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USDA LTAR Common Experiment measurement: Depth to water table

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Abstract

Groundwater is water held beneath the land surface in rock and soil pore space. The upper surface of this saturated water zone is called the water table. Depth to groundwater, also referred to as the water table, can change in response to management activities and environmental factors. Groundwater is measured in observation wells (i.e., piezometers or non-pumping wells) using manual methods or with pressure transducers. The water table is the level in the saturated zone at which the hydraulic pressure is equal to atmospheric pressure and is represented by the water level in observation wells. Below the water table, the hydraulic pressure increases with increasing depth. Water table aquifers, also known as unconfined aquifers, are influenced by the unsaturated zone, and the water table is free to rise and decline. Wells with pipes screened to allow water to flow laterally within the pipe measure the position of the water table in the surrounding aquifer.

Manual methods rely on an observer with a linear measuring device (e.g., a steel measuring tape with wettable chalk or beeping electric tape) dropped into the well and subtracted from a permanent reference point above the land surface. These measurements are performed at certain points in time and are known as synoptic measurements.

In networks such as the LTAR network, it is common practice to use automated pressure transducers with an internal or external data logger. Transducers have the advantage of continuous in situ monitoring. Submersible pressure transducers are installed at a fixed depth in a well (typically 2” polyvinyl chloride (PVC) pipe) - refer to manuals on groundwater well design) and measure pressure exerted by the water column and atmosphere against a membrane in units of pressure (Pascals, pounds per square inch, or equivalent). This pressure measurement is converted into the height of the water column above the transducer (or water depth) using a conversion formula (e.g., 1 psi = 2.303 ft of water). Submersible transducers are vented or non-vented. The former type has a tube from the transducer whose end is maintained above the water surface to automatically exclude the atmospheric pressure from the pressure measurement, thus providing a direct measure of the water depth. In contrast, a non-vented transducer reads the combined pressure of the water column over the transducer and the atmospheric pressure; hence, atmospheric pressure must be subtracted from non-vented transducer data. The atmospheric pressure can be obtained from a nearby weather station or by installing a transducer above the water surface in a well. **Monitoring well layout and installation** procedures are designed to ensure that the water level inside the well is identical to the water table level. In addition, wells will likely need to be periodically de-silted.

Another approach to measuring the depth to the water table (in surface water bodies) is to use an ultrasonic range finder (**Maxbotix**) placed on the underside of a bridge or structure pointing directly down, overlooking the water surface of interest (canal, lake, etc.). This device transmits an ultrasonic wave that travels downward and gets reflected back to the sensor from the water surface; the distance to the water surface is the product of the speed of the wave (speed of sound) and the time taken for this wave to travel and return. This device is considerably more economical than submersible transducers, interfaces easily with open-source data loggers, and is used in monitoring networks globally where funds are limited. However, scattering of the ultrasonic wave from emergent aquatic vegetation or waves in choppy conditions poses limitations to this method. In addition, scattering from the inner surfaces of a narrow well (e.g., 2” PVC tube) poses a limitation to the use of these rangefinders to measure groundwater levels in wells.

Materials

- Submersible vented or non-vented pressure transducer (brands include Campbell Scientific, InSitu, KPSI, Onset, Solinst, and Stevens)
- Power source: typically 12 V deep-cycle battery, 10-20 W solar panel, and Morningstar SS-10-12 V charge controller, unless the data logger has a built-in charge controller. Or a battery-operated Vu-link attached to a Rugged Troll (both by InSitu) both installed inside a well.
- Suspension wire
- Readout device/data logger. Note that a recently available solution is to add direct streaming service, such as offered from InSitu Vu-Link that has an on-board cellular modem.
- Well pipe with cap, known depth of transducer placement, and known depth of screened opening
- Established permanent reference point aboveground with reference to elevation point.
- Water level tape, steel or electric (for manual measurements to periodically check transducer measurements)
- Affix transducer cable to the well top using zip ties or other fasteners through a pair of holes drilled on the side of the well. This contrivance prevents the transducer from slipping or being pulled out.

Before start

Please refer to the *Placement and Site Maintenance* section in the *USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements* protocol (Baffaut, 2024) for general equipment siting considerations.

Data collection

1 **Measurement**

1.1

- Commonly, water-level data in wells are collected hourly. For some applications, more frequent measurements may be desirable.
- Absolute pressure sensors respond to atmospheric (barometric) pressure and the pressure head of water above the sensor. When using absolute pressure sensors, take a barometric measurement and the submersible pressure sensor measurement simultaneously to compensate for the barometric fluxes. This task requires a separate barometric measurement instrument at the land surface (for example, Solinst barologger or Insitu Rugged Troll placed above the water level) and post-processing of the data to compensate for the barometric pressure.
- Vented pressure sensors use a vented cable, with a small vent tube down this cable from the land surface and terminating behind the pressure transducer. This vent tube compensates for barometric pressure changes at the surface, canceling the barometric pressure on the water column with the pressure transmitted in the tube, and a post-processing correction for atmospheric pressure is not required. These sensors require desiccant tubes to prevent atmospheric water vapor from interfering with the vent tube.
- The reference point should be a permanent mark on the well pipe, as the surface soil may change over time.

2 **Site Maintenance**

2.1 1. Overall steps when maintaining equipment:

a) Collect data
b) Visually inspect wiring and physical conditions
c) Check indicating desiccant (vented transducers only) or the enclosure humidity indicator; service if necessary
d) Check battery condition or power supply
e) Check all sensor readings; adjust transducer offsets, if necessary, with manual verification measurements
f) Check recent data

2. Make manual water level measurements to the nearest 3 mm to determine in situ calibration. Measuring to the nearest 3mm accounts for human error in reading staff gages or placing a water level sounder tape (such as https://www.ysi.com/wl500) exactly at the water level.

3. Pressure transducers are subject to drift and offset and should be recalibrated by the manufacturer or the user. Pressure transducers hung on cables may slip. During monthly site visits (and perhaps more frequently after events that could produce substantial changes in groundwater levels), routinely verify the readings against manual readings with a tape measure. Verification measurements, commonly known as calibration checks, are necessary for troubleshooting, drift determination, and data correction during office computation.

4. Field verification measurements of ancillary data may include voltage output from the power supply, barometric pressure, shelter temperature, and outside air temperature, all of which can be compared with the recorded values, to alert the user to potential problems that might indicate data loss or instrument damage.

Data processing and quality control

3 Recommendations on data processing and quality control follow the general recommendations for water quantity variables. Please refer to the *Quality Control* section in the *USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements* protocol (Baffaut, 2024). In addition, specific details for water table measurement are listed below:

3.1 The accuracy of a pressure transducer varies among manufacturers, measurement ranges, and water depths. The measurement error and accuracy standard for most situations is 3 mm, 0.1% of the range in water level fluctuation, or 0.01% of the depth to water above or below the level of the pressure transducer, whichever is least restrictive.

3.2

- It is good practice to correct the data for instrument drift, hysteresis, temperature effects, and offsets by comparison against periodic (e.g., monthly) manual water depth measurements. The difference between the manual reading and the transducer reading is added to an offset so that the transducer reading coincides with the manual reading.
- If the transducer drifts again on the next manual check, and if this happens several times, calibrate the transducer. This calibration can first be done in-house, on-site by manually dipping the transducer to a series of known depths (1”, 3”, 6”, 12" 18", 24" and so on until 4 or 5 feet if possible) and verifying whether the transducer readings coincide with the actual depths.
- If the transducer readings differ from actual readings by the same amount, add this amount to the offset. However, if the difference between the sensor and the manual varies with depth, the transducer may need to be returned to the manufacturer for calibration or replacement.

3.3 Transducers operate in a limited water-level (pressure) range; depths outside the minimum and maximum ranges of the transducer will produce erroneous values that need to be discarded.

3.4 Rapid, transient water level changes (e.g., brief floods) may go unnoticed because of data logging frequency.

3.5
- Quality control - step, range, and persistence checks, with the values obtained from site-specific water level behavior are required. It is crucial to become familiar with water level behavior at a site to determine whether changes in data reflect reality or arise from sensor malfunction/dislocation.
- A steady decline in water level is normal over rainless periods. Sudden increases and decreases in the water level indicate nearby water management, such as canal gates opened/closed or pump activity, or a heavy rain shower. However, the magnitude of these sudden changes needs examination to determine how realistic they may be.
- Diurnal ups and downs in water level can be normal, and indicate ET-driven water table drawdowns with this typically declining over the day and recovering at night.
- Sometimes, a transducer can become physically dislodged inside the well; it can get pulled up or weighed down because of mats of vegetation growing over the transducer cable, or waterborne debris may push the cable. Pulling the transducer up will result in sudden (or even gradual) increases in the data. These increases are detectable in periodic field visits and correctable.
- Adjusting the data for this error may be straightforward for sudden slipping, in which case the difference between before and after the slip can be adjusted from the data. It is trickier to adjust data in the absence of a discernable reason for sudden increases/decreases (such as a rise of 30 cm over 15 minutes). Such data can be flagged to be used at the user's discretion.

Data file formats and metadata

4 Data collection formats include raw data from the pressure transducer and converted later to depth or elevation; record data in the same units used during field calibration checks; or program the data logger to provide water-level elevations with respect to a datum such as NGVD29 or NAVD88. Doing the latter enables the water level data to be used with topographic models and be compared across regions. Collecting and archiving raw data from the sensor is preferable.

5 A record of adjustments to the data, including the type of adjustment, over what period, who performed the adjustment and when, and whether the adjustment occurred in the data logger program or elsewhere, is necessary.

6 **Metadata**

Unique site identifiers, latitude and longitude, casing depth, depth of the uppermost screened open hole, depth of the lowest open screened hole, casing material, screen material, description of reference location top of the well above land surface, the height of the permanent reference point location from land surface elevation (altitude). Record of units, indication of accuracy, sensor type, sensor ID (to identify when sensors are replaced and datum used).

Recommendations for data collection

7 Table 1. Summary of recommendations for measuring the depth to the water table.

A	B	C	D
Attribute	Preferred	Minimum	Comments
Spatial scale	Plot and field	Plot	A network of instrumented or manually measured wells can be used to determine the field scale
Frequency	-Weekly for manual measurements -15 minutes for recording transducers	-Monthly for manual -Daily for transducers	Many applications measure the water level at the 15-min resolution that affords a finer temporal scale understanding of the effects of rainfall/ET/irrigation on the water table
Covariate metrics	Atmospheric barometric pressure, overland flow events, streamflow discharge if applicable, precipitation, evapotranspiration, changes in management	Atmospheric barometric pressure	The choice of covariate metrics depends on the purpose/use of the water table data. For instance, investigating the effects of land use change on water resources requires evapotranspiration, precipitation data, and water table data.

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