## Groundwater

This module provides the standard of practice for the investigation, characterization, evaluation, and determination of the design groundwater elevation for geotechnical purposes. The characterization of groundwater is critical information for design, reporting, and construction. Design groundwater elevation refers to the highest anticipated groundwater level used for design and will likely differ from the historical or measured groundwater during the investigation. Reporting the highest anticipated design groundwater elevation ensures that project components (e.g. foundations, embankments, slopes, and utilities) are designed appropriately and identify the need for mitigation measures, such as dewatering, during construction. Inaccurately represented design groundwater may impact projects and result in design modifications, unforeseen environmental impacts, and construction issues.

Groundwater behavior can be complex due to factors such as seasonal variations in precipitation, local pumping resulting in drawdown, tidal fluctuations, and/or fluctuations in surface water levels. Geologic features such as landslides, formation contacts, faults, and/or bedding, may influence groundwater and should be considered on a site-specific basis.

The references cited at the end of this module contain additional information for the characterization of groundwater.

### Groundwater Characterization Process

The extent of groundwater characterization is a function of the type(s) of proposed improvements, complexity of site conditions, and availability and reliability of existing information. A literature search (see Geotechnical Investigations) must be completed along with a field reconnaissance as needed prior to characterizing groundwater during a site investigation. Document the groundwater investigation plan in the Site Investigation Plan (SIP) to ensure required groundwater information is collected.

### Literature Search

Perform a groundwater literature search to become familiar with all available current and past information. Identify the anticipated subsurface conditions at the site to develop a groundwater investigation plan.

Collect information from sources such as, but not limited to, topographic maps, aerial imagery, site ownership and utilization records, geologic and hydrogeologic maps and reports, mineral resource surveys, water well logs, information from local well drillers, and agricultural soil reports. Research and review available As-built geotechnical engineering reports, As-built Log of Test Borings (LOTBs), and other engineering maps, plans, and reports related to the project area. Refer to the Geotechnical Investigations module for a list of information resources.

When using historical groundwater information, either from As-built LOTBs or public databases, review the data to ensure the information is accurate and applicable to the project. Historical data should be verified if used for final design. Examine historical LOTBs for the drilling method used, subsurface conditions and groundwater measurements then assess the data. For example, if mud rotary drilling methods were used in cohesive soils and groundwater was measured the same day of completion of drilling, this measurement is likely inaccurate as groundwater levels would not have time to equilibrate. Use the measuring methods described later in this module to ensure reliable groundwater data is produced. When reviewing historic data consider the elevation datum used and determine if a conversion to current datum is necessary.

Once the literature search is complete, consider whether the available groundwater information is adequate for the project. If the literature search does not provide enough groundwater information, develop a groundwater investigative plan as part of the SIP. If the literature search reveals a groundwater condition that may have significant impact on the planned improvements, contact the Project Engineer to discuss options. This will allow time for the client to adequately consider groundwater implications rather than waiting for the geotechnical reports which could result in a delay in design.

### Groundwater Site Visit

Perform a site visit to assist in preparing the groundwater investigative plan. The goal of the site visit is to identify the topography and surficial features that provide information about the subsurface and groundwater conditions, e.g., presence of roadcuts, stream-cuts, springs, seeps, vegetation (e.g., phreatophytes), and creek water levels. Document and map these features, during the site visit. Give special consideration to soil color and textural changes, landslides, wetlands, seeps, and springs within or near the project area. These observations help to identify surficial flow pathways and determine logistics of the groundwater investigative plan.

### Groundwater Investigative Planning

The number of measurements and method(s) used to measure groundwater across the site will be dependent upon the type and size of project, subsurface conditions, geology, environmental, and right-of-way restrictions. While planning the site investigation take into consideration the subsurface conditions anticipated and the time it will take for groundwater elevations to equilibrate. Depending on subsurface conditions it may take days to weeks to equilibrate (i.e., fat clays) so installation of a standpipe and or vibrating wire piezometer may be necessary. It is not required to measure groundwater in every boring, however enough measurements must be taken to determine groundwater elevation conditions at the site. If mud rotary drilling is used it does not preclude measuring groundwater. Groundwater elevations may be directly measured in auger borings and pore pressure dissipation tests can be used in Cone Penetration Tests (CPTs). An example of how to determine depth to groundwater using porewater dissipation results is included in Appendix A.

Standpipe and vibrating wire piezometers may be installed to determine seasonal fluctuations, tidal fluctuations, pumping and drawdown, recharge areas, and surface water influence on groundwater elevation.

If perched groundwater is anticipated, plan to measure both perched and regional groundwater elevations for project specific needs. If artesian conditions are anticipated, plan to measure pressure head differentials when structural components are proposed to be constructed in these groundwater zones. If necessary, plan to measure hydraulic conductivity.

**Piezometer Installation Planning**

Piezometers are instruments sealed within a boring and respond only to the hydraulic head at the piezometer and not to hydraulic head at other elevations. Depending on the specific type of piezometer used, piezometers may or may not allow access for groundwater sampling for corrosion testing. Piezometers are used to determine groundwater pressure (or pressure head) at a specific location. Measurements from several piezometers can be used to establish profiles of groundwater pressure (or pressure head) or to determine hydraulic gradients and flow directions. Piezometers can also be utilized to monitor seasonal patterns. Standpipe piezometers and vibrating wire piezometers are the common types installed for most geotechnical projects and are described below. A complex project may require more advanced piezometer(s) to be installed for measuring groundwater elevations.

<u>Standpipe Piezometers:</u> Standpipe piezometers consist of an open pipe that is placed within a drilled borehole with a screened section and a bentonite seal. Standpipe piezometers are typically constructed with a limited screened section, so the instrument only responds to the hydraulic head at a discrete elevation. Screen lengths (including the filter pack) for standpipe piezometers should be as discrete as possible to isolate the groundwater elevation response. Standpipe piezometers are carefully sealed above and below the location of the screened section to prevent hydraulic “short circuiting” from formations at different depths and are grouted following installation. Drilling Services has Installation Details for a flush mount piezometer and stovepipe piezometer that may be used as a detail and can be modified as needed per installation. The Installation Details are available for consultants upon request.

Vibrating Wire Piezometer: Vibrating wire piezometers are devices placed within the boring to monitor pore-water pressure. A transducer inside the piezometer converts water pressure to a frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. The transducer is constructed so that a change in water pressure on the diaphragm causes a change in the tension of the wire. The electromagnetic coil excites the wire, which vibrates at its resonant frequency. The coil then acts as a pickup, senses the frequency of vibration, and transmits through a cable to a signal readout device. Once the pore water pressure is calculated at a known depth below ground surface, the groundwater surface elevation can be calculated. Vibrating wire piezometers can be installed using a sand pack and bentonite seal, attached to a casing, or grouted in place using a bentonite-cement grout per manufacture instructions. An advantage of vibrating wire piezometers is that several instruments can be installed in the same boring at different elevations. Currently Geotechnical Services has no Installation Details for a vibrating wire piezometer; develop a detail as needed with a flush mount or stovepipe well monument.

When installing a standpipe or vibrating wire piezometer, consider the depth of the screened interval. The piezometer needs to be designed to only screen the zone to be measured. Excessive screen may cause more than one water bearing zone to be intercepted and result in an incorrect groundwater elevation. Conversely, inadequate screen may result in the water bearing zone to be missed. The correct size of well perforations and filter pack will keep the surrounding soils from entering the piezometer. If there are confining clay layers above the water bearing strata, the annular seal must be made in these confining zones to keep different levels of groundwater separated from each other. Give special consideration if there are artesian conditions and plan to measure the pressure head differential in addition to the elevation of groundwater.

**Table 1. Piezometers (after Dunnicliff, 1993).**

| Instrument Type | Advantages | Limitations |
|---|---|---|
| Standpipe Piezometer | • Reliable<br>• Simple construction<br>• Inexpensive<br>• Successful performance record<br>• Can sample groundwater<br>• Can be used to measure hydraulic conductivity | • Potential for long time lag.<br>• Filter section can plug from repeated inflow/outflow of water. |
| Vibrating Wire Piezometer | • Easy to read<br>• Short lag time<br>• Minimal lead wire effects<br>• Can measure negative pore water pressure | • Special manufacturing needed to minimize zero shift.<br>• Cannot be allowed to freeze. |

Note: GEC-5 provides piezometer types not typically installed for geotechnical projects that may be considered if needed for a complex project; although, careful consideration needs to be given to these types of piezometers that may require hiring a contract drill rig for installation and data collection (such as complex pneumatic or fiber-optic transducer piezometers).

A thorough knowledge of site-specific geology and hydrogeology is necessary to properly apply the piezometer design and installation procedures. Develop a preliminary conceptual site model that identifies the target groundwater zone(s) prior to piezometer design and installation.

To develop a preliminary conceptual site model, create a geologic and hydrogeologic cross section by plotting the subsurface conditions observed in available As-built data. Next add surficial or subsurface information documented during the field reconnaissance and interpret between this information using geologic and engineering interrelationships. Extrapolation of data into adjacent areas should be done only where geologically uniform subsurface conditions are known to exist. Then determine where to construct piezometer(s) to target the appropriate groundwater zone(s). In areas where the geology is relatively uniform, well documented in the literature, and substantiated by the site visit, further refinement of the conceptual model may not be necessary unless anomalies are discovered during the site investigation.

When planning locations of piezometers take advantage of areas that do not require traffic control for taking subsequent readings.

Where limited or no background data is available or where the geology is complex, plan to modify the groundwater site investigation in the field according to site conditions (i.e., changes in borehole lithology).

## Groundwater Measurement

The method selected for measuring groundwater is dependent on physical site constraints, time available for site investigation(s), project type, and the anticipated groundwater depth. When measuring groundwater within a boring, each measurement represents groundwater at a single point in time and does not provide information on how significantly it may change over time. For projects that require continuous or multiple groundwater measurements, installation of piezometers may be necessary to obtain accurate groundwater variation data.

Prior to measuring groundwater, record the northing, easting, and vertical elevation in accordance with the Borehole Location module. The vertical elevation reference point will be used to calculate the groundwater elevation from the measured groundwater depth.

Record groundwater measurements by using an electronic water sensing tape measure, otherwise known as a water level meter. This device consists of an electrical wire encased within a cable or tape with a weighted sensing tip on one end and an electric meter at the other. When the sensing tip contacts water the electric meter will make a sound, and an indicator light will illuminate. The groundwater depth can be directly read from the tape measure on the device. The groundwater depth can be subtracted from the surface elevation or reference point to determine the elevation of the groundwater. Be cautious of false readings as moisture on the inside of the boring or casing can cause the probe to sound and light. Record the depth, date, and time of measurement on the field log at the time of measurement. For subsequent measurements of piezometer installations, document the reading date, groundwater depth, and groundwater elevation.

Table 2 lists various methods available at Geotechnical Services to measure groundwater.

**Table 2. Methods to Measure Groundwater**

| Preference | Method | Near Surface Groundwater (<10 feet) | Shallow Groundwater (10-30 feet) | Moderately Deep Groundwater (30-80 feet) | Deep Groundwater (80+ feet) |
|---|---|---|---|---|---|
| Most Preferred | Hand Auger | X | | | |
| | Test Pits | X | | | |
| | Auger Drilling | X | X | X | |
| | CPT Pore Pressure Dissipation Test | X | X | X | X |
| | Piezometer | X | X | X | X |
| Least Preferred | [1]Mud Rotary Drilling | [2]X | [2]X | X | X |
| Not | [3]No groundwater measurement taken. | -- | -- | -- | -- |
| Acceptable | Groundwater measurement after mud rotary drilling with no flushing or bailing | -- | -- | -- | -- |

[1]Mud rotary drilling observation is the least preferred option as it may require leaving an open hole for several days for groundwater to equilibrate.

[2]Pumping is typically limited to a maximum of 20 feet.

[3]Measure groundwater as many times as needed to determine groundwater level at the project site.

## Hand Auger

Hand augers are preferred when groundwater depth is anticipated to be 10 feet or less. It is a simple and quick method that can be used to directly confirm groundwater level across multiple locations. The working area has a small footprint and minor environmental impacts. To use this method, hand auger to the target depth then stop and let the groundwater level stabilize. Once stable, measure and record the depth to groundwater.

## Test Pits

Test pits are an alternative to the hand auger or can be used when a test pit is already scheduled for other purposes. If groundwater is present, use a water level meter or a reeled weighted tape to measure the depth to groundwater. **If shallow groundwater is present test pit walls can rapidly destabilize. Follow all Caltrans and Cal OSHA safety requirements for entering excavations.**

## Auger Drilling

If groundwater is anticipated to be present within the drilled depth, initiate drilling using solid flight or hollow stem auger methods. Measure groundwater within the boring once it is encountered then switch to mud rotary drilling to continue advancing to the target depth. This will provide the most accurate groundwater level reading without interference from drilling fluid and additives. Groundwater level measurements must be made at the end of auger drilling and after any prolonged interruptions in auger drilling. Measure groundwater until a stable reading is recorded. Groundwater level within a boring may or may not change substantially over time and it is dependent on the surrounding soils. In silts and clays, groundwater levels may not stabilize for several hours or days. In coarse-grained soils, groundwater level may stabilize in minutes to hours. In other materials, borings may cave or collapse once augers are removed. Be prepared to use an alternate method to measure groundwater should this occur.

Pore Pressure Dissipation Test Using CPT

A Pore Pressure Dissipation Test (PPDT) is an indirect measurement that can be used to measure the equilibrium water pressure of a CPT at various intervals. The measured equilibrium water pressure can be used to determine the approximate depth of groundwater level at the date and time of measurement. During the investigation using CPT, it is recommended to conduct a PPDT if groundwater is anticipated. When soils are sandy, without clays, the PPDT is a quick way to get several water measurements. The PPDT has limitations. In clayey soils it will take hours or days for the pore pressure to dissipate. It may still be used but the extended dissipation time must be considered and incorporated into the SIP.

Piezometers

Verify the presumed geology is consistent with the conditions logged during drilling operations. If consistent, observe piezometer installation in the field to confirm the piezometer is installed per the approved installation details.

For a standpipe piezometer, make a notch on the north side of the casing as a repeatable location to take measurements with the water level meter. The notch should be surveyed for northing, easting, and elevation in accordance with the Borehole Location module.

For a vibrating wire piezometer, prior to installation, perform calibration and collection of a “zero reading” per manufacturer’s instructions. When monitoring the vibrating wire piezometer, record the frequency reported using the signal readout device. Typically, there are two small wire connectors exposed at the top of the cable: one for temperature (colored green/white) and one for the frequency (colored red/black). These small wire connectors must be attached to the correct terminal on the readout device.

Mud Rotary Drilling

Mud rotary is the least-preferred method to measure groundwater but is an option when site limitations preclude the use of the auger method. Measurements of groundwater at the time of drilling can be misleading, the time required for groundwater levels to reach equilibrium after drilling with mud rotary can be lengthy. Prior to measuring groundwater in a mud rotary drilled boring, pump or bail the drilling fluid out of the boring or flush the boring with clean water until the fluid runs clear. Once the drilling fluid has been removed, measure the groundwater until a stable reading is recorded.

**Hydraulic Conductivity of Subsurface Formations**

Samples can be collected during the site investigation and tested in the laboratory for hydraulic conductivity. Some considerations for laboratory testing are the size of the specimen, stress level, sample disturbance, and direction of hydraulic gradient within the sample, actual groundwater used for testing (vs tap water), temperature, and anisotropy of the hydraulic conductivity. Additional pumping tests, slug testing, and drawdown tests may be necessary to assist in determining the in-situ hydraulic conductivity at the site.

**Special Conditions**

Groundwater behavior in areas with complex geology such as fractured rock, layered soils, or heterogeneous sediments can be unpredictable. Variations in permeability and porosity between soil layers or rock formations can cause localized differences in groundwater elevation, even over short distances. The presence of confining layers (such as clay or bedrock) that restrict groundwater movement can lead to confined aquifers or perched water tables, where groundwater levels behave differently than in unconfined aquifers. Additional information regarding some special conditions is discussed below.

<u>Perched Groundwater</u>

Perched groundwater is a discontinuous zone of groundwater that is not hydraulically connected to the regional groundwater. Perched groundwater can occur above regional groundwater elevation due to impermeable bedrock or clay layers. Perched groundwater may be seasonal and may not be present all year long in some areas.

An interbedded riverine depositional environment may have discontinuous clay layers present above the regional groundwater elevation. These clay layers may impede the downward infiltration of groundwater. Downward infiltrating groundwater may build up a layer of perched groundwater in the area above the clay layer.

Perched groundwater can cause challenges when designing structures or roadway improvements. Being discontinuous zones, the perched groundwater may be present in some areas of a site and may be absent in other areas. Perched groundwater must therefore be adequately characterized in the subsurface investigation.

<u>Artesian Conditions</u>

Artesian conditions exist where a confined aquifer has a piezometric head elevation that is greater than the elevation of the ground surface, that is, the pressure in the aquifer forces

groundwater above the ground surface. The term sub-artesian indicates where the piezometric elevation is greater than the overlying formation but is lower than the ground surface.

To measure the piezometric head elevation at the time of drilling, add additional casing above the ground surface and measure the height above the ground to the groundwater level. For multiple or continuous measurements of the artesian water pressure multiple piezometers can be installed.

Groundwater in Rock

Groundwater flow in rock with low permeability is controlled by the presence, orientation, and connectivity of fractures, joints, and faults. In fractured rock, the design groundwater elevation is usually based on the piezometric head at the site. This is typically measured from monitoring wells in fractured zones and can differ from the unconfined water table due to the nature of confined or semi-confined flow.

## Design Groundwater Evaluation

Once the groundwater characterization and measurement process has been completed, the groundwater information collected must be evaluated for use in geotechnical designs and deliverables.  The design groundwater elevation can have significant impact during analysis of soil and rock cut slopes, liquefaction, settlement, pile downdrag, and more.

The worst-case groundwater condition should be considered when determining design groundwater elevation. The worst-case design conditions that may rationally arise during construction or operation must be inferred using considerable judgment, knowledge of the groundwater fluctuations at the site, and any other pertinent information relating to groundwater flow. The objective when determining the design groundwater elevation is to establish an appropriate, rational, and defensible elevation for use in analyses and design of geotechnical assets.

When evaluating the worst-case groundwater condition for use in design, direct measurements that are recent and/or near the project should be considered more reliable, while indirect measurements that are old and/or far away from project should be considered less reliable. Direct measurements do not require a transformation or manipulation to produce estimates of groundwater. Indirect measurements require manipulation or transformation to produce an estimate of groundwater. For example, a CPT pore pressure dissipation test is an indirect measurement that is used to calculate groundwater elevation. Both direct and indirect measurements are subject to variability and uncertainty as groundwater conditions vary in three-dimensions and with time.

If you have minimal data, due to project constraints, it is acceptable to assign a higher groundwater elevation to account for temporal fluctuations in the water table. This practice varies depending on the historical groundwater data/trends and site-specific geologic conditions. Consider everything mentioned above, discuss with the project design team, and use your engineering judgement.

Appendix B provides an example for determining design groundwater elevation at a site.

## Reporting

Groundwater measurements must be reported on Log of Test Borings and Boring Records per the requirements in the *Soil and Rock Logging, Classification, and Presentation Manual*. Follow the Foundation Report and/or Geotechnical Design Report modules to report observed groundwater measurements, design groundwater elevation(s), and to discuss pertinent groundwater conditions.

There are numerous groundwater-dependent Special Provisions; collect enough information to determine which Standard Special Provisions will be needed. Refer to the Geotechnical Notes for Specifications module for more information.

## References

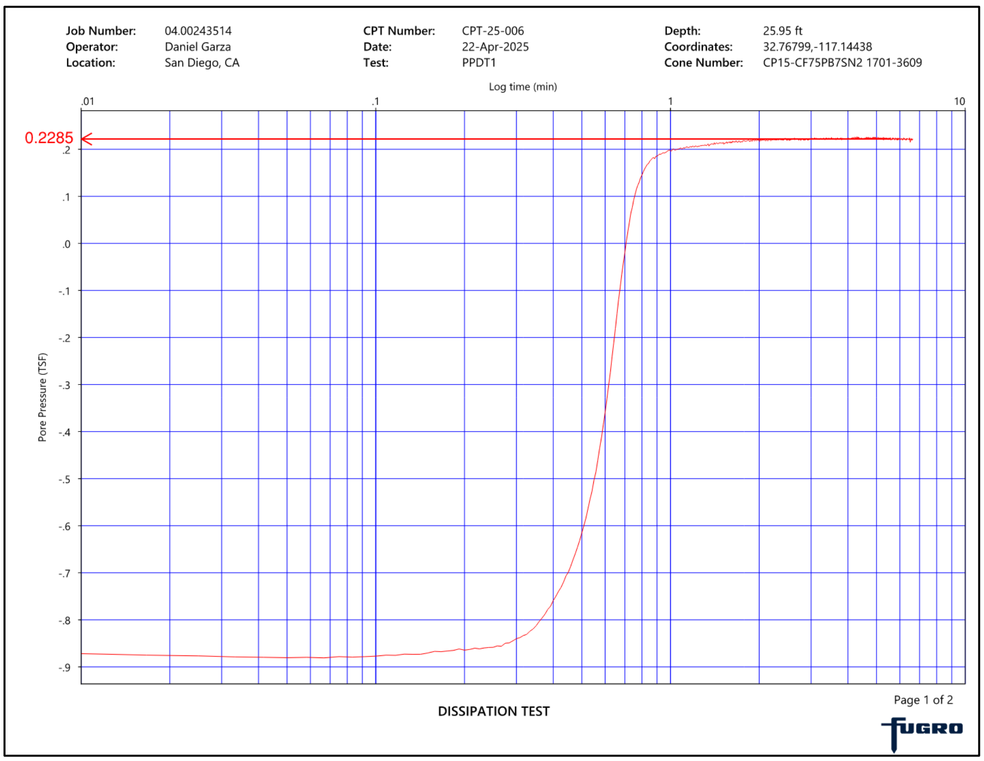

- ASTM D5778 *Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils*, June 1, 2020.
- Drilling, Sampling, and Construction of Monitoring Wells Under Flowing Artesian Conditions, *Environmental & Engineering Geoscience, Vol. III, No. 3, Fall 1997, pp. 369-373.*
- California Water Code (https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=WAT&division=7.&title=&part=&chapter=10.&article=4)
- CA Water Code Bulletins
- U.S Department of Transportation, Federal Highway Administration, *Geotechnical Engineering Circular No.5, Geotechnical Site Characterization*, April 2017.
- VW2100 Vibrating Wire Piezometer Instruction Manual, RST Instruments, August 27, 2020.

# Appendix A: Determining depth to groundwater from CPT pore pressure dissipation test

$$z_w = z_u - \frac{u_{eg}}{\gamma_w}$$

Where:
$z_w$: Depth to groundwater (ft)
$z_u$: Depth to pore pressure transducer during the test (ft)
$u_{eg}$: Equilibrium pore water pressure, typically at end of test after normalizing (lb/ft$^2$)
$\gamma_w$: Unit weight of water (62.4 lb/ft$^3$)

Example 1:




$z_u$: 25.95 ft
$u_{eg}$: 0.2285 TSF => 457.0 lb/ft$^2$
$\gamma_w$: 62.4 lb/ft$^3$

$$z_w = 25.95\,ft - \frac{457.0\,\frac{lb}{ft^2}}{62.4\,\frac{lb}{ft^3}} = 18.26\,feet\ bgs$$

## Appendix B: Determining design groundwater elevation at a project site

The following text provides an example project, and the steps take to evaluate the worst-case groundwater condition.

Example: Determining Design Groundwater Elevation

Project site topography consists of rolling hills that slope west. Subsurface material generally consists of silty sands with no bedrock encountered. During the desktop study, historic data was obtained from the Department of Water Resources' Water Data Library, and reviewed for Well A and Well B. The wells had consistent biannual readings with the high water readings occurring in April and May. Boring A-24-001 was initially drilled with hollow stem auger methods, then switched to rotary wash drilling upon encountering groundwater. The groundwater level was measured using a water level meter 1 hour after initial encounter, prior to mud rotary drilling. A piezometer, P-01, was installed in Boring A-24-001, and all subsequent readings were collected by Caltrans personnel.

**Table B1: Example Groundwater Data Table**

| Instrument ID | Ground Surface Elevation (feet) | Groundwater Table or Piezometric Elevation | | Date Measured | Notes |
|---|---|---|---|---|---|
| | | Depth (feet) | Elevation (feet) | | |
| A-24-001 | 820 | 32 | 788 | August 13, 2024 | Installation of P-01 |
| P-01 | 820 | 30 | 790 | August 14, 2024 | Located on site |
| | | 22 | 798 | December 18, 2024 | |
| | | 14 | 806 | April 28, 2025 | |
| Well A | 835 | 14 to 40 | 821-795 | 2000-2022 | Located 1,000 feet east of site |
| Well B | 790 | 20 to 36 | 770-754 | 1980-2010 | Located 5,000 feet west of site |

Note: Elevations are based on the North American Vertical Datum of 1988 (NAVD 88).

Steps to determine design groundwater elevation:

1. Consider site topography and location of instruments.
    a. Well A is located east of the site and at a higher ground surface elevation. Well B is located west of the site and at a lower ground surface elevation.
    b. Boring A-24-001/P-01 are within the project footprint.
2. Evaluate the historic data from Wells A and B.
    a. The high water elevations were generally recorded in April or May.
    b. The historic data from Well A was considered more applicable than the historic range from Well B because it is more recent and closer to the site.

3. Review piezometer data.
    a. Typical seasonal fluctuation from January to September was observed.
    b. The highest groundwater elevation was in April.
4. Determine design groundwater elevation.
    a. In Well A, the high groundwater elevation of 820 feet is not applicable at our site because elevation 820 feet is the ground surface elevation at the site. The depth below ground surface at Well A, however, is generally consistent with the depth below ground surface at the site (14 feet).
    b. Well B is located further from the site, has older data, and shows groundwater generally deeper than the data closer to the site, therefore, historical information from Well A takes precedent.
    c. P-01 was installed for this project and regular readings were taken.
    d. Based on the information above, the design groundwater elevation was selected to be elevation 806 feet, the highest anticipated groundwater elevation. This determination was made based on the recent piezometer readings and consistent depth to groundwater readings of 14 feet below ground surface in Well A.