September 15, 2021 NOTE: This replaces the SOP found on page 34 of the Water Resources Program Groundwater Monitoring Quality Assurance Project Plan, contained in the Water Resources Program, Integrated Statewide Groundwater Monitoring Strategy **(Culhane, 2017).**

9.0 Measuring Well Water Levels Using Submersible Pressure Transducers

9.1 Purpose

This procedure describes how to collect time-series, static water-level data in wells using submersible pressure transducers/data loggers.

9.2 General Description

Submersible pressure transducers are used to collect "time series" (a.k.a. "continuous") pressure (water and barometric) and temperature data. When installed at fixed well depths, pressure transducers measure and record pressures in the water column above the sensor. Those readings can be used to calculate static water level depths over time for the well.

Pressure transducers can be of the vented (a.k.a. gauged) or non-vented (a.k.a. absolute) variety. Vented transducers have sensors that connect to the outside atmosphere and usually do not require post-processing calculations to compensate measurements for the effects of atmospheric pressure changes. Non-vented pressure transducers are constructed as sealed units and collect total head pressures observed from submergence depths, so do not automatically compensate for barometric pressure. Total head is the summation of the hydraulic pressure above the transducer and atmospheric pressure above the water column. Barometric transducers deployed near non-vented pressure transducers collect synchronous barometric pressure data that can be used to compensate for the effects of atmospheric pressure on the water column. One advantage of vented transducers is a cable extends to the top of the well, thus simplifying data downloads. Disadvantages of vented transducers include that they are more expensive, they may require more maintenance, and excess cable must be stored at the well head. Currently, Water Resources uses only non-vented transducers, although staff could use vented transducers at some point in the future.

Pressure transducers are deployed by hanging them beneath the water surface in a well at a point where they will not go dry. For the Water Resources Program, these units are frequently set to record water temperatures and water levels at the top of the hour, every one to four hours. When they are first deployed, a manual static water level is measured in the well (typically with e-tape) to confirm instrument placement and provide a basis to convert pressure transducer measurements to values representing depths to water below a fixed point (either the well's measurement point or the land surface datum). The well is then visited several times per year to download data and collect corresponding manual static water level measurements. Once the data have been retrieved, these can be processed by comparing the computed water-level measurements to the manual water-level measurements. Transducers operate only within a limited depth range, so the unit installed in a well must have the correct range to accommodate anticipated water level changes.

9.3 Materials and Instruments

1. Water-level pressure transducer/data logger and a barometric transducer (if applicable). Communication cable for vented transducer (if applicable).
2. Line for suspending the transducer, such as braided (zero stretch), 50-pound test, fishing line. Alternately, stainless steel downrigger cable or Surflon nylon coated 1 X 7 stainless steel leader wire can be used, both of which require appropriately sized crimping sleeves.

3. A plastic reel, such as one for extension cords, to roll up the suspension line.
4. Device for anchoring the top of the suspension line, such as a flat square of plastic 1-inch larger than the casing upon which it will sit. An inexpensive, plastic cutting board can be used as stock material from which to fabricate the square.
5. A programming or data readout device (e.g. laptop computer loaded with correct software), and hardware such as a cable to connect this with the transducer.
6. A clean towel or rag to dry the end of the transducer before reconnecting it to the communication cable.
7. Calibrated water-level indicator graduated in hundredths of feet (e.g. e-tape).
8. Calibrated tape to attach to the transducer if a field calibration test is made.
9. Copies of well construction report and water level history for the well that is being instrumented (if available).
10. Key(s) for wells or site access gates as appropriate.
11. Form A-2 – Transducer Installation Form, and Form A-5 - Transducer Download and Site Visit Record Form.
12. Pen or pencil.
13. Replacement batteries (if replaceable in the unit).
14. Tool box.
15. Digital camera.
16. GPS instrument.

9.4 Data Accuracy and Limitations

1. Water level measurements, including in-place measurements for calibration of pressure transducers, should be measured to 0.01 ft., where possible.
2. Measurement accuracy depends on the accuracy of the transducer and that of the manual water-level measurement device. For example, typical static measurements for 30 psi AquiStar pressure transducers are ± 0.04 feet, while the accuracy of an e-tape for a 250 to 500 foot measurement might also be ± 0.04 feet, total error, which leads to a potential compounding error ± 0.08 feet for a single measurement.
3. Pressure transducers are subject to drift, offset and slippage of the suspension system. For this reason, the transducer readings should be checked against water levels measured with an e-tape on every visit.

9.5 Assumptions

1. An established measuring point (MP) exists or will be established as part of measurement. See Section 4.0 - Establishing a Measuring Point.
2. The user is familiar with the transducer specifications and limitations.
3. The transducer's range is appropriate for the range of water levels expected in the well.
4. The transducer has been calibrated, either by the manufacturer or by the user, for the conditions expected in the field installation.
5. All field notes are neat, legible, and leave no doubt about interpretation.

9.6 Instructions

9.6.1 When establishing new installations:

1. Due to the possibility of losing equipment down wells, installing transducers in water supply wells or other wells containing pumps is not recommended without separate transducer sleeves. If equipment is installed in a drinking-water supply well, it should

be disinfected as described in Section 6.0 - Equipment Cleaning and Disinfection.

2. Check circuitry of the e-tape before
3. Select a transducer in the proper pressure range for the well that is being instrumented – preferably based on static water-level measurements collected over several years.
4. Prior to heading to the field with the device used to program the transducer (typically a laptop), be sure that its internal clock is synchronized with the official U.S. time.
5. Before heading to the field, select a device to anchor the suspension line to the top of the well. Since it is important to hang the transducer from the same location each time, one option for PVC casings is to loop the line through two holes drilled in a small, plastic plate at least 1-inch larger than the casing. It is often desirable to have several devices, including zip ties, rings, the above plastic plate, etc. on hand to adapt to conditions found at the site.
6. Fabricate a cable to suspend the transducer, preferably with a length based on water-level measurements collected over one or more years. The cable should suspend the transducer deep enough that it will remain submerged as water levels fluctuate, yet not so deep that the transducer depth range is exceeded (see Figure 6). If the transducer is of the vented variety, the unit should be hung on a suspension line and not the communication cable.

   Materials for suspension line construction can include: braided (zero stretch), 50-pound test, fishing line; stainless steel downrigger cable; or Surflon nylon coated 1 X 7 stainless steel leader wire (or similar product). The latter two require crimping an appropriately sized sleeve, and should always include two sleeves at each end for redundancy. If 30-pound test Surflon nylon coated 1 X 7 stainless steel leader wire is used, it may help to tie a knot in the wire before crimping it with two sleeves.

   In order to fabricate the suspension line, it can be laid out and stretched tight beside a measuring tape that can be used to determine the proper length. One closed loop should be made through the eyelet on the transducer, and another on the anchor at the top of the casing. A plastic reel can be useful to roll up the suspension line. If desired, the suspension line and transducer can be connected with a stainless steel key ring (or equivalent) in between, to allow changes with different types of instruments in the future.
7. Connect the transducer to the laptop or other programming device, and follow directions in the instrument user manual to program the transducer to log at the desired frequency (e.g. 4 times per day), with readings typically taken at the top of the hour. To facilitate compensation calculations, collecting all data in units of "feet of H20" is recommended.
8. Check that sufficient memory exists and the battery has sufficient charge to collect data until the next anticipated field visit.
9. Slowly lower the transducer without allowing it to free fall. If it is difficult to tell whether the transducer has reached the full desired depth (it should bounce slightly when gently pulling up on the cable), stainless steel weights can be added to hang below the transducer. Extra weight can also be helpful in overcoming adhesion of the cable to the casing through surface tension, which can particularly be a factor if the well is not plumb.
10. An optional step is to conduct a field calibration by lowering the transducer over a range of water-level fluctuations and comparing measurements. This is most easily accomplished by attaching the transducer to the end of a calibrated tape, then lowering the unit at four or more regular interval depths (e.g. every 5 feet). If a field calibration is conducted, transducers should be set to record frequent measurements such as once per

minute. If the transducer is vented, a field calibration will be easier, since measurements can be viewed real time through the communication cable. However, a field calibration can also be achieved with non-vented transducers by subsequently removing the transducer and connecting to a programming device to review measurements (while drying the end of the transducer before connecting to the cable).

11. Fasten the cable or suspension system to the well head using a secure, consistently repeatable method (see Step 5). Depending on the type of anchor used, it may be appropriate to make a permanent mark on the cable at the hanging point using a marking pen or piece of black electrical tape, so future slippage, if any, can be determined.
12. Depending on whether the Manual Measurement method (MM method) or the Hanging Cable Length method (HCL method) will be used to process the data (see Section 9.6.3), instrument installation documentation will vary. If the HCL method is used, information should be recorded on Form A-2 - Transducer Installation Form (below). In that instance, the hanging point offset distance from the water level MP should be recorded, and it should be noted whether the hanging point is higher (+) or lower (-) than the water level MP with regard to the land surface datum. It also may be helpful to make a sketch on the back of Form A-2.

    If the MM method is used, installation information can be recorded in a field notebook, and this should include the measured hanging cable length, transducer model type, transducer serial number, battery percent remaining, memory percent remaining, launch time, and logging interval.
13. Measure the static water-level depth using a device such as an e-tape. Repeat if measurements are not consistent within 0.02 ft.
14. If a barometric transducer is deployed, installation can be done by hanging it within the well casing above the well water level, or placing it within a well monument, well house, etc. Deployed barometric transducers should be programmed to record measurements at the same time and frequency as associated water-level transducers. In instances where multiple wells are near one another, one barometric transducer can be used to collect data for more than one well. However, large differences in ground surface elevations or water depths can affect the atmospheric pressure exerted on water surfaces in wells, so limiting the number of barometric transducers may complicate post processing of data.

Note: *If field observations indicate that readings from a particular transducer have not been consistent with field static water-level measurements, then optional "wet" calibration tests may be run on transducers using a technique similar to that described in Appendix B in Standard Operating Procedure for the use of Submersible Pressure Transducers during Groundwater Studies, Version 1.1 (Sinclair and Pitz, 2015). And in situations where studies warrant that there be no significant outliers with regard to transducer accuracy (say when multiple transducers are deployed within close proximity to one another), it may be useful to perform a simpler calibration test by placing multiple transducers in a bucket of water. Then, after collecting readings for several days, results can be compared to see if there are any outliers. However, it is important to recognize that this test cannot indicate whether particular instruments are accurate over the range of pressure values that will be encountered in the field. If a transducer fails a "wet" calibration tests or otherwise is deemed to be inaccurate, it should be returned to the manufacturer for new calibration or discarded.*

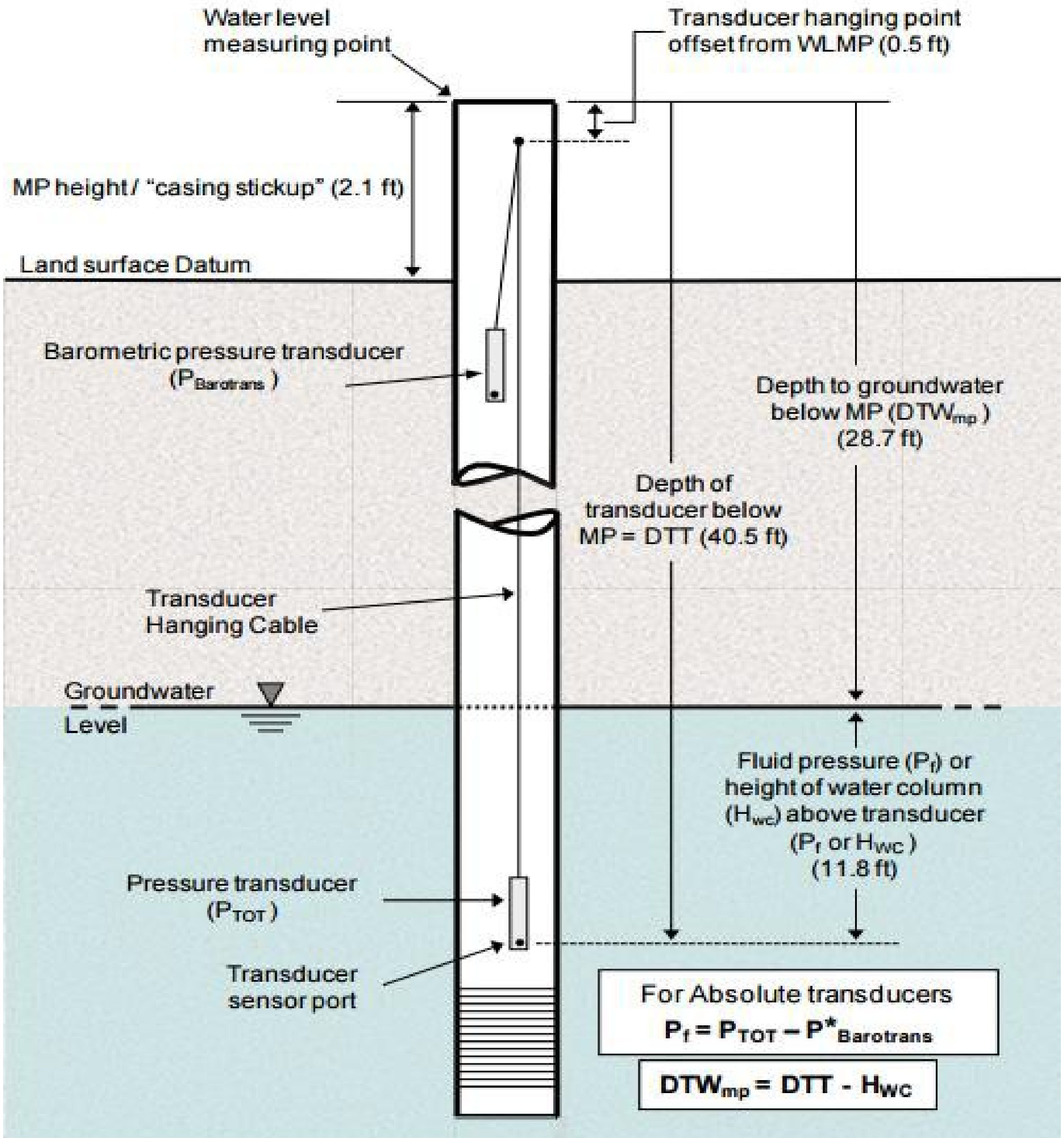


Figure 6. Example terms, measurements and calculations for pressure transducer placement.

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

Site Location Information

Project:______________ Site name:____________________ Date (mm/dd/yyyy):____________

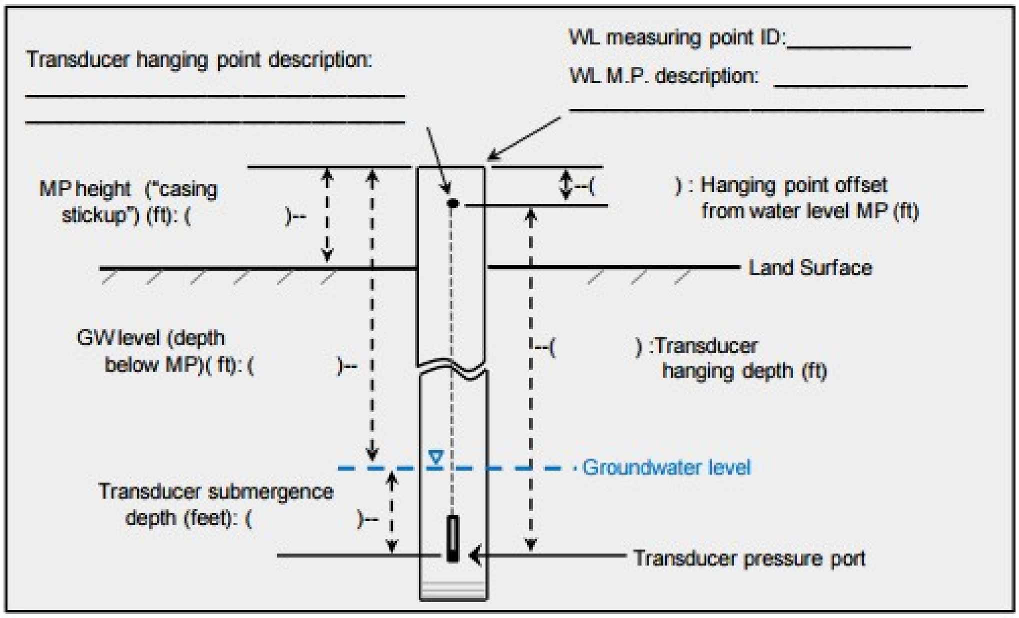
Well Tag No:___________ Project well ID:_____________ Field crew:________________

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)

Instrument Placement Check Measurements

Other Observations

9.6.2 When visiting an existing installation:

Pressure transducers must be serviced periodically during use, to check and replace instrument batteries, download data, and assess potential changes in local site conditions or instrument integrity over time. Manual static water level measurements made during these visits are compared to readings stored on the transducer to determine whether corrections are needed or there has been equipment failure. Visiting a site 3 or 4 times per year is recommended, unless the possibility of losing data and/or increased chance of error are deemed acceptable. Information collected during field visits can be recorded either in a field notebook or Form A-6 - Transducer Download and Site Visit Record Form (below).

If equipment is installed in a drinking-water supply well, it should be disinfected as described in Section 6.0 - Equipment Cleaning and Disinfection.

1. Record the well number and location, MP, and any changes at or near the site that may affect the measurements (e.g. adjacent land use changes, recent flooding, nearby well construction activity, etc.).
2. Measure the water level with a device such as an e-tape, using the same MP as when the transducer was installed. Make at least two measurements to confirm static conditions. Record the measurement time and the water level in feet below the MP, noting whether the well was pumping during the measurement, was pumped recently, or a nearby well was pumping during the measurement.
3. If a non-vented transducer is being used, pull up the cable to raise the transducer during a period when the unit is not actively making a measurement. An extension cord storage reel or equivalent can be used to help keep the cable clean and kink free as it is reeled up. Note any possible indications that the cable has slipped. Before connecting the transducer to the computer with a communication cable, dry the end of the transducer with a clean towel or rag.
4. Connect the transducer to the field computer and use the instrument software to download the transducer per manufacturer instructions. Record the download time and file name. View the data graph to confirm a successful download has occurred and to identify obvious problems such as missing or unusual values that might suggest a compromised instrument or installation. Check and record the battery and memory status.
5. While in the field compare the manual measurement to the measurement predicted following either the MM or HCL method conversion steps, whichever is applicable (see Section 9.6.3 below). If readings differ significantly, consider replacing the transducer.
6. If data collection is continuing and the transducer memory may fill up prior to the next field visit, reprogram the logger to start at the next scheduled time interval and free up adequate memory storage. Similarly, if data collection is continuing and there may not be sufficient battery to last until the next field visit, replace the batteries for user serviceable units or replace the transducer for other units.
7. If a new transducer is deployed:
    a. Launch the unit using the same measurement frequency and time period as the previous deployment using a time-delayed launch command.
    b. Launch the unit using the same time datum as the initial launch or make thorough notes that the time datum changed between deployments.
    c. Confirm instrument placement depth if a different instrument type is used to replace the unit (not all instruments are the same length).

    d. Record information on these changes on the field form.
8. Record all other necessary information either in the field notebook or on the transducer download form.
9. If a barometric transducer was deployed, retrieve and download the logged data. View the data graph to confirm a successful download and identify problems such as missing values, unusual data spikes, or other issues that might suggest a compromised unit. Follow similar steps to those for the water-level transducer to ensure the memory and battery are sufficient.
10. Secure the well.

TRANSDUCER DOWNLOAD AND SITE VISIT RECORD **Form A-6**

Project:______________________________Project Well No.____________________Well Tag ID: __________

TRANSDUCER DOWNLOAD AND SITE VISIT RECORD			Form A-6
Project:Project Well No: ________ Well Tag ID: _____ _			
Background Information			
Date of site visit (mm/dd/yyyy):			
Field personnel initials:			
Manual GW Level Measurement			
Measuring point ID number:			
Measuring point description:			
Water level watch time (hh.mm):	PST PDT	PST PDT	PST PDT
WL measurement method:	(Steel Tape or E-tape)	(Steel Tape or E-tape)	(Steel Tape or E-tape)
WL accuracy(+/-ft):	(0.01) (0.1) (0.5) (1.0J (>1)	(0.01) (0.1) (0.5) (1.0J (>1)	(0.01) (0.1) (0.5) (1.0J (>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):			
Remaining memory:			
Re-deployment time (hh:mm):			
Pressure value (ft of $H_2 0$):			
Barometric Transducer Information			
Model:			
Serial Number:			
Download time (hh:mm):	PST PDT	PST PDT	PST PDT
Download file name:			
Battery voltage (percent):			
Remaining memory:			
Re-deployment time (hh:mm):			
Pressure value (ft of $H_2 0$):			
Additional Observations of Comments			

9.6.3 Follow-up office work

Pressure transducer data must be processed and verified to produce water-level data and prepare it before it is uploaded to Ecology's Environmental Information Management System (EIM). Water Resources personnel typically use one of two methods to do this conversion. For the purposes of this SOP, these methods will be referred to as the Manual Measurement method (MM method) and the Hanging Cable Length method (HCL method). The HCL method is similar to that described in the previous submersible pressure transducer SOP found in Culhane (2017).

For non-vented transducers, one key decision point during data processing relates to whether or not water pressure data will be barometrically compensated. If the data are so compensated, either the MM method or the HCL method can be used. However, if the data are not barometrically compensated, the MM method should be followed since it does not require barometric data to complete the steps.

A range of options exists for processing pressure transducer data, and more than one method may be appropriate depending on the nature of the site and the data being collected. And professional judgement must be used when processing the data, since a method that may be appropriate at one site may not be appropriate at another. It is important to keep sight of data quality objectives for the data collection effort. Minor deviations from the "true" water level depth are to be expected in all field-collected data. Manual water-level measurements made with e-tapes include inherent errors (i.e. kinks in the e-tape), and transducers have a factory calibrated accuracy which introduces error before they are even deployed. The goal is to minimize introduced errors to achieve acceptable accuracy.

9.6.3.1 Decision Whether to Barometrically Compensate Non-Vented Pressure Transducer Data

Non-vented transducers record total water pressure located above a transducer pressure port, which includes atmospheric pressure imposed at the water surface. The barometric pressure recorded near a well changes as weather fronts move through a landscape. Often it is advantageous to compensate data for changing barometric effects on the recorded non-vented pressure transducer data.

Generally, as barometric pressure increases, the added weight of the atmosphere will depress the water-level elevation in an aquifer. Conversely, as barometric pressure decreases, the water level in an aquifer will rise. This inverse relationship is most obvious in data associated with aquifers that have a barometric efficiency (BE) of 100%. Barometric efficiency is the water-level change caused by a barometric-pressure change divided by that barometric pressure change (Clark, 1967). Correcting head data for an aquifer with a BE of 100% or nearly 100% can remove much of the "barometric noise" evident in a dataset (Figure 7).

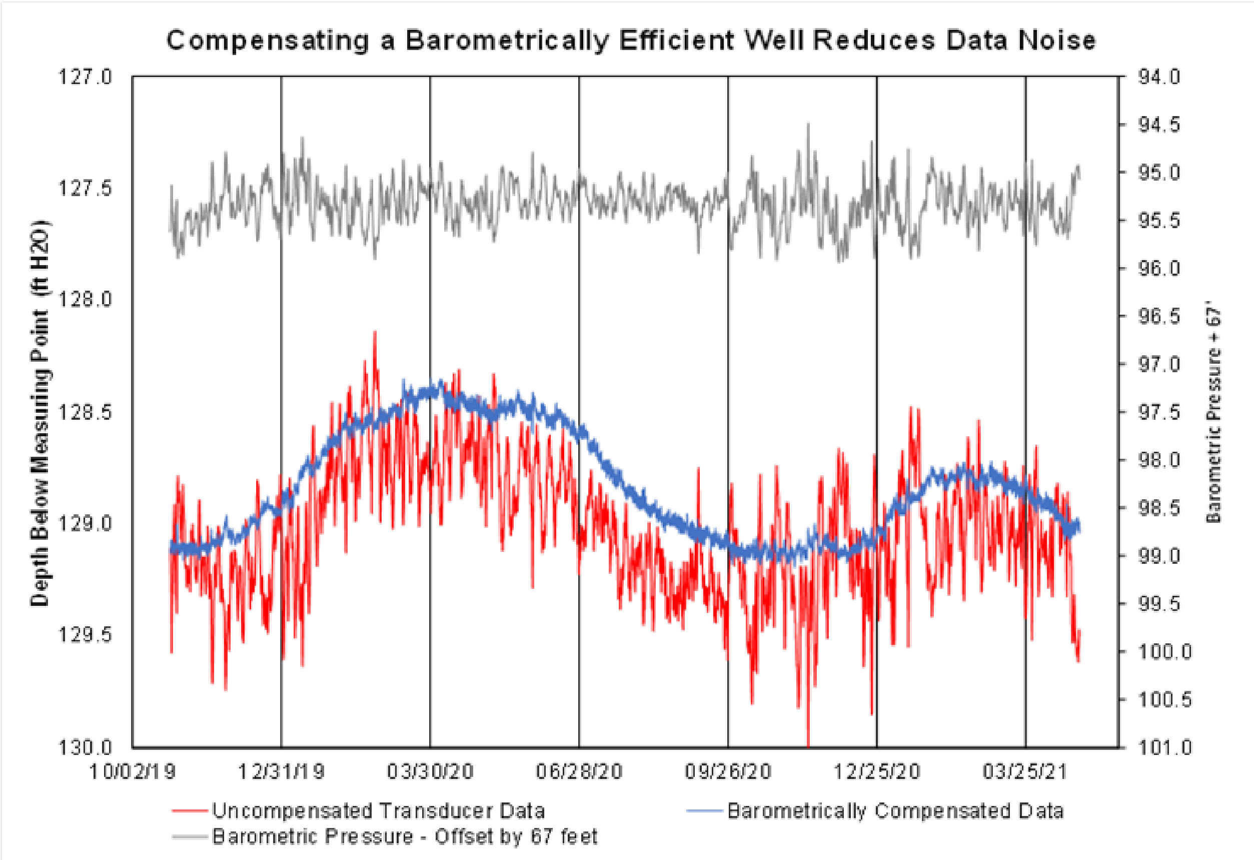


Figure 7. Graph demonstrating how barometrically compensating head data (blue) for a 100% BE aquifer can remove "barometric noise" from original raw data (red).

Either the MM method or the HCL method can be used compensate non-vented submersible transducer data for the effects of barometric pressure. Similarly, most transducer manufacturers supply software that can barometrically compensate non-vented transducer data relying upon barometric data recorded on dedicated barometric transducers. In essence all these methods assume that a subject well is very barometrically efficient. The barometric pressure is subtracted from the raw (uncompensated) transducer reading, which results in a value for the feet of water above a transducer pressure port for each reading. However, for barometrically inefficient aquifers (BE much less than 100%), barometric effects and decisions regarding barometric corrections are more complicated.

If the BE of an aquifer is much less than 100%, and the standard barometric compensation is applied, those "corrections" can introduce "barometric noise" to the data, which will be evident on subsequent graphs of the data (Figure 8). This is because subtracting the atmosphere's contribution to total pressure in a barometrically inefficient well over-corrects the data, by subtracting more pressure than the aquifer has actually experienced.

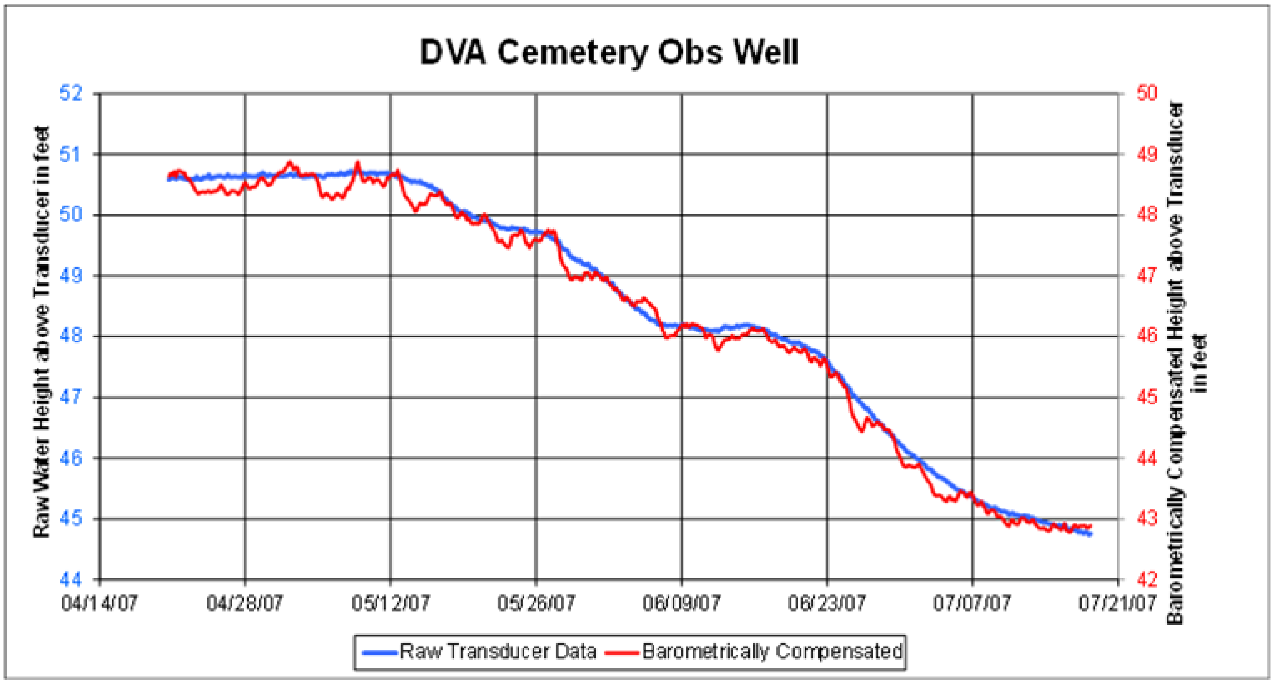


Figure 8. Graph demonstrating how, for a barometrically inefficient well, relatively smooth raw transducer data (blue) can be made "noisier" (red) by barometrically compensating data.

The process for determining the BE of a particular aquifer is complicated and subjective, and the experience of Water Resources staff is that a wide range of results are possible. Because of this Water Resources believes in most instances it is not practical to estimate and factor in the BE of an aquifer at a well. However, it is worthwhile to try performing a standard barometric compensation by subtracting the barometric readings from the raw data. Once that analysis is complete, professional judgement can be used to decide whether the results are better or worse than the uncompensated, raw data. That determination should be based, in part, on the amount of "barometric noise" evident in the resultant graph (see Figures 7 and 8).

Water Resources staff have observed that barometric compensation has been an appropriate tool to use at many Washington locations. The primary exceptions anticipated are wells completed in deep, confined aquifers, such as those completed in the Columbia River Basalts of eastern Washington. Experience has shown that for those wells, compensating continuous total water pressure transducer data for barometric changes tends to introduce unnecessary noise and make the results less accurate. In instances where barometric corrections make results less accurate, data entered into EIM should not be barometrically compensated.

9.6.3.2 Compensating Data for Other Factors

During vented transducer site visits subsequent to initial installation, manual depth to water-level measurements are made, and transducer data are downloaded onto field laptops via a vent tube/ communication cables. During subsequent non-vented transducer site visits, transducers are removed from wells, manual depth to water-level measurements are made, transducer data are downloaded onto field laptops, and transducers are redeployed into wells. These manual measurements are used to determine whether adjustments to the method formulas are warranted. If manual depth to water measurements adequately match calculated depth-to-water measurements derived from transducer data (for the site visit date and time), no adjustments are needed. If significant differences are detected, the formula can be adjusted to realign the continuous data with manual measurements.

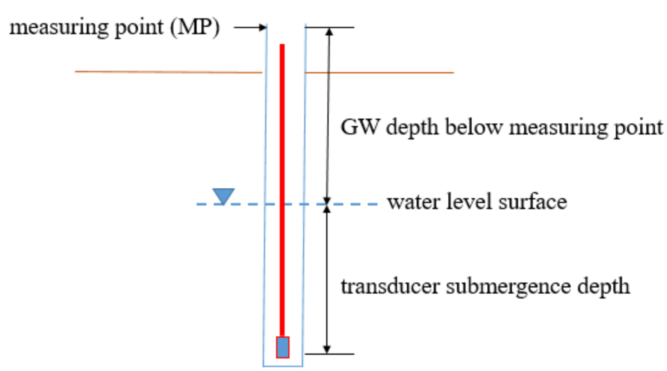
Both the MM and HCL methods require staff to decide whether to shift the data to account for various factors. Differences between manual water-level measurements during site visits and calculated depth to water below measuring point values can result from many causes. When dealing with observed discrepancies and suspected causes, potential options include applying an instantaneous shift to the data (e.g. if a change in cable length is suspected), applying a gradual change based on an assumed linear relationship (e.g. if instrument drift is suspected), or applying no correction at all.

Care must be taken when deciding whether and how to make either instantaneous shift of drift corrections. For example, it is not appropriate to use gradual drift corrections to compensate for differences in effective hanging cable length since that change will have occurred instantaneously. It is also important to recognize that manual measurements may not always be correct (e.g. numbers can be transposed while being recorded, and downhole flow can create inaccurate measurements). If a subset of manual measurements is suspected of not reflecting actual depths to water, they can be excluded from conversion calculations and noted in accompanying metadata. Such values should be preserved and plotted in graphs, where their departure from continuous curves will be evident.

Overall it should also be kept in mind, that whenever a data set is altered there is no guarantee that it more closely reflects actual conditions experienced in the aquifer. Therefore, changes to data sets should always be made judiciously, and generally should not occur for small differences.

<u>9.6.3.3 MM Method</u>

The MM method relies on the sum of a transducer's submergence depth and a manual groundwater (GW) depth-below-measuring-point (MP) value – both taken concurrently.



That sum is used to create a value from which subsequent transducer measurements are subtracted to produce calculated Depth to GW Below MP values for the continuous data.

[GW depth below measuring point + transcducer submergence depth] - individual transducer measurements = depth to GW below measuring point

This method can be used to process either barometrically compensated or uncompensated data. For uncompensated data, the submergence depth uses raw transducer readings, since barometric pressure is not subtracted. This is the same depth to water conversion method employed by the transducer manufacturer software supplied with the transducers that the Program uses.

The steps to process non-vented pressure transducer data using the MM method are as follows:

1. In the office create a folder on one of Ecology's backed up network drives to store documentation for the well. If the well is contained in a regional well circuit, this new folder should be a sub-folder within the well circuit folder.
2. Begin data processing by first saving a digital copy of the unprocessed transducer file(s) and supporting documentation including: the original field forms and notes, transducer installation forms, manual water level records, and other transducer download notes. Archive the records in the proper project subdirectory stored on an agency shared drive. Do not alter the original transducer file and instead make a copy, then process the data using the copied file.
3. In a Microsoft Excel® (Excel) spreadsheet create columns for the date, time, serial date/ time, raw transducer pressure, and manual Depth to GW below MP values (see Figure 9).
4. Depending on the circumstances, perform one of the following:
    - I. If the data come from a vented transducer, add a field to the spreadsheet with the compensated data.
    - II. If the data come from a non-vented transducer, barometrically compensate the data either using software provided by transducer manufacturer or manually within the Excel spreadsheet.
        - i. If manufacturer software is used for this purpose, add a field to the spreadsheet with the software compensated data.
        - ii. If the data are to be barometrically compensated within Excel, add a field with the barometric data to the spreadsheet, subtract the barometric pressure from the transducer's submergence depth, and place the result in column labeled "Baro-compensated submersible transducer pressure"

    See Figure 9a for example of data processing using the MM method with barometrically compensated data, and Figure 9b for processing using the MM method with raw data.
5. If the data have been collected using a non-vented transducer, graph the raw water height above the transducer data on the Y axis (left side), the compensated water height above the transducer data on the secondary Y axis (right side), and time on the X axis. Adjust the secondary Y axis scale to be on a comparable range with the primary Y axis scale. Determine whether barometric compensation has improved the data set or primarily added "noise", based on the considerations presented in Section 9.6.3.1. Select either the compensated data or the uncompensated data, whichever appears to have less "barometric noise", for use in Step 6.

6. Within Excel, for each value where a manual GW measurement has been taken, add the transducer's submergence depth (compensated, if applicable) for that time to the Manual depth to GW below MP value for that time and place the result in the MM formula value column. Copy and paste that value (not the formula) through the subsequent rows until the next instance where a manual GW measurement was taken is reached.
7. Subtract the individual transducer measurement values from the values generated by the previous step and place result in the Calculated depth to GW below MP column.
8. Graph the calculated depth to GW below MP values versus time, and inspect the result for shifts in the record. If significant shifts are noted, consider potential causes, including changes in cable length due to a logger abruptly hanging up or slipping down - paying particular attention to times when manual measurements have been collected.
9. Add manual e-tape measurements data to the graph created in Step 8, to evaluate the match between the manual measurements and the Calculated depth to GW below MP values. Decide whether any manual measurements are suspect, bearing in mind the ± 0.05 foot accuracy of an e-tape.
10. Based on the steps 8 and 9, and considerations described in Section 9.6.3.2, decide whether to compensate the data:
    a. If an apparent data shift is coincident with a site visit, consider whether this may be due to a re-deployment issue, and whether an instantaneous data shift may be appropriate.
    b. If a subset of manual measurements are suspected of not reflecting true depths to water, consider excluding those values from the conversion calculations and noting these exclusions in the accompanying metadata. In some cases, an iterative process may be necessary to determine whether or not to exclude certain values.
    c. If transducer instrument drift is suspected of being the cause of a difference between a manual measurement and the Calculated depth to GW below MP values, consider applying a gradual linear drift correction following the procedure described in Appendix C in Standard Operating Procedure for the use of Submersible Pressure Transducers during Groundwater Studies, Version 1.1 (Sinclair and Pitz, 2015). Apply linear corrections only if transducer instrument drift is the suspected cause.

    Recall that small separations between continuous data and the manual measurements may be acceptable given the data quality objectives of continuous data collection efforts.
11. Compensate the data based on the analyses described in the previous steps.
12. Document the data reduction steps employed to produce the final results for each transducer, potentially within the Excel file. Using a few sentences describe each data download/data processing event, including: 1) equipment problems or other issues that influenced the results, 2) water level/barometric measurements corrections applied 3), datum or drift corrections, if any, and 4) remarks or other observations that influenced the quality of the final results.
13. When the data are entered into EIM, the overall data quality will need to be assessed, and appropriate water-level method, accuracy code, and data qualifier(s) (if any) will need to be assigned. Additionally, a brief description should be entered into the associated EIM comment field.

Date	Time	Serial date/time	"Raw" submersible transducer pressure (ft)	Baro-transducer pressure (ft)	Baro-compesnated submersible transducer pressure (ft)	Manual depth to GW below MP (ft)	MM formula value (ft)	Calculated depth to GW below MP (ft)
3/1/2010	10:00	40238.41667	48.72	33.50	15.22	19.73	34.95	19.73
3/1/2010	11:00	40238.45833	48.77	33.51	15.26		34.95	19.69
3/1/2010	12:00	40238.50000	48.80	33.52	15.28		34.95	19.67
"	"		"	"	"		34.95	"
6/5/2010	9:00	40334.37500	44.18	33.75	10.43	24.48	34.91	24.48
6/5/2010	10:00	40334.41667	44.19	33.77	10.42		34.91	24.49
6/5/2010	11:00	40334.45833	44.21	33.76	10.45		34.91	24.46
"	"		"	"	"		34.91	"
9/30/2010	10:00	40451.41667	42.30	34.33	7.97	27.06	35.03	27.06

Figure 9a. Example data processing steps using MM method with barometrically compensated data

Date	Time	Serial date/time	"Raw" submersible transducer pressure (ft)	Manual depth to GW below MP (ft)	MM formula value (ft)	Calculated depth to GW below MP (ft)
3/1/2010	10:00	40238.41667	48.72	19.73	68.45	19.73
3/1/2010	11:00	40238.45833	48.77		68.45	19.68
3/1/2010	12:00	40238.50000	48.80		68.45	19.65
"	"		"		68.45	"
6/5/2010	9:00	40334.37500	44.18	24.48	68.66	24.48
6/5/2010	10:00	40334.41667	44.19		68.66	24.47
6/5/2010	11:00	40334.45833	44.21		68.66	24.45
"	"		"		68.66	"
9/30/2010	10:00	40451.41667	42.30	27.06	69.36	27.06

Figure 9b. Example data processing steps using MM method with raw data (same raw data as Figure 9a)

9.6.3.4 HCL Method

As described in the older SOP, the HCL method requires incorporating both the hanging cable length and barometric pressure data during the water-level conversion and compensation steps. Those steps are described here and illustrated in Figure 10 below.

1. In the office create a folder on one of Ecology's backed up network drives to store documentation for the well. If the well is contained in a regional well circuit, this new folder should be a sub-folder within the well circuit folder.
2. Begin data processing by first saving a digital copy of the unprocessed transducer file(s) and supporting documentation including: the original field forms and notes, transducer installation forms, manual water level records, and other transducer download notes. Archive the records in the proper project subdirectory stored on an agency shared drive. Do not alter the original transducer file and instead make a copy, then process the data using the copied file.
3. In Excel create columns for the date, time, serial date/time, raw transducer pressure, and manual Depth to GW below MP values (see Figure 10).
4. Depending on the circumstances, perform one of the following:

I. If the data come from a vented transducer, add a field to the spreadsheet for the compensated data.

II. If the data come from a non-vented transducer, barometrically compensate the data either using software provided by the transducer manufacturer or manually within the Excel spreadsheet.

  i. If manufacturer software is used for this purpose, add a field to the spreadsheet with the software compensated data.

  ii. If the data are to be barometrically compensated within Excel, add a field with the barometric data to the spreadsheet, subtract the barometric pressure from the transducer's submergence depth, and place the result in a column labeled "Baro-compensated submersible transducer pressure" (see Figure 10).

5. If the data have been collected using a non-vented transducer, graph the raw water height above the transducer data on the Y axis (left side), the compensated water height above the transducer data on the secondary Y axis (right side), and time on the X axis. Adjust the secondary Y axis scale to be on a comparable range with the primary Y axis scale. Determine whether barometric compensation has improved the data set or primarily added "barometric noise", based on the considerations presented in Section 9.6.3.1. If the compensated data appears to have less "barometric noise", use those data in Step 6. If there is less "barometric noise" in the uncompensated data, switch to the MM method and use those data starting at Step 6 in that process.
6. Calculate the depth to GW below MP following Step 2 in Figure 10. If the suspension line hanging point is different than the water level MP, an additional offset must be added or subtracted. Similarly, if measurements in feet below land surface datum are desired, the water level MP height should be subtracted from the depth to groundwater below the water level MP.
7. Graph the calculated depth to GW below MP values versus time, and inspect the result for shifts in the record. If significant shifts are noted, consider potential causes, including changes in cable length due to a logger abruptly hanging up or slipping down - paying particular attention to times when manual measurements have been collected.
8. Add manual e-tape measurements data to the graph created in Step 7, to evaluate the match between the manual measurements and the Calculated depth to GW below MP values. Decide whether any manual measurements are suspect, bearing in mind the ± 0.02 foot accuracy of an e-tape for depths of less than 250 feet.
9. Based on steps 7 and 8, and the considerations described in Section 9.6.3.2, decide whether to compensate the data:
   a) If an apparent data shift is coincident with a site visit, consider whether this may be due to a re-deployment issue, and whether an instantaneous data shift may be appropriate.
   b) If a subset of manual measurements are suspected of not reflecting true depths to water, consider excluding those values from the conversion calculations and noting these exclusions in the accompanying metadata. In some cases, an iterative process may be necessary to determine whether or not to exclude certain values.
   c) If transducer instrument drift is suspected of being the cause of a difference between a manual measurement and the Calculated depth to GW below MP values, consider applying a gradual linear drift correction following the procedure described in Appendix C in Standard Operating Procedure for the use of Submersible Pressure Transducers during Groundwater Studies, Version 1.1 (Sinclair and Pitz, 2015). Apply linear corrections only if transducer instrument drift is the suspected cause.

Recall that small separations between continuous data and the manual measurements may be acceptable given the data quality objectives of continuous data collection efforts.

10. Compensate the data based on the analyses described in the previous steps.
11. Document the data reduction steps employed to produce the final results for each transducer, potentially within the Excel file. Using a few sentences describe each data download/data processing event, including: 1) equipment problems or other issues that influenced the results, 2) water level/barometric measurements corrections applied 3), datum or drift corrections, if any, and 4) remarks or other observations that influenced the quality of the final results.
12. When the data are entered into EIM, the overall data quality will need to be assessed, and appropriate water-level method, accuracy code, and data qualifier(s) (if any) will need to be assigned. Additionally, a brief description should be entered into the associated EIM comment field.

Note: *Even if a cable length is carefully measured before placing it in a well, deployment conditions often result in an actual cable length different than the measured length. Moreover, actual hanging cable lengths can change over time as transducers are removed and re-deployed during site visits (e.g. if a transducer does not go back into the exact same spot). Due to these issues, assuming that a measured cable length is always correct or that a hanging cable length does not change once deployed can introduce errors when using the HCL method.*

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Figure 10. Example data processing steps using the HCL method

STEP 1) Correcting "raw" submersible transducer data for the effects of barometric pressure

Typically, this step can be done using the manufacturer supplied baro-compensation software rather than Excel.

Baro-compensated submersible transducer pressure = Raw transducer pressure - Baro-transducer pressure

Date	Time	Serial date/time	"Raw" submersible transducer pressure (ft)	Baro-transducer pressure (ft)	Baro-compesnated submersible transducer pressure (ft)
3/1/2010	10:00	40238.41667	48.72	33.50	15.22
3/1/2010	11:00	40238.45833	48.77	33.51	15.26
3/1/2010	12:00	40238.50000	48.80	33.52	15.28
"	"		"	"	"
6/5/2010	9:00	40334.37500	44.18	33.75	10.43
6/5/2010	10:00	40334.41667	44.19	33.77	10.42
6/5/2010	11:00	40334.45833	44.21	33.76	10.45
"	"		"	"	"
9/30/2010	10:00	40451.41667	42.30	34.33	7.97

STEP 2) Calculating depth to groundwater (GW) in feet below the water level measuring point (MP)

If the hanging point for the transducer suspension line is different than the water level measuring point, then an additional offset will need to be added or subtracted. Similarly, if measurements in feet below land surface datum are desired, the water level measuring point height should be subtracted from the depth to groundwater below the water level measuring point.

Calculated depth to GW below MP = transducer hanging depth - Baro-compensated submersible transducer pressure

Date	Time	Serial date/time	"Raw" submersible transducer pressure (ft)	Baro-transducer pressure (ft)	Baro-compesnated submersible transducer pressure (ft)	Transducer hanging depth (ft)	Calculated depth to GW below MP (ft)
3/1/2010	10:00	40238.41667	48.72	33.50	15.22	35	19.78
3/1/2010	11:00	40238.45833	48.77	33.51	15.26	35	19.74
3/1/2010	12:00	40238.50000	48.80	33.52	15.28	35	19.72
"	"		"	"	"	"	"
6/5/2010	9:00	40334.37500	44.18	33.75	10.43	35	24.57
6/5/2010	10:00	40334.41667	44.19	33.77	10.42	35	24.58
6/5/2010	11:00	40334.45833	44.21	33.76	10.45	35	24.55
"	"		"	"	"	"	"
9/30/2010	10:00	40451.41667	42.30	34.33	7.97	35	27.03

STEP 3) Validating submersible transducer data using manual depth to groundwater measurements

If submersible transducer validation results are less than or equal to project acceptance criteria the results are acceptable. If validation results are greater than project acceptance criteria, then the equivalent depth to groundwater data can be evaluated for linear drift per the procedure in Appendix C of Sinclair and Pitz (2015) and corrected if necessary.

Submersible transducer validation (ft) = Calculated depth to GW below MP - Manual depth to GW below MP

Date	Time	Serial date/time	"Raw" submersible transducer pressure (ft)	Baro-transducer pressure (ft)	Baro-compesnated submersible transducer pressure (ft)	Transducer hanging depth (ft)	Calculated depth to GW below MP (ft)	Manual depth to GW below MP (ft)	Submersible transducer validation (ft)
3/1/2010	10:00	40238.41667	48.72	33.50	15.22	35	19.78	19.73	0.05
3/1/2010	11:00	40238.45833	48.77	33.51	15.26	35	19.74		
3/1/2010	12:00	40238.50000	48.80	33.52	15.28	35	19.72		
"	"		"	"	"	"	"		
6/5/2010	9:00	40334.37500	44.18	33.75	10.43	35	24.57	24.48	0.09
6/5/2010	10:00	40334.41667	44.19	33.77	10.42	35	24.58		
6/5/2010	11:00	40334.45833	44.21	33.76	10.45	35	24.55		
"	"		"	"	"	"	"		
9/30/2010	10:00	40451.41667	42.30	34.33	7.97	35	27.03	27.06	-0.03

9.7 References

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