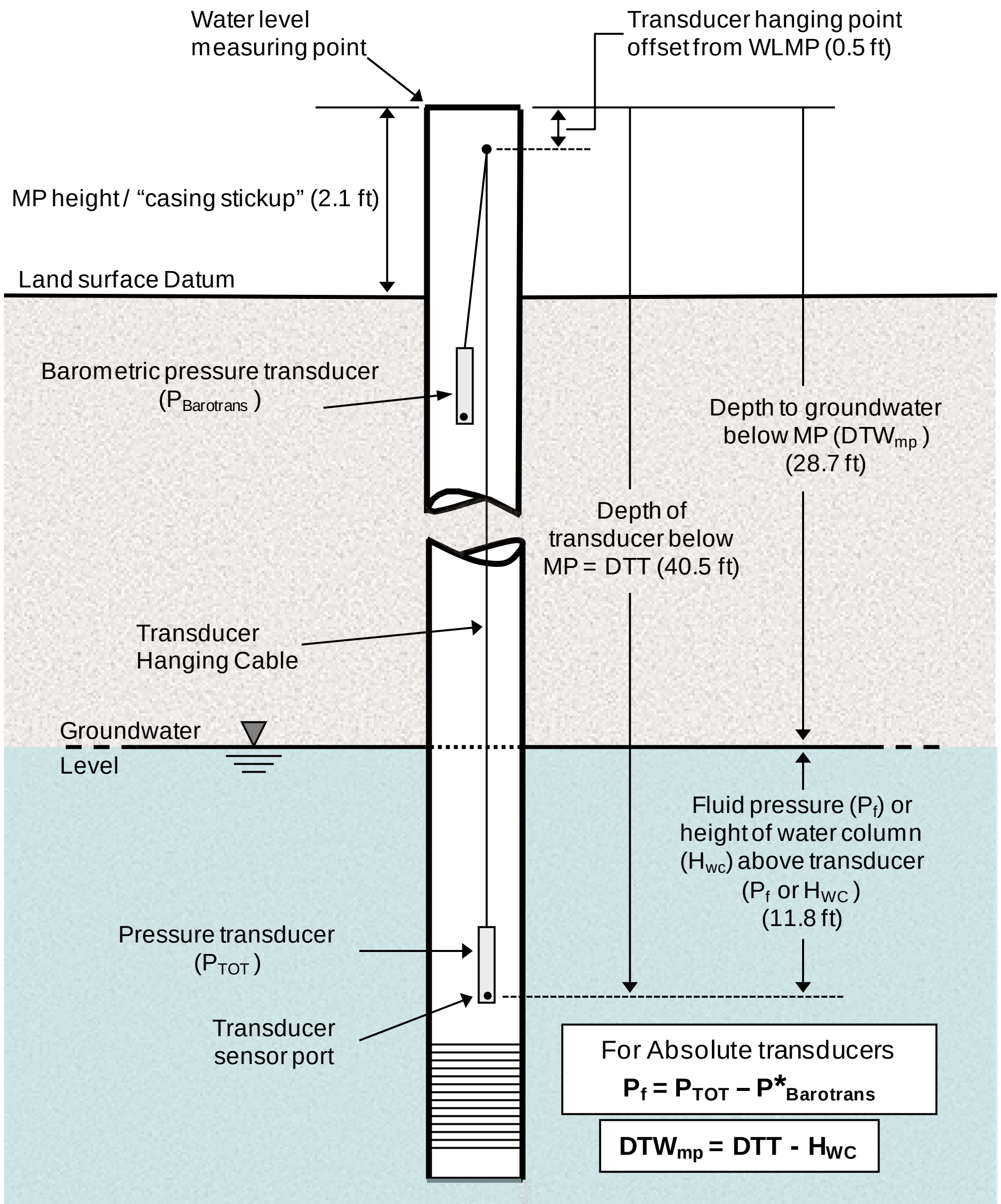
[4] Ambient atmospheric pressure can easily be measured and recorded during baro-transducer setup (section 5.7.8) or later using a certified field barometer.



* Note: Gauged transducers are zero referenced to ambient atmospheric pressure. For these instruments $\mathbf{P_f = P_{TOT}}$

Figure 7 – Example measurements and calculations for confirming transducer placement when installing absolute or gauged transducers on a dedicated communication cable

5.8.14 Finally, use the laptop and supporting software to program the submersible transducer to log at the frequency specified in the project work plan; log water pressure as psi, and water temperature as °C.[5] When attempting to monitor static conditions in actively used supply wells set the transducer to log during a period(s) when pumping is least likely to occur. (Note: for absolute transducers the logging interval for both the submerged and barometric instruments should be frequent enough (e.g. hourly) to provide sufficient data for later barometric correction of the submersible transducer data (see Spane, 1999 for a detailed discussion of barometric pressure effects and removal techniques as applied to both confined and unconfined aquifers).

5.8.15 Record the instrument launch and deployment times, the time datum, and the measurement interval on the installation form.

5.8.16 Review the installation form. Confirm that all measurements required to document the installation have been made and recorded in the appropriate location. Complete and record any missing measurements or observations.

5.8.17 Detach the computer, carefully coil and stow any extra communication cable inside the well casing or protective instrument housing, if used, and secure the well. (Note: Do not use an air-tight locking well cap unless the casing itself is vented to allow free air exchange with the atmosphere).

5.8.18 For new installations recheck instruments within a few days or weeks if possible to verify proper operation. Correct any identified problems.

5.9 Periodic instrument field checks and retrieval of logged data

5.9.1 Pressure transducers must be serviced periodically during use to check and replace instrument batteries, download logged data, and to assess potential changes in local site conditions or instrument integrity over time. Manual groundwater level and barometric pressure check measurements are also made during these visits to confirm transducer operation and instrument accuracy.

5.9.2 The schedule for field checks should be established during project planning and documented in the quality assurance plan. Generally speaking, field visits should be scheduled no more than 4-8 weeks apart for longer-term (multi-year) monitoring efforts. For shorter-term deployments field checks should be frequent enough to provide a sufficient number of manual water level measurements to assess instrument drift that may occur during the deployment period, and correct for it if necessary. (Note: For short term deployments, such as aquifer tests, field checks are often limited to confirmatory manual water level and barometric measurements).

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[5] Transducers can generally be set to record pressures and temperatures in a variety of units (raw pressure, feet of water over sensor, depth below MP, etc.). EAP's standard is to record water level and barometric pressure in consistent units (e.g. psi, ft of water, etc.).

5.9.3 Before leaving the office connect the laptop computer to the Ecology network. This will synchronize the computer clock with the official U.S. time. (Note: For aquifer tests or other short term deployments the computer clock need only be set at the time of deployment).

5.9.4 After arriving at the well site complete the project and background information sections of the transducer download and site visit record (Form A-5, Appendix A). If necessary, lay a tarp around the well to provide a clean working surface. Document any obvious changes in site conditions since the last visit; including adjacent land use changes, recent flooding, nearby well construction activity, or other factors that may aid data interpretation or qualification. Also note any changes in the condition of the well or installed instrumentation (i.e. recent casing damage, etc.).

5.9.5 Manually measure the groundwater level using a calibrated electric meter or steel tape (Marti, 2009). Make two measurements to confirm static conditions, using the same measuring point as when the transducer was installed. Record the measurement time and the water level hold and cut values, in feet below the MP, on the field form. (Note: In some wells, water cascading between screened or perforated intervals within the well may prevent accurate measurements with an E-tape or steel tape. In these cases consider installing a permanent PVC sounding tube into the well to shield the E-tape or steel tape during measurements).

5.9.6 Retrieve the transducer and/or attach the transducer communication cable to the computer (as appropriate). (Note: If the transducer must be removed from the well to perform downloads; attempt to do so during a period when the transducer is not actively making a measurement, if possible. You can use an extension cord storage reel or equivalent to help retrieve and temporarily store the hanging cable. This will help keep the cable clean and kink free – particularly when working with longer cables.).

5.9.7 Use the computer and instrument software to download the transducer per the manufacturer instructions. Record the download time and file name on the field form (see Example Form A-5). View the data graph to confirm a successful download and to identify obvious problems such as missing or unusual values that might suggest a compromised instrument or installation. Check the battery and memory status. For user serviceable instruments replace batteries as necessary.

5.9.8 If a separate temperature monitoring device (e.g. a StowAway TidbiT™ or equivalent) was also deployed download it too. Record the instrument number on the field form along with the download date and time.

5.9.9 When downloading instruments deployed on dedicated communication cables, check the cable desiccant canister(s) and replace them if necessary.

5.9.10 If one was deployed at the site, attach the baro-transducer to the computer and download the logged data. Record the filename on the field form. View the data graph to confirm a successful download and to identify obvious problems such as missing values, unusual data spikes, or other issues that might suggest a compromised instrument or installation. For user serviceable instruments check the battery status and replace as necessary.

5.9.11 Take an instantaneous barometric pressure reading with a calibrated surveying altimeter or equivalent. Record the result, measurement units, the time, and the time datum on the field form.

5.9.12 If problems with the baro-transducer are suspected, compare the barometric reference pressure to the most recent baro-transducer value (after normalizing measurement units) (see Appendix F for example calculations). The difference between the measurements should ideally be within the accuracy range specified in the project QAPP. Similarly, suspected problems with submersible transducers can be verified by comparing the manual water level measurement to the most recent transducer value (after normalizing the measurements as depths to water in feet below land surface datum or the water level measuring point) (see Appendix F for example calculations). Failed instruments or instruments that are outside the accuracy range specified in the QAPP should be replaced.

5.9.13 Visually inspect the field form to confirm that all required manual measurements and data downloads were completed and recorded in the appropriate location.

5.9.14 If continuing data collection, redeploy all removed instruments to their previous position, note the reinstall time on the field form, and secure the well. (Note: If the transducer or baro-transducer was stopped to download data, follow the transducer manufacturer instructions to re-launch the instrument(s) for the next scheduled measurement using the same time datum as the previous deployment).

5.10 Data Processing

5.10.1 The raw pressure values from transducers must be processed and verified before being used and/or uploaded to Ecology's groundwater data management system (EIM). The general steps required to accomplish this are described below, shown schematically in Figure 8 and by example in Appendix F. (Note: The processing steps for individual transducers may include all or only part of the procedures described here - depending on the transducer manufacturer and initial instrument programming. When working with unfamiliar equipment always check the instrument instruction manual for recommended data processing steps and procedures).

5.10.2 Begin data processing by first creating a digital copy of the unprocessed transducer file(s) and supporting documentation including: the original field forms and notes, transducer calibration and installation forms, manual water level records, transducer download notes, and other salient information. Temporarily archive the records in a project subdirectory on the agency shared drive. These data and records are part of the official project archive and provide a convenient backup should data files become corrupted or lost during later processing steps.

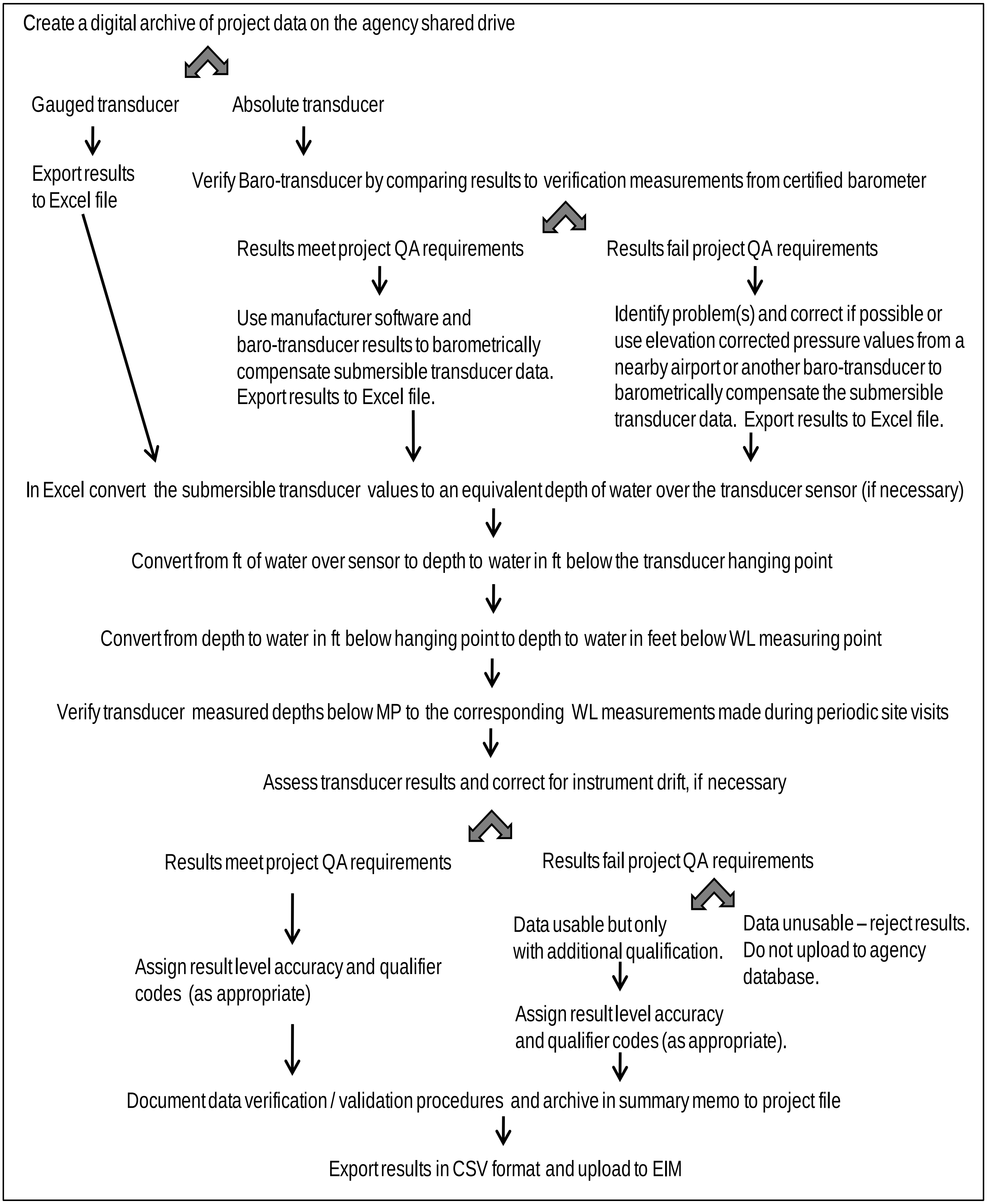

Figure 8 – General data processing steps for transducers
(See Appendix F for a numeric example of the processing steps described here).

5.10.3 When working with absolute transducers, atmospheric pressure effects are typically measured and subtracted from the recorded water pressure values before they are used in subsequent analyses. This is most easily done using the transducer manufacturer's software and a validated baro-transducer data file - since these software tools may also include utilities to adjust the data to accommodate aquifer barometric efficiency where necessary[6]. (Note: Gauged transducers do not require barometric correction. When working with gauged instruments, begin data processing by exporting the raw pressure values to an Excel workbook before proceeding to section 5.10.6).

5.10.4 Prior to performing the actual barometric corrections, check the baro-transducer data file for completeness and accuracy. Do this by comparing the barometric reference measurements made during periodic site visits to the corresponding measurements made by the baro-transducer (both referenced as psia) (see example in Appendix F). Confirm that differences between the transducer measurements and check measurements are within the acceptance range specified in the project QAPP. (Note: If necessary, assess and correct the baro-transducer values for linear drift, at this time, using the procedures outlined in Appendix C).

5.10.5 Use the validated baro-transducer data and the manufacturer supplied software to correct the raw water pressure data files from the submersible transducer(s) for barometric affects. Save the barometrically corrected water pressures to a new file and then export the results to an Excel workbook (Appendix F).

5.10.6 Use Excel to convert the transducer reported values to equivalent feet of water over the sensor, if necessary (see example calculation in Appendix F).

5.10.7 Use the measuring point stickup, hanging point off-set, and transducer hanging depth values measured at the time of transducer installation to normalize the transducer water levels as depths to groundwater in feet below the water level measuring point (see example in Appendix F). (Note: If the hanging point lies below the WL measuring point then add the hanging point offset to the result when performing this calculation. If the hanging point is above the WL MP, then subtract the hanging point offset from the result when making this calculation. If the transducer position was adjusted during deployment to account for greater than expected water level fluctuations or other issues, remember to shift the recorded transducer values by the appropriate amount and direction and for the affected time period(s) to account for these influences).

5.10.8 Compare the resulting transducer values against their corresponding manual water level values to confirm that the transducer measurements are within the acceptable accuracy range specified in the project QAPP (see example in Appendix F). If the transducer

[6] The barometric efficiency of confined aquifers typically ranges from 0.2 to 0.75 (where a value of 1 represents an aquifer that is 100% efficient at transmitting barometric pressure changes). Barometric pressure variations can also cause small but measurable fluctuations in the water table position of unconfined aquifers. The effect manifests as an apparent drop in water level when atmospheric pressure rises and an apparent water level rise when atmospheric pressure falls (Freeze and Cherry, 1979). See Rasmussen and Crawford, 1997, and Spane, 1999 for additional discussion.

results do not meet project acceptance criteria use the drift assessment procedure described in Appendix C to determine if the transducer was influenced by correctable linear drift influences. Apply drift corrections as appropriate and reassess the drift corrected transducer results against the manual confirmation measurements.

5.10.9 Assess the overall data quality and assign the appropriate water level method, accuracy code, and data qualifier(s) (if any), to individual transducer results.

5.10.10 Based on the above analysis either 1) accept the results for use, 2) assign additional data qualifiers, if warranted, or 3) reject the results as unusable.

5.10.11 Finally, document the data reduction steps that were employed to produce the final results for each transducer. Use the data processing summary sheet to: 1) describe equipment problems or other issues that negatively influenced the quality of the final results, 2) document applied datum or drift corrections if any, 3) summarize water level and barometric confirmation measurements/comparisons, and 4) record remarks or other observations that influenced the quality of the final results.

6.0 Record Management

6.1 The submersible transducers that EAP installs or monitors must be documented to enable information about their location, construction, and subsequent monitoring to be archived in Ecology's Groundwater Data Management system. Consult the system help documents and EAP SOP-052 subsection 7.0 (Marti, 2009) for a list of required well-specific metadata.

6.2 EAP staff have developed several field forms and analysis spreadsheets to standardize transducer data collection and reduction. See the EAP GW TCT website for the most up-to-date version of these tools.

6.3 Station information and monitoring notes should be documented, during each site visit, using EAP's standard field forms (or equivalent) (Appendix A). All field entries should be neat and concise. The field lead is responsible for reviewing the form(s) for completeness before leaving a field site.

6.4 The original project files (including transducer installation forms, well construction reports, routine monitoring notes, and documents describing data reduction procedures) should be compiled in a formal project notebook and archived along with a copy of the raw and processed transducer files. These records constitute the permanent project archive.

6.5 Load the final processed data for each transducer into EIM

7.0 **Quality Control and Quality Assurance**

7.1 EAP staff that install and monitor submersible pressure transducers during groundwater studies must adhere to this SOP and EAP's standard operating procedures for measuring water levels and calibrating water level meters (Marti, 2009).

7.2 All instruments must be operated and maintained in accordance with the operating instructions supplied by the manufacturer, unless otherwise specified in the project's Quality Assurance Project Plan (QAPP).

7.3 Repeat measurements of the well depth or depth-to-water at each location must be made to ensure reproducibility and accuracy. Repeat measurements should be within the method's specified accuracy standards. If repeated check measurements are not reproducible, then a reason must be established and documented.

7.4 All data and other measurements must be documented and permanently archived on project field data forms.

8.0 **Safety**

8.1 Care should be taken when working around wells; particularly those with installed pumps or other electrical equipment. Always be aware of the potential for electrical shock when installing transducer hangers, suspension cables, or other equipment. When in doubt, shut off power to the pump before working on the well.

8.2 Wells and well pump houses can also harbor stinging or poisonous insects such as spiders, wasps, and bees.

8.3 Before leaving the office for the field, staff should complete and file a Field Work Plan and Contact Person Form to document the names of field personnel, expected sampling locations, overnight lodging, and emergency contact information.

9.0 **References**

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9.12 Wagoner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors: station operation, record computation, and data reporting. U.S. Geological Survey Techniques and Methods 1-D3, 51 p. + 8 attachments.

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Appendix A: Example Field Forms

EAP has developed several spreadsheet templates and field form to speed and where possible automate the tasks required to evaluate, install, and process the results from pressure transducers. Examples of commonly used forms are included here. See EAP's GW TCT (Technical Coordination Team) Sharepoint site for up-to-date versions. These tools and forms can easily be modified to accomodate the needs of particular instruments or projects.

Well Inventory and Preliminary Transducer Installation Plan **(Form A-1)**

Site Location Information

Project:________________ Site name:______________________ Site inventory date:____________

Well Tag No:____________ Project well ID:______________ Field crew:___________________

Well owner name:_________________________________ phone:_____________ Access approval: Yes / No

Well site address:____ City:_______________

Site Latitude (DD):____________ Site Longitude (DD):______________ Datum: NAD27 / NAD83 / WGS84

GPS indicated horizontal accuracy (ft): _________ Number of satellites used for determination: _________

Site land surface elevation (ft):_________ Elevation method:_____________ Elevation accuracy (ft): _________

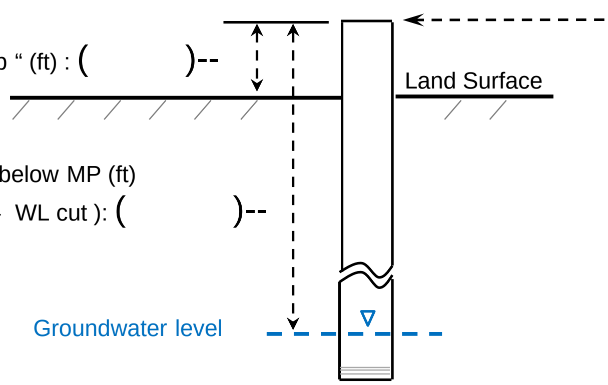
Vertical datum: NGVD29 / NAVD88 Site photo ID numbers ____________________

Well construction details and inventory groundwater level measurement

Total well depth (ft):_____________ Well diameter (in):__________ Drillers log available: (Y) (N)

MP height /
“casing stickup “ (ft) : ( )--

Depth to GW below MP (ft)
(WL hold – WL cut): ( )--



WL measuring point ID: ______________

MP description: ______________________
____

WL Time:_____________ (PST) (PDT)

WL hold value (ft):_____________

WL cut value (ft):_____________

WL method:_____________

WL accuracy:_____________

Preliminary Transducer Selection and Installation Information

Well previously vented to atmosphere (Yes) (No)
Describe required well modifications (if any): ____

Transducer hanger already installed (Yes) (No)
Describe required well modifications (if any):____

Estimated annual average GW level fluctuation at site (ft): ___________

Estimated month of highest GW level: ___________

Estimated month of lowest GW level:___________

Suggested transducer type (Gauged) (Absolute) If gauged, suggested total cable length:__________ (ft)

Minimum required transducer pressure range:__________(psi) (ft) Suggested hanging depth: __________ (ft)

(NOTE: Use form back for site maps or other observations)

Transducer Installation Form (see well inventory form for additional site details) (Form A-2)

Site Location Information

Project:_______________ Site name:______________________ Date (mm/dd/yyyy):____________

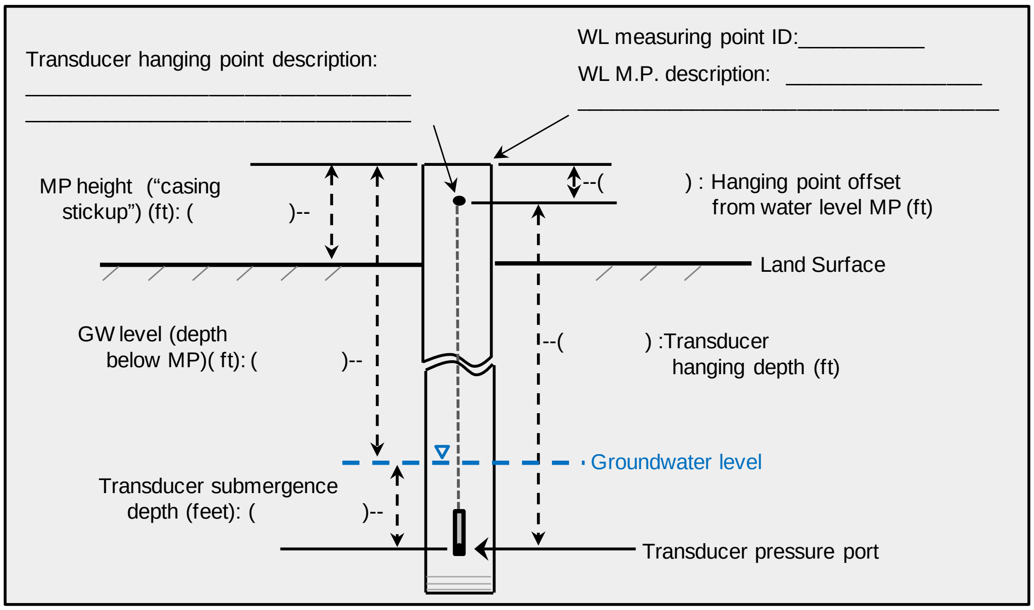
Well Tag No:____________ Project well ID:______________ Field crew:___________________

Site address:____

Manual GW level and transducer reference measurements

GW level hold value (ft):____________ GW level cut value (ft):____________ Time (hr/min):__________ (PST) (PDT)

WL method: (E-tape) (Steel tape) _______________ WL accuracy (ft): **+-** (0.01) (0.1) (1.0) (>1.0)



Transducer information

	Submersible Transducer	Barometric Transducer
Transducer model:	____________________	____________________
Serial Number:	____________________	____________________
Last calibration (mm/dd/yyyy):	____________________	____________________
Pressure range (psi):	____________________	____________________
Instrument type:	Absolute / Gauged	---
Vented Communication Cable ID:	____________________	____________________
Communication Cable Length (ft):	____________________	____________________
Battery percent remaining:	____________________	____________________
Memory percent remaining:	____________________	____________________
Launch time (hh:mm) :	________________ (PST) (PDT)	________________ (PST) (PDT)
Measurement interval:	____________________	____________________
Deployment time (hh:mm):	________________ (PST) (PDT)	________________ (PST) (PDT)

(Over)

(Form A-2: Page 2)

Barometric Reference Pressure and Method

Barometric reference pressure :___________(mm Hg) (in Hg) (psia)   Measurement time (hh:mm):__________

Reference method:

Certified barometer type:___________________________ Last calibration: (mm/dd/yyyy) ______________

Local airport – name:________________________________ distance from site (mi) ________

NOAA station – name:_____________________________ distance from site (mi)_________

Instrument placement check measurements

Other observations

TRANSDUCER DRY-TEST CALIBRATION CHECK WORKSHEET **Form A-3**

Evaluation Date (mm/dd/yyyy): _____/_____/_______

Transducer serial number: _________________ Transducer Type: Gauge / Absolute (circle one)

Transducer model: ________________________ Manufacturer stated performance accuracy___________(ft)

Transducer pressure range (psi): ____________ Project accuracy requirements_____________(ft)

Staff Initials: ____________

Barometric Reference Method or Instrument ***:______________________________

Reference Method performance accuracy:_________________(psi) (ft)

Date of last calibration (mm/dd/yyyy):_____/_____/_______

Evaluation of Absolute and Barometric Transducers					
Reference measurement number	Watch time (hh:mm)	Barometric reference pressure (BRP) (psi) **	Transducer reported pressure (TRP) (psi) **	Transducer error (TE): (TRP-BRP) (psi)	Transducer error as equivalent feet of water: (TE x 2.3067*) (ft)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Evaluation of Gauged Transducers			
Reference measurement number	Watch time (hh:mm)	Transducer reported pressure (TRP) ** (psi)	Transducer error as equivalent feet of water: (TRP x 2.3067*) (ft)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

* Note: 2.3067 is a conversion factor to convert from psi units to feet of pure water at 4 deg C. See Appendix E for additional conversion factors for other water temperatures and dissolved solids concentrations.

** Note: Baro-transducer pressures values and Barometric reference measurements are generally recorded as equivalent inches of Mercury (in Hg). To convert to units of psi, multiply (in Hg) values by 0.491154.

*** Note: Gauged transducers do not require an external barometric reference pressure to perform a dry-test calibration check, since these instruments are zero referenced to ambient atmospheric pressure. The effective error for these instruments is therefore the transducer reported pressure value (TRP).

TRANSDUCER WET-TEST CALIBRATION CHECK WORKSHEET **Form A-4**

Evaluation Date (mm/dd/yyyy): _____/_____/_______

Transducer serial number: _________________ Transducer Type: Gauge / Absolute (circle one)

Transducer model: ________________________ Manufacturer stated performance accuracy___________(ft)

Transducer pressure range (psi): ____________ Project accuracy requirements_____________(ft)

Staff Initials: ____________

Average transducer out-of-water pressure reading at start of test (psi): ____________

Average transducer out-of-water pressure reading at end of test (psi): _____________

Stilling well measurements							
Watch time (hh:mm)	Manual water level (ft)	Calibration mark	Distance between calibration marks (ft)	Manual measurement of transducer submergence depth (MM) (ft)	Raw pressure value from transducer (RP) (psi)	Transducer measured submergence depth (TM) (ft) **	Effective transducer error (TM-MM) (ft)
1)							
2)		1					
3)							
4)							
5)		2					
6)							
7)							
8)		3					
9)							
10)							
11)		4					
12)							
13)							
14)		5					
15)							
16)							
17)		4					
18)							
19)							
20)		3					
21)							
22)							
23)		2					
24)							
25)							
26)		1					
27)							

** For absolute transducers subtract the average of the two out-of-water pressure readings (as psi) from each of the raw pressure values from the transducer (RP) (as psi) before calculating the transducer measured submergence depth (TM) (as feet)

TRANSDUCER DOWNLOAD AND SITE VISIT RECORD **Form A-5**

Project:________________________________ Project Well No:____________________ Well Tag ID:____________

Background Information			
Date of site visit (mm/dd/yyyy):			
Field personnel initials:			

Manual GW Level Measurement			
Water level measuring point ID number:			
Measuring point description:			
Water level watch time (hh:mm):	(PST) (PDT)	(PST) (PDT)	(PST) (PDT)
WL method:	(Steel Tape) (Calibrated E-tape) (E-tape)	(Steel Tape) (Calibrated E-tape) (E-tape)	(Steel Tape) (Calibrated E-tape) (E-tape)
WL accuracy (+- ft):	(0.01) (0.1) (0.5) (1.0) (>1)	(0.01) (0.1) (0.5) (1.0) (>1)	(0.01) (0.1) (0.5) (1.0) (>1)
Manual WL hold value (ft):			
WL cut value (ft):			
Manual WL depth below MP (ft):			
Manual WL depth below LS (ft):			

Submersible Transducer Information			
Model:			
Serial number:			
Download time (hh:mm):	(PST) (PDT)	(PST) (PDT)	(PST) (PDT)
Download file name:			
Battery voltage (percent):			
Memory status (percent):			
Instrument re-deployment time (hh:mm):	(PST) (PDT)	(PST) (PDT)	(PST) (PDT)

Barometric Transducer Information			
Model:			
Serial Number:			
Download time (hh:mm):	(PST) (PDT)	(PST) (PDT)	(PST) (PDT)
Download file name:			
Battery voltage (percent):			
Memory status (percent):			
Instrument re-deployment time (hh:mm):	(PST) (PDT)	(PST) (PDT)	(PST) (PDT)

Barometric Reference Measurements			
Reference instrument/method:			
Barometric reference pressure (in Hg):			
Barometric reference time (hh:mm):	(PST) (PDT)	(PST) (PDT)	(PST) (PDT)

Additional Observations or Comments

Note: (PST) - Pacific standard time: currently starts a 2 am on the first Sunday in November and ends at 2 am on the second Sunday in March

(PDT) - Pacific daylight savings time: currently starts at 2 am on the second Sunday in March and ends at 2 am on the first Sunday in November

Appendix B: Summary of "Dry" and "Wet" Test Verification Procedures to Assess Transducer Performance and Calibration Prior to Deployment

1. Pressure transducers can deviate from the factory calibration for many reasons. The most common include: exposure to pressures or temperatures beyond the sensors designed operating range, physical bumps or jolts, and electrical surges (Freeman et al., 2004). To confirm proper operation, EAP conducts performance checks of all transducers prior to initial deployment.

2. A "dry" (air only) calibration test is conducted for **all** transducers, prior to deployment, to determine the amount of electronic noise present in the instrument. To perform a dry test connect a transducer to the laptop computer and record 10 real time air-only pressure readings, at 1-minute intervals, using the transducer software. Gauged transducers should ideally read zero or near zero psi (within the instrument accuracy range) during this test. Similarly, absolute transducers (both barometric and submersible) should report ambient atmospheric pressure values equal to those of an adjacent certified reference barometer (within the instrument accuracy ranges). (Note: If a certified reference barometer is not available, the station pressure measured at a nearby national weather service station can serve as a *rough* check of transducer performance. When comparing weather station barometric pressures to absolute transducer values, one must first correct for the elevation difference between the test site and the weather station to obtain optimum results).

3. Instruments that fail the "dry" test calibration check (i.e. show air-only electronic noise values greater than the instrument accuracy range) should be returned to the manufacturer for servicing and recalibration prior to further use.

4. A second more rigorous "wet" test calibration check procedure is also run on those transducers that have not been factory calibrated and certified within six months of their planned deployment. A wet test calibration check involves comparing a transducer's response to a series of different, known water column heights above the sensor. (Note: For efficiency sake, a modified "dry" test procedure is often incorporated into the "wet" test calibration procedure as discussed below).

5. For most wet calibration tests EAP uses an above-ground-stilling tube constructed from a 20-foot length of translucent 2¼ - inch ID rigid-walled plastic. The pipe is wide enough to enable two-to-three transducers to be evaluated simultaneously (Figure B-1). (Note: When deploying transducers that will be subjected to water level differences of more than 20 feet, consider performing the wet calibration on site as part of the actual transducer installation).

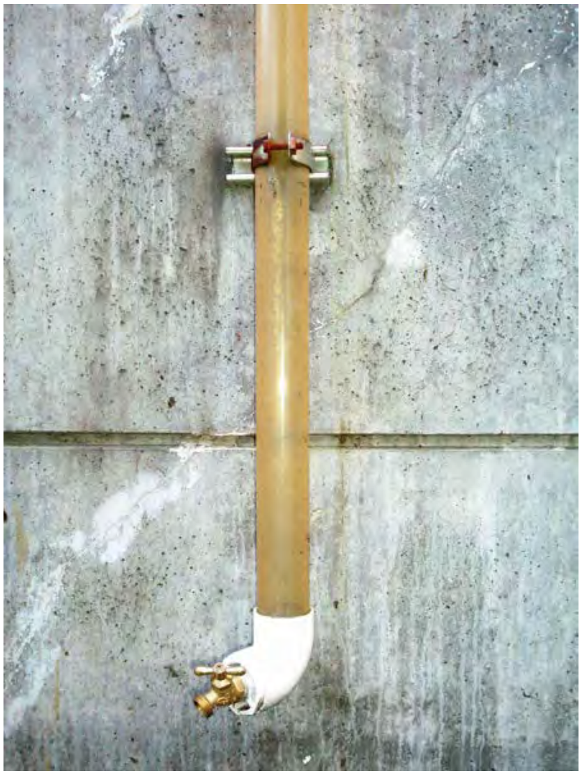


Figure B-1: Bottom portion of EAP's transducer check stilling tube

6. To conduct a wet test using the stilling tube attach a garden hose to the valve at the bottom of the stilling tube and fill the tube with tap water from the adjacent hose bib. Fill until the tube overflows before closing the bottom valve and shutting off the water. Disconnect the hose from the stilling tube valve and confirm that there are no water leaks. (Note: If the tube leaks it won't provide meaningful results and must be repaired before proceeding).

7. Select two or three transducers of similar type (gauged or absolute) and program them to simultaneously launch at a convenient near-term start time. (Note: Remember to synchronize the transducers with the computer clock during programming. When evaluating gauged transducers always program and test them using the actual data communication cable and transducer pair that will be used for deployment). Program each transducer to record pressure at one minute intervals.

8. Attach the first batch of launched transducers to the attachment loop at the lower end of the transducer calibration cable? (see stilling tube schematic on Figure B-2). Have a coworker hold the cable and transducer assembly in the vertical position while you measure the distance from each transducer sensor port to the bottom of the calibration mark 1 cable stop (see Figure B-2, schematic). Measure to the nearest 0.01 foot with a steel engineer's hand tape. Record the value for each transducer on a separate test form as the "Manual measurement of transducer submergence depth (MM)" for calibration mark 1 (column 5 on form A-4) (see Figure B-2 for example). (Note: This distance marks the starting submergence depth for each transducer at the beginning of the test. Additional calibration marks (stops) are precisely placed at 3 foot increments along the cable and provide a

convenient and reproducible means of defining the manual transducer submergence depth at successive calibration marks).

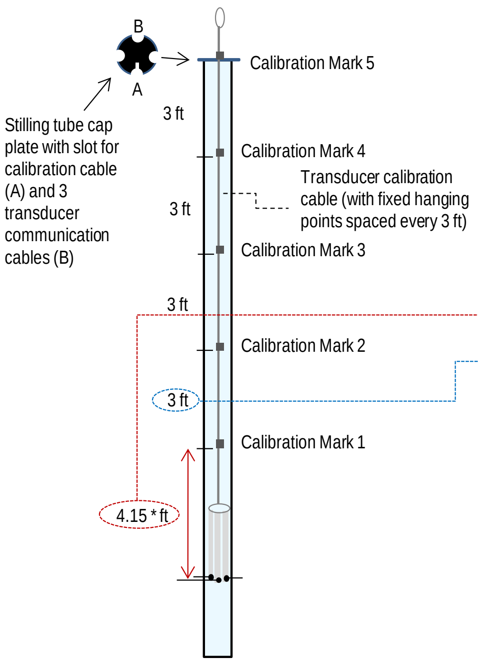
9. After measuring and recording the “calibration mark 1” submergence depth for each transducer, set the instruments in a secure location and allow them to log and record undisturbed for 5 minutes in open air. [Note: These air only readings serve two purposes; 1) they provide data to perform a modified dry test as mentioned above and 2) can be used to barometrically correct the raw pressure values logged by an absolute transducer (RP) - see below and Figure B-2].

10. When 5 minutes have passed slowly begin lowering the transducer(s) into the stilling tube. (Note: To ensure an accurate test verify that there are no air bubbles trapped in the transducer sensor port). Continue lowering until the transducer(s) can be secured in place by sliding the cable stop for the calibration mark 1 into the slot on the well cap plate (Figure B-2).

11. With the transducer(s) secured in place at calibration mark 1, use a hose or a container of water to top off the stilling tube until it overflows. Allow the transducers to equilibrate to the in-well conditions for 10 minutes. Check the water level periodically during this time to confirm the water level is stable at the top of the tube and that there are not leaks.

12. At the 10 minute mark, note and record the watch (start) time on the transducer test form (Column 1 for calibration mark 1, see example Figure B-2). Allow the transducers to measure and record three pressure readings at the first hanging depth. To help locate these values in the transducer data file, note the time for each reading on the calibration form.

Stilling Tube Schematic



* Example value: Measure the actual distance from the bottom side of calibration mark 1 to the sensor port of each transducer. Record the result in the column titled "Manual measurement of transducer submergence depth (MM) (ft)" for calibration mark 1 (see example worksheet). (Note: The distance to calibration mark 1 will likely differ for each transducer. Use a separate calibration worksheet to record the results for each instrument).

Example Wet-Test Calibration Check Worksheet

TRANSDUCER WET-TEST CALIBRATION CHECK WORKSHEET
(NOTE: THIS EXAMPLE USES DATA FROM A GAUGED TRANSDUCER)**

Evaluation Date (mm/dd/yyyy): 05 / 05 / 2010 Time (hh:mm): __________(PST)_(PDT)
Transducer serial number: 000125 Transducer Type: (Gauge) / Absolute (circle one)
Transducer model: Hydromon 30 Manufacturer stated performance accuracy +-0.07 (ft)
Transducer pressure range (psi): 0-30 Project accuracy requirements +-0.1 (ft)
Staff Initials: A. Tester

Average transducer out-of-water pressure reading at start of test (psi): 0.0006
Average transducer out-of-water pressure reading at end of test (psi): 0.0005

Stilling well measurements							
Watch time (hh:mm)	Manual water level (ft)	Calibration mark	Distance between calibration marks (ft)	Manual measurement of transducer submergence depth (MM) (ft)	Raw pressure value from transducer (RP) (psi)	Transducer measured submergence depth (TM) (ft) **	Effective transducer error (TM-MM) (ft)
1)	4.15				1.793	4.136	-0.014
2)	4.15	1	NA	* 4.15	1.798	4.148	-0.002
3)	4.15				1.812	4.180	0.030
4)	7.15				3.121	7.200	0.050
5)	7.15	2	3	7.15	3.089	7.126	-0.024
6)	7.15				3.098	7.147	-0.003
7)							
8)	etc	3	etc	etc	etc	etc	etc
9)							
10)							
11)		4					
12)							
13)							
14)		5					
15)							
16)							
17)		4					
18)							
19)							
20)		3					
21)							
22)							
23)		2					
24)							
25)							
26)		1					
27)							

** For absolute transducers subtract the average of the two out-of-water pressure readings (as psi) from each of the raw pressure values from the transducer (RP) (as psi) before calculating the transducer measured submergence depth (TM) (as feet)

Worksheet Notes: **

For gauged transducers:
TM = RP x 2.307

For absolute transducers:
TM = (RP-BP) x 2.307

Where:

TM = The transducer measured submergence depth (ft)

RP = The raw pressure value from the transducer (psi)

BP = The average of the before and after air only barometric pressure readings recorded at the beginning and end of the wet test calibration check procedure

2.307 = A conversion factor to convert from psi units to feet of pure water at 4 deg C. See Appendix E for the appropriate conversion factor at different water temperatures and dissolved solids concentrations.

Figure B-2: Schematic of EAP's transducer stilling tube and an example worksheet showing hypothetical test results for a gauged transducer.

13. When the third reading at calibration mark 1 is complete, carefully lower the transducer assembly and re-anchor it at the second hanging point on the cable (calibration mark 2). Re-top the stilling tube to overflowing. Wait 5 minutes for the transducers to stabilize at this depth and then record the water depth (calibration mark 1 distance + 3ft) and watch (start) time on the test form as the "manual measurement of transducer submergence depth (MM)" for calibration mark 2. Wait for the transducer(s) to measure and record three one-minute readings at calibration mark 2. Repeat this procedure for the three remaining calibration marks.

14. When the readings for the deepest calibration position are complete reverse the procedure and repeat the test by working from deepest to shallowest. (Note: The test is performed under both increasing and decreasing water pressures to confirm that the transducer(s) respond correctly to pressure differences regardless of the direction of the imposed change).

15. After completing the final depth reading remove the transducer(s) from the well, note the removal time on the transducer test form, and then allow them to record for 5 additional minutes in open air.

16. Test any remaining transducers per the above procedure.

17. Download the data from each of the tested transducers to Excel. Compare the manual transducer submergence depth values to their corresponding transducer values per the example in Figure B-2. Based on this comparison determine whether the instruments meet the manufacturers (and/or project) accuracy requirements (see example Figure B-2). (Note: To perform this evaluation the raw transducer values can either be transposed from the data file to the wet-test worksheet (as shown in example Figure B-2) or alternatively, the manual instrument submergence depths can be input into Excel to perform the evaluation. Document whichever method you adopt).

18. When testing absolute transducers remember to subtract the ambient barometric pressure from the raw pressure values reported by the transducer before comparing them to their corresponding reference measurements. Do this by subtracting the average of the air only pressure readings recorded at the beginning and end of the test period from the three transducer values recorded at each calibration mark (see example worksheet, Figure B-2).

19. New transducers that fail these initial dry and wet calibration tests should be sent back to the manufacturer for exchange. Older units should be sent back to the manufacturer for servicing and recalibration.

Appendix C: Evaluating and Correcting Transducer Data for Linear Drift

1. All pressure transducers are subject to internal and external influences which cause them to deviate from calibration over time[7]. The generic term "drift" is commonly used to describe these undesirable and often unavoidable changes in the electronic input-output relationship of transducers during deployment.

2. Fortunately, the manual water-level measurements made during periodic field visits can often be used to assess drift influences on the performance and accuracy of individual transducers. Where transducer drift exceeds the project water level accuracy requirements these data can often be used to develop regression equations to help remove linear drift influences from the transducer measured water levels (or pressures). The general procedures for accomplishing this are described below.

3. Begin the evaluation by entering the paired manual-confirmation measurements (WL_{MM}) and transducer-measured (WL_{TM}) depth to water values into the appropriate columns on the transducer evaluation workbook[8]. The manual measurements are considered the "true" depth to water values and are the reference against which the transducer values are evaluated.

4. Evaluate the adjacent XY scatter plot of the paired data which also includes a theoretical best fit line and a linear trend line for the paired data series (see example Figure C-1). If the r-squared value for the regression equation is strong (>0.95) then the drift can be described as a linear function of the elevation and you can proceed. If the r-squared values is <0.9 check to see if there's a non-linear regression technique that better fits the data.[9]

5. Visually compare the plotted trend line to the "ideal" (theoretical best fit) line. They may have parallel but offset slopes (i.e. the difference between the manual and transducer measured water levels remains constant as one moves along the X axis), or they may have noticeably different slopes over the water level range (i.e. the difference between the manual and transducer water levels steadily changes as one moves along the X axis).

---

[7] For additional guidance and background information regarding transducer drift see Freeman et al., 2004.

[8] EAP has developed a drift assessment and correction worksheet in EXCEL. Check the GW TCT website for the most up to date version.

[9] Another possibility to consider is that the measured difference between the manual water levels and transducer values (the error) changes with time; as opposed to pressure (i.e. the magnitude of the error increases the longer the transducer is deployed). To assess this possibility plot the error against time to determine whether it manifests as a linear function of time.

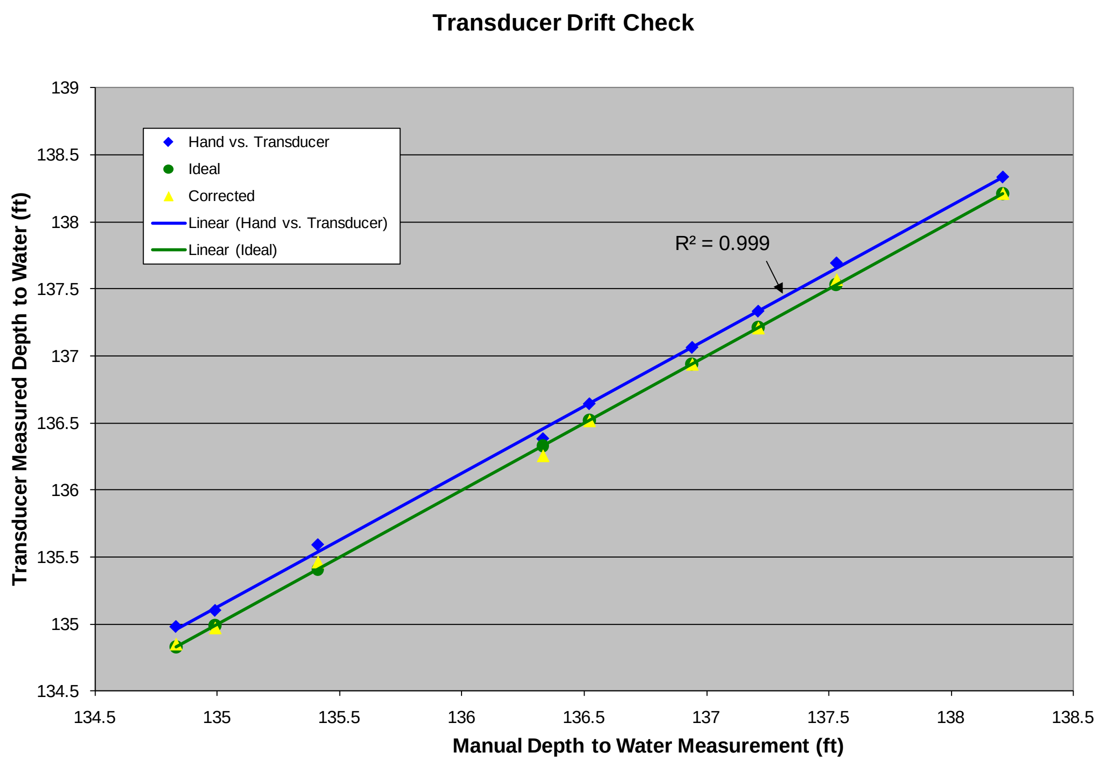


Figure C-1

6. In a third spreadsheet column, calculate the error difference between each data pair. Use the formula:

$$T_{ERR} = (WL_{MM} - WL_{TM}) * (-1)$$

where:

T_{ERR} = Transducer error
WL_{MM} = Manual depth to water measurement
WL_{TM} = Transducer measured depth to water

(Note: The (-1) value will provide a positive error if the transducer measurement is too big, and a negative error if the transducer measurement is too small).

7. Make a new XY scatter plot, using the WL_{TM} values for the X coordinates, and the T_{ERR} values for the Y coordinates (Figure C-2). This results in a plot that shows how the error systematically relates to or changes with a given series of transducer reported depth to water values. Plot a linear trend line, and the trend line slope equation (y = mx+b), for this data series.

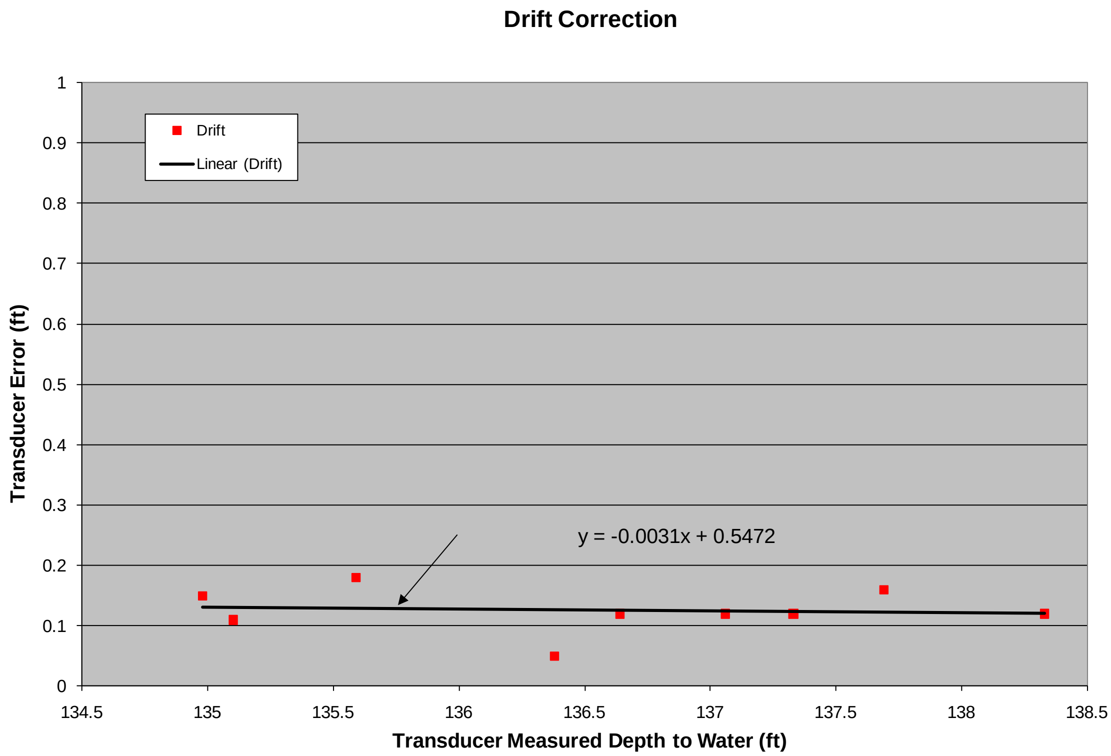


Figure C-2

8. The trend line slope equation on the drift correction graph can be used to run a linear correction on all of the transducer data (presumably you have manually checked the transducer over most of the range of water level values measured by the transducer). To do this, make a new column called "Corrected Transducer depth to water".

   Insert the following formula into each cell of the new column:

   $WL_{TC} = WL_{TM} - ((m*WL_{TM}) + b)$

   Where:

   WL_{TC} = Corrected transducer depth to water
   WL_{TM} = Transducer measured depth to water
   m = the "m" slope value in the drift trend line equation
   b = the "b" value in the drift trend line equation

   (Note: Be sure to assign the appropriate sign to the "m" and "b" values)

9. Double-check the correction by plotting the WL_{MM} values (X axis) against their corresponding WL_{TC} values (Y axis) to see how closely the resulting data set plots to the "ideal" trend line (Figure C-1).

Appendix D: Equipment and Supplies

Transducer Deployment and periodic downloads

Copies of construction reports and water level histories for the wells being instrumented (if available)
Submersible pressure transducer(s)
Vented transducer cable (or stainless steel hanger cable, as appropriate)
Baro-transducer(s) (if applicable)
Portable laptop computer with transducer software and communication cable/hardware
Transducer software manual(s), project logbook, and field forms
Steel tape or calibrated water-level meter (e-tape)
Engineer’s hand tape
Pencils, indelible ink pen
Extra batteries (for transducers, e-tape, computer)
Disinfectant for down well equipment (10% bleach solution and squirt bottle)
De-ionized water and squirt bottle
Paper towels
Key(s) for wells or site access gates (as appropriate)
Personal field gear
Portable reference barometer or survey grade altimeter/barometer

Field Toolbox

Two pipe wrenches
Hammer and assorted nails
Knife
Screwdriver set with commonly used head types and sizes
Assorted stainless steel screws, nuts, and bolts
Duct tape
Electrician’s tape
Assorted pliers
Standard and metric socket sets (¼ - inch drive)
Crescent wrenches
Wire clippers
Engineer’s hand tape
Wire-reinforced zip ties, various sizes
Indelible ink pen
Stainless steel nuts - extra weight for hanging transducers
Spool of 1/16th inch diameter flexible stainless steel cable (or equivalent)
Cable clamps
Swaging tool and cable swages
Small carabineers to attach transducer and cable to hanger
Assorted eye bolts, washers, and lock nuts
Hack saw and extra blades
Portable drill, battery charger, drill bits, and two charged batteries

Appendix E: Equivalent feet of water per psi of water pressure, at representative water temperatures and TDS concentrations

Water Temperature (deg-C)	Specific gravity (g/cm^3)	Equivalent feet of water for each psi of water pressure (ft)
Pure Water		
4	1	2.3067
8	0.99988	2.3064
10	0.99973	2.3060
12	0.99952	2.3056
14	0.99927	2.3050
16	0.99897	2.3043
Water with 500 mg/L TDS		
4	1.000403	2.3076
8	1.000273	2.3073
10	1.000122	2.3069
12	0.999917	2.3065
14	0.999662	2.3059
16	0.999358	2.3052
Water with 1,000 mg/L TDS		
4	1.000804	2.3085
8	1.000668	2.3082
10	1.000514	2.3078
12	1.000307	2.3074
14	1.000049	2.3068
16	0.999744	2.3061
Water with 2,500 mg/L TDS		
4	1.002005	2.3113
8	1.00185	2.3109
10	1.001688	2.3106
12	1.001473	2.3101
14	1.001208	2.3094
16	1.000896	2.3087
Water with 5,000 mg/L TDS		
4	1.003999	2.3159
8	1.003814	2.3155
10	1.003638	2.3151
12	1.003411	2.3145
14	1.003135	2.3139
16	1.002812	2.3131
Water with 10,000 mg/L TDS		
4	1.007972	2.3250
8	1.007729	2.3245
10	1.007527	2.3240
12	1.007276	2.3234
14	1.006977	2.3228
16	1.006634	2.3220
Water with 20,000 mg/L TDS		
4	1.015902	2.3433
8	1.015547	2.3425
10	1.015295	2.3419
12	1.014998	2.3413
14	1.014657	2.3405
16	1.014274	2.3396

Appendix F: Example field forms and basic data processing steps for an absolute transducer deployment

The following example illustrates the documentation and basic data processing steps shown schematically in Figure 8 for an absolute transducer / baro-transducer pair - including the general calculations and normalization steps required to convert “raw” transducer pressure values to an equivalent groundwater level referenced either as depth below the water level measuring point or land surface datum. The processing steps for a gauged transducer are similar to those shown here, minus the barometric correction steps.

Depending on your project goals and local hydrogeologic setting, it may be necessary to perform additional data processing and analysis steps beyond the basic steps described here (e.g. determination of barometric efficiency, barometric delay, etc.). This is particularly true when analyzing the results from aquifer tests or when working with water level information from low-gradient confined aquifers. See the referenced works of Rasmussen and Crawford, 1997; Spane, 1999; Halford, 2006; and Halford et. al., 2012, for further discussion of these topics.

Transducer Installation Form (see well inventory form for additional site details) (Example Form A-2)

Site Location Information

Project: **WA ambient GW** Site name: **Henry Well** Date (mm/dd/yyyy): **08/01/2010**

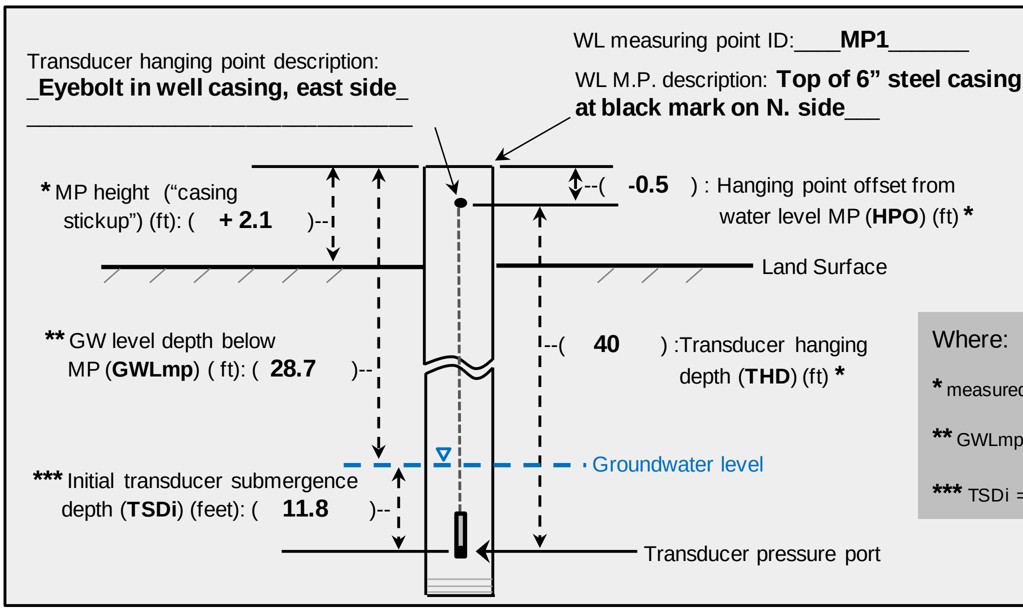
Well Tag No: **AAB123** Project well ID: **NA** Field crew: **A. Tester**

Site Address: **123 Main St. Sequim, WA.**

Manual GW level and transducer reference measurements

* GW level hold value (ft):__**30.0**______ * GW level cut value (ft):____**1.30**____ Time (hr/min):__**10:25**___ (PST) (PDT)

WL method: (E-tape) (Steel tape)_______________ WL accuracy (ft): +- (0.01) (0.1) (1.0) (>1.0)



Where:

* measured values

** GWLmp = GWL Hold – GWL cut

*** TSDi = (TDH – GWLmp) - HPO

Transducer information

	Submersible Transducer	Barometric Transducer
Transducer model:	_**Water Logger**_____	_**Baro-logger** ________
Serial Number:	_**WL000001**__ ________	_**BL0001**_____________
Last calibration (mm/dd/yyyy):	_**05/01/2010** __________	__**05/01/2010** _________
Pressure range (psi):	__**0-30 PSIA**__________	__**0-15 PSIA**__________
Instrument type:	(Absolute) Gauged	---
Vented Communication Cable ID:	__**NA**_______________	___**NA**______________
Communication Cable Length (ft):	__**NA**_______________	___**NA**______________
Battery percent remaining:	___**100**______________	___**100**______________
Memory percent remaining:	___**100**______________	___**100**______________
Launch time (hh:mm) :	__**10:30**______________ (PST) (PDT)	___**10:30**______________ (PST) (PDT)
Measurement interval:	__**60 minute** __________	___**60 minute**_________
Deployment time (hh:mm):	__**10:47**_____________ (PST) (PDT)	___**10:47**_____________ (PST) (PDT)

(Over)

Barometric Reference Pressure and Method

Barometric reference pressure :__**14.665**_____(mm Hg) (in Hg)
Measurement time (hh:mm):__**10:39**_____(PST)(PDT)
Reference method:
Certified barometer type:__**AIr-HB-1L**__________________ Last calibration: (mm/dd/yyyy) __**05/01/2010**______
Local airport – name:_____**NA**___________________________ distance from site (mi) __**NA**______
NOAA station – name:____**NA**_________________________ distance from site (mi)____**NA**_____

Instrument placement check measurements

Note: See the shaded box on the previous page for examples of these calculations

Other observations

Note: The barometric transducer was suspended on the same hanging cable as the submersible transducer at a depth of 15 feet below the hanging point.

TRANSDUCER DOWNLOAD AND SITE VISIT RECORD Example Form A-5

Project:__WA Ambient GW____________________ Project Well No:___Henry Well_________ Well Tag ID:_AAB123______

Background Information			
Date of site visit (mm/dd/yyyy):	8/5/2010	8/30/2010	
Field personnel initials:	A Sampler	A Sampler	
Manual GW Level Measurement			
Water level measuring point ID number:	MP1	MP1	
Measuring point description:	TOC at black mark, N. side	TOC at black mark, N. side	
Water level watch time (hh:mm):	9:20:00 (PST) (PDT)	10:20:00 (PST) (PDT)	(PST) (PDT)
WL method:	(Steel Tape) (Calibrated E-tape) (E-tape)	(Steel Tape) (Calibrated E-tape) (E-tape)	(Steel Tape) (Calibrated E-tape) (E-tape)
WL accuracy (+- ft):	(0.01) (0.1) (0.5) (1.0) (>1)	(0.01) (0.1) (0.5) (1.0) (>1)	(0.01) (0.1) (0.5) (1.0) (>1)
WL hold value (ft):	30	30	
WL cut value (ft):	1.5	1.69	
Manual WL depth below MP (ft):	28.5	28.31	
Manual WL depth below LS (ft):	26.4	26.21	
Submersible Transducer Information			
Model:	Water Logger	Water Logger	
Serial number:	WL000001	BL0001	
Download time (hh:mm):	9:35:00 (PST) (PDT)	10:35:00 (PST) (PDT)	(PST) (PDT)
Download file name:	WL000001_Aug5_2010	WL000001_Aug30_2010	
Battery voltage (percent):	90	70	
Memory status (percent):	90	80	
Instrument re-deployment time (hh:mm):	9:50:00 (PST) (PDT)	10:50:00 (PST) (PDT)	(PST) (PDT)
Barometric Transducer Information			
Model:	Baro-logger	Baro-logger	
Serial Number:	BL0001	BL0001	
Download time (hh:mm):	9:45:00 (PST) (PDT)	10:45:00 (PST) (PDT)	(PST) (PDT)
Download file name:	BL0001_Aug5_2010	BL0001_Aug30_2010	
Battery voltage (percent):	90	70	
Memory status (percent):	90	80	
Instrument re-deployment time (hh:mm):	9:50:00 (PST) (PDT)	10:50:00 (PST) (PDT)	(PST) (PDT)
Barometric Reference Measurements			
Reference instrument/method:	AIR-HB-1L barometer	AIR-HB-1L barometer	
Barometric reference pressure (in Hg):	29.801	29.911	
Barometric reference time (hh:mm):	9:25:00 (PST) (PDT)	10:25:00 (PST) (PDT)	(PST) (PDT)
Additional Observations or Comments			

Note: Both transducers were removed on Aug 30, 2010 after completing instrument downloads and performing check measurements

Note: (PST) - Pacific standard time: currently starts a 2 am on the first Sunday in November and ends at 2 am on the second Sunday in March

(PDT) - Pacific daylight savings time: currently starts at 2 am on the second Sunday in March and ends at 2 am on the first Sunday in November

Example Data Processing steps for an Absolute pressure transducer/Baro-transducer pair

STEP 1) Use the transducer software to export the pressure values for the water transducer and baro-transducer to Excel.
If necessary convert the baro-transducer results from inches of mercury (Hg) to an equivalent pressure as psia, as follows:

Pressure as psia = (pressure as in Hg) x 0.491154

Example barometric data file (minus header information)

Measurement Date	Measurement Time	Elapsed Time (minutes)	Baro-transducer pressure measurement (in Hg)	Baro-transducer pressure [A] (psia)	Barometric reference pressure [B] (in Hg)	Barometric reference pressure [A] (psia)
--------	--------	------------	---------------	---------------	---------------	---------------
8/1/2010	10:30:00	0	29.668	14.572	29.660	14.568
8/1/2010	11:30:00	60	29.672	14.574	-	-
8/1/2010	12:30:00	120	29.674	14.575	-	-
"	"	"	"	"	-	-
8/5/2010	9:30:00	5700	29.795	14.634	29.801	14.637
8/5/2010	10:30:00	5760	29.793	14.633	-	-
8/5/2010	11:30:00	5820	29.791	14.632	-	-
"	"	"	"	"	-	-
8/30/2010	10:30:00	12960	29.915	14.693	29.911	14.691

[A] pressure as psia = (pressure as in Hg) x 0.491154
[B] These values measured during field visits and recorded on field forms A-2 and A-5 (see examples in this appendix)

STEP 2) Validate the baro-transducer results against barometric reference measurements, as follows:

Baro transducer validation (as psia) = Baro-transducer pressure (BTp) - Barometric reference pressure (BRp)

Measurement Date	Measurement Time	Elapsed Time (minutes)	Baro-transducer pressure (BTp) (psia)	Barometric reference pressure (BRp) (psia)	Baro-transducer validation * (psia)
--------	--------	------------	---------------	---------------	---------------
8/1/2010	10:30:00	0	14.572	14.568	0.004
8/1/2010	11:30:00	60	14.574	-	
8/1/2010	12:30:00	120	14.575	-	
"	"	"	"	-	
8/5/2010	9:30:00	5700	14.634	14.637	-0.003
8/5/2010	10:30:00	5760	14.633	-	
8/5/2010	11:30:00	5820	14.632	-	
"	"	"	"	-	
8/30/2010	10:30:00	12960	14.693	14.691	0.002

* If resulting value <= project acceptance criteria for barometric confirmation measurements, then accept results
If the resulting value is > the project acceptance criteria, then use the procedure in Appendix C to evaluate the instrument for linear drift and correct the results for this influence if possible. Repeat this analysis on the drift-corrected values to confirm acceptable results.

STEP 3) Perform barometric corrections on the submersible transducer data using validated pressure values from the baro-transducer as follows [A]:

Baro-corrected transducer pressure (BCSTp) = Raw transducer pressure (STp) - Validated Baro-transducer pressure (VBTp)

Example transducer data file (minus header information)

Measurement Date	Measurement Time	Elapsed Time (minutes)	"Raw" Submersible transducer pressures (STp) (psia)	Validated Baro-transducer pressure (VBTp) (psia)	Baro-corrected submersible transducer pressures (BCSTp) (psia)
--------	--------	------------	---------------	---------------	---------------
8/1/2010	10:30:00	0	19.689	14.572	5.117
8/1/2010	11:30:00	60	19.691	14.574	5.118
8/1/2010	12:30:00	120	19.693	14.575	5.119
"	"	"	"	"	"
8/5/2010	9:30:00	5700	19.896	14.634	5.262
8/5/2010	10:30:00	5760	19.894	14.633	5.261
8/5/2010	11:30:00	5820	19.894	14.632	5.262
"	"	"	"	"	"
8/30/2010	10:30:00	12960	19.940	14.693	5.247

[A] This step is often done using the manufacturer supplied baro-correction software rather than Excel

STEP 4) Convert baro-corrected transducer pressure (as psia) to equivalent feet of water over the transducer sensor, as follows:

Transducer submergence depth (TSD) in ft = Baro-corrected submersible transducer pressure (BCSTp) in psia x 2.306 *

Measurement Date	Measurement Time	Elapsed Time (minutes)	Baro-corrected Submersible transducer pressure (BCSTp) (psia)	Transducer measured ft of water over sensor (transducer submergence depth) (TSD) * (ft)
--------	--------	------------	---------------	---------------
8/1/2010	10:30:00	0	5.117	11.800
8/1/2010	11:30:00	60	5.118	11.801
8/1/2010	12:30:00	120	5.119	11.803
"	"	"	"	"
8/5/2010	9:30:00	5700	5.262	12.135
8/5/2010	10:30:00	5760	5.261	12.132
8/5/2010	11:30:00	5820	5.262	12.134
"	"	"	"	"
8/30/2010	10:30:00	12960	5.247	12.100

* This conversion factor is for pure water at 10 deg C. See Appendix E for other temperature and TDS specific correction factors

STEP 5) Convert Ft of water over sensor to equivalent depth to water in Ft below the water level measuring point, as follows:

Transducer depth to groundwater below measuring point (TWLmp) in ft = (THD-TSD) - HPO *

Measurement Date	Measurement Time	Elapsed Time (minutes)	Transducer measured ft of water over sensor (transducer submergence depth) (TSD) (ft)	Transducer depth to GW below water level measuring point (TWLmp) * (ft)
--------	--------	------------	---------------	---------------
8/1/2010	10:30:00	0	11.800	28.700
8/1/2010	11:30:00	60	11.801	28.699
8/1/2010	12:30:00	120	11.803	28.697
"	"	"	"	"
8/5/2010	9:30:00	5700	12.135	28.365
8/5/2010	10:30:00	5760	12.132	28.368
8/5/2010	11:30:00	5820	12.134	28.366
"	"	"	"	"
8/30/2010	10:30:00	12960	12.100	28.400

* Where: THD is the transducer hanging depth measured during installation (see example Form A-2 this appendix)
TSD is the transducer submergence depth
HPO is the transducer hanging point offset from the water level measuring point (see example Form A-2 this appendix)

STEP 6) Validate the submersible transducer data using manual depth to groundwater confirmation measurements, as follows:

Submersible transducer validation (ft) = Transducer depth to GW below MP (TWLmp) in ft - Manual depth to GW below MP (MWLmp) in ft *

Measurement Date	Measurement Time	Elapsed Time (minutes)	Transducer depth to GW below WL measuring point (TWLmp) (ft)	Manual depth to GW below WL measuring point (MWLmp) (ft)	Submersible transducer validation * (ft)
--------	--------	------------	---------------	---------------	---------------
8/1/2010	10:30:00	0	28.700	28.70	0.000
8/1/2010	11:30:00	60	28.699	-	-
8/1/2010	12:30:00	120	28.697	-	-
"	"	"	"	-	-
8/5/2010	9:30:00	5700	28.365	28.50	-0.135
8/5/2010	10:30:00	5760	28.368	-	-
8/5/2010	11:30:00	5820	28.366	-	-
"	"	"	"	-	-
8/30/2010	10:30:00	12960	28.400	28.31	0.090

* If TWLmp - MWLmp <= project acceptance criteria for paired transducer and manual WL confirmation measurements then accept results
If TWLmp - MWLmp > project acceptance criteria, then evaluate transducer for linear drift per procedure in Appendix C and correct the data if warranted.
Repeat this analysis on the drift-corrected values to confirm (as acceptable) or to qualify overall result accuracy.

STEP 7) If desired, convert validated GW depths reported as feet below MP to ft below land surface datum, as follows:

Transducer depth to GW below land surface datum (TWLlsd) in ft = Validated transducer depth to GW below MP (VTWLmp) in ft - WL MP height in ft *

Measurement Date	Measurement Time	Elapsed Time (minutes)	Validated transducer depth to GW below WL measuring point (VTWLmp) (ft)	Transducer depth to GW below land surface datum (TWLlsd) * (ft)
--------	--------	------------	---------------	---------------
8/1/2010	10:30:00	0	28.700	26.60
8/1/2010	11:30:00	60	28.699	26.60
8/1/2010	12:30:00	120	28.697	26.60
"	"	"	"	"
8/5/2010	9:30:00	5700	28.365	26.27
8/5/2010	10:30:00	5760	28.368	26.27
8/5/2010	11:30:00	5820	28.366	26.27
"	"	"	"	"
8/30/2010	10:30:00	12960	28.400	26.30

* Where: MP height is the water level measuring point height (or "casing stickup") measured during well inventory (see example Form A-2 this appendix)

STEP 8) Prepare end of year (or project) data summary and QA assessment (see Figure 44 in Freeman, 2004 for an example).

STEP 9) Save the final processed data and export in CSV format. Upload final QA'd results to GW data management system.