



Hydrologic Monitoring of Wetlands

MN Board of Water & Soil Resources

Supplemental Guidance

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1. Introduction

As federal, state, and local wetland protection efforts have evolved over the last two decades, there has been increasing emphasis on hydrologic monitoring of wetlands. Hydrologic monitoring in this context refers to evaluation over a period of time of one or more of the following:

- Indicators of wetland hydrology
- Ground water levels:
 - saturation depths
 - piezometric “head” or potential
- surface water levels:
 - ponding
 - flooding
- water budget inputs and outputs
 - precipitation
 - surface water inflow and outflow
 - ground water inflow and outflow

Hydrologic monitoring in this context emphasizes water **quantity** (levels, flows, volumes, duration, and frequency) rather than quality (chemistry).

The reasons for undertaking hydrologic monitoring may include: wetland identification, boundary determination, functional assessment, determining success of wetland restoration or replacement, assessing potential for wetland restoration or creation, measuring water movement, and measuring duration, frequency, or seasonality of wetness. The specific questions to be answered will determine the approach to monitoring.

The purpose of this document is to give some practical guidance based on our years of collective experience at the Minnesota Board of Water and Soil Resources (BWSR). This guidance is meant to supplement the following publications of the U.S Army Corps of Engineers and Natural Resources Conservation Service.

Sprecher, S. W., 2000. *Installing Monitoring Wells/Piezometers in Wetlands*. WRAP Technical Notes Collection, ERDC TN-WRAP-00-02. U.S. Army Engineer Research and Development Center, Vicksburg, MS. (<http://el.erd.c.usace.army.mil/elpubs/pdf/tnwrap00-2.pdf>)

U.S. Army Corps of Engineers, 2005. *Technical standard for water-table monitoring of potential wetland sites*. WRAP Technical Notes Collection, ERDC TN-WRAP-05-2. U. S. Army Engineer Research and Development Center, Vicksburg, MS. (<http://el.erd.c.usace.army.mil/wrap/pdf/tnwrap05-2.pdf>)

Noble, C., 2006. *Water Table Monitoring Project Design*. WRAP Technical Notes Collection, ERDC TN-WRAP-06-02. U.S. Army Engineer Research and Development Center, Vicksburg, MS. (<http://el.erd.c.usace.army.mil/elpubs/pdf/tnwrap06-2.pdf>)

Sprecher, S.W., 2008. *Installing monitoring wells in soils (Version 1.0)*. National Soil Survey Center, Natural Resources Conservation Service, USDA, Lincoln, NE. (ftp://ftp-fc.sc.egov.usda.gov/NSSC/wells/monitoring_wells.pdf)

2. Why Hydrologic Monitoring?

Hydrology is the driving force behind wetlands and their important functions. Measuring hydrology provides insight into these functions. Wetlands are defined by three parameters: vegetation, soils, and hydrology. Of the three, hydrology is the most variable and dynamic, making it difficult to get representative observations; the “snapshot-in-time” of a particular observation may not accurately represent the hydrology of a site. By contrast, soils have integrated the effects of hydrology over hundreds to many thousands of years, so observable soil characteristics will not change over human-scale periods of time. Vegetation integrates the effects of hydrology over the several-year time scale. It may vary over the years with fluctuating climate, but will not change from day to day. While soil and vegetation characteristics can be good indicators of hydrology, recent alterations can make these characteristics unreliable.

Given that directly-observable hydrology may vary over days to months, Hydrologic monitoring over a period of time (typically three to five years or more) provides direct measurement of depth of saturation, duration of wetness, frequency of wetness, and timing or seasonality of wetness – all important factors governing wetland function.

There are many reasons to undertake hydrologic monitoring of a wetland site, each posing its own set of questions to be answered. The following list gives some reasons for undertaking hydrologic monitoring and some representative questions posed by each:

Reasons to Monitor	Questions to Answer
Wetland identification and determination	<ul style="list-style-type: none"> Is the wetland hydrology technical standard met at this point? What is the hydrologic regime and its associated wetland type?
Wetland boundary determination	<ul style="list-style-type: none"> Where does wetland hydrology begin and end on the landscape?
Assessing wetland functions dependent upon hydrologic regime.	<ul style="list-style-type: none"> What are the depth, duration, frequency, and seasonality of saturation? How does this wetland interact with ground water (recharge or discharge)? How does water flow into or out of the wetland? What are the hydrologic inputs and outputs?
Assess potential for wetland restoration or creation	<ul style="list-style-type: none"> What is the lateral effect of a drain or ditch? What depth is the current water table? What are the hydrologic inputs and outputs?
Evaluate hydrologic alteration	<ul style="list-style-type: none"> What is the lateral effect of a drain or ditch? Has a wetland been effectively drained? Or partially drained? How well is ditch or drain tile functioning?
Determine success of wetland restoration or replacement	<ul style="list-style-type: none"> How much has the water table depth changed since a drain was removed? Has wetland hydrology been restored? Is the wetland hydrology technical standard met at this point? Is the restored hydrology adequate to support the planned plant communities
Calcareous fen determination	<ul style="list-style-type: none"> Is there localized groundwater discharge to the wetland? If so, is the discharging ground water cold & alkaline? What is the direction of ground water flow? Are there calcareous fen indicator plants there? <p>files.dnr.state.mn.us/natural_resources/water/wetlands/calcareous_fen_fact_sheet_dec_2011.pdf</p>

Figure 1: Some possible reasons for wetland hydrologic monitoring and corresponding questions to answer.

3. Sources of Hydrologic Monitoring Data

There are two general categories of hydrologic monitoring data:

- Hydrologic data available from public sources, e.g.:
 - Climate data - MN State Climatology Office[climate.umn.edu]
 - Observation well data - MN DNR observation wells [dnr.state.mn.us/waters/groundwater_section/obwell]
 - Lake Level Data – MN DNR [dnr.state.mn.us/lakefind]
 - WETS tables [www.wcc.nrcs.usda.gov/climate/wetlands.html]
 - USGS Water data - [water.usgs.gov/realtime.html], [waterdata.usgs.gov/nwis]

- Direct measurement via on-site hydrologic monitoring, e.g.:
 - Wetland hydrology indicators
 - Measurements in boreholes
 - Staff gauges and other surface water level measurements
 - Monitoring wells and piezometers

This guidance focuses on the second category – direct measurements at wetland sites. However, it is always advisable to check publicly-available hydrologic data. These can significantly augment data collected on site.

4. Hydrologic Monitoring Methods

Monitoring is evaluation **over a period of time** of some measurable attribute. To many, “hydrologic monitoring” means installing monitoring wells or gauging stations. These certainly are part of the spectrum. However, there are other less labor-intensive monitoring methods that also belong in the toolbox. It is helpful to think in terms of “levels” or “stages” of hydrologic monitoring – methods involving varying levels of effort. A goal is to match the needs of a project and the questions being asked with the appropriate level of effort (and cost).

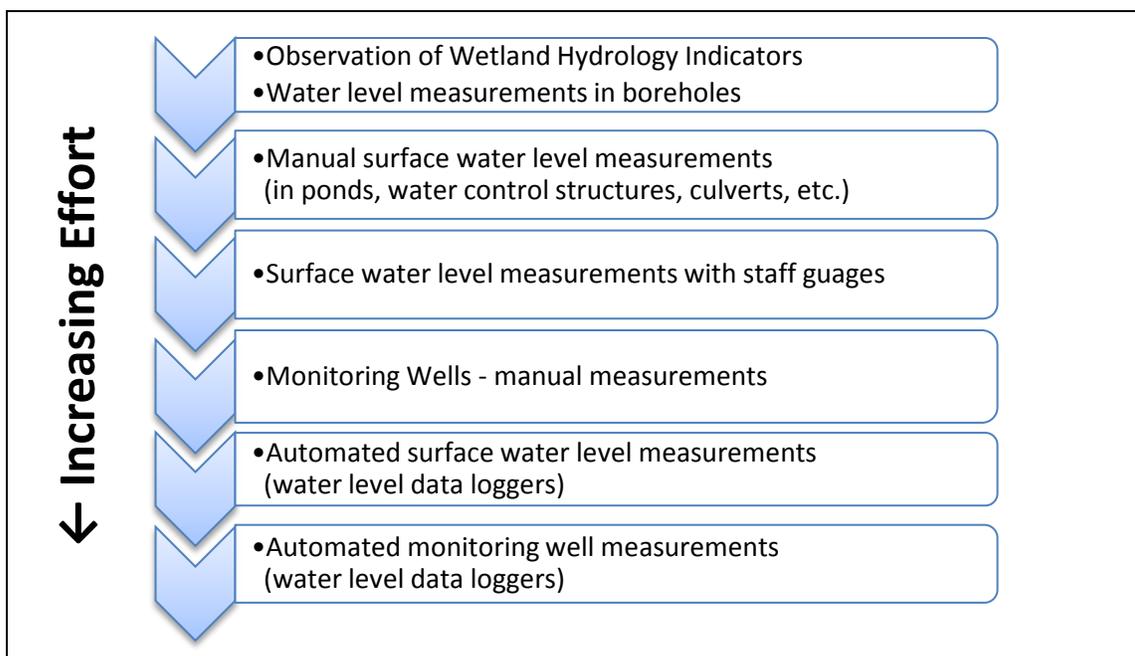


Figure 2: Hydrologic monitoring methods in order of increasing effort.

4.1. Observation of Wetland Hydrology Indicators

A basic and often overlooked approach to hydrologic monitoring of wetlands is observation of wetland hydrology indicators. Wetland hydrology indicators are used in combination with indicators of hydric soil and hydrophytic vegetation to determine whether an area is a wetland under the Corps of Engineers Wetland Delineation Manual. Wetland hydrology indicators provide evidence that the site has a continuing wetland hydrologic regime and that hydric soils and hydrophytic vegetation are not relicts of the past. The indicators are described in detail in the regional supplements to the Corps Manual. The following regional supplements are applicable in Minnesota.

U. S. Army Corps of Engineers, 2010. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Midwest Region (Version 2.0)*, ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-16. Vicksburg, MS: U.S. Army Engineer Research and Development Center. www.usace.army.mil/CECW/Documents/cecwo/reg/erdc-el-tr-10-16.pdf

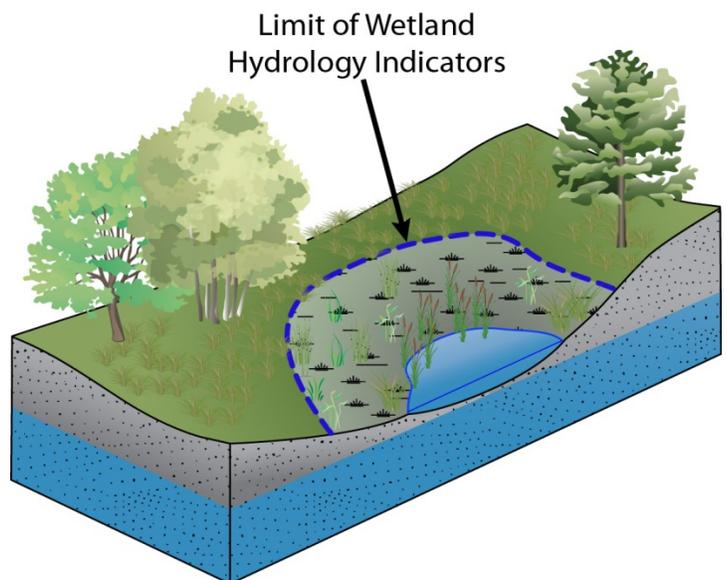
U.S. Army Corps of Engineers, 2010. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Great Plains Region (Version 2.0)*, ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center. www.usace.army.mil/CECW/Documents/cecwo/reg/gp_supp.pdf

U.S. Army Corps of Engineers, 2011. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Northcentral and Northeast Region (Version 2.0)*, ed. J. S. Wakeley, R. W. Lichvar, C. V. Noble, and J. F. Berkowitz. ERDC/EL TR-12-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center. www.usace.army.mil/CECW/Documents/cecwo/reg/trel09-19.pdf

In many cases, observation of wetland hydrology indicators over a period of time at established reference locations will be sufficient to answer the relevant questions (**Figure 3**).

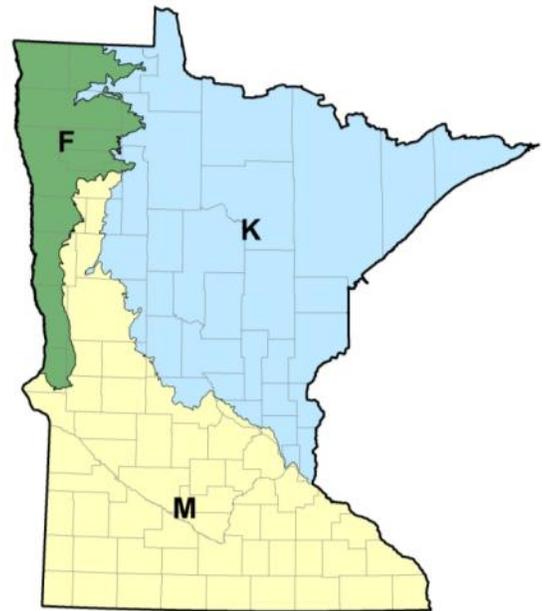
Figure 3: Hydrologic monitoring using indicators

The diagram to the right depicts a depressional wetland supplied by surface water – precipitation and runoff. Water ponds on the surface, leaving visible evidence, such as water-stained leaves, sediment deposits, etc. – hydrology indicators. In this case, observation of wetland hydrology indicators over a period of time at established reference locations will be sufficient to determine the extent of wetland hydrology.



Wetland hydrology indicators are specific to the Land Resource Regions (**Figure 4**). Although these indicators were developed for wetland determinations, many of them can be used as a surrogate for direct hydrologic monitoring. In particular, Group B indicators (water marks, water-stained leaves, drift deposits, etc.) can be used to document recent hydrologic events prior to field observations. Using these indicators in lieu of direct measurements can be justified in instances where a high degree of precision is not required and/or time and money for direct monitoring is not available.

Indicator	Land Resource Region (LRR)		
	F	M	K
Group A – Observation of Surface Water or Saturated Soils			
A1 – Surface water	P	P	P
A2 – High water table	P	P	P
A3 – Saturation	P	P	P
Group B – Evidence of Recent Inundation			
B1 – Water marks	P	P	P
B2 – Sediment deposits	P	P	P
B3 – Drift deposits	P	P	P
B4 – Algal mat or crust	P	P	P
B5 – Iron deposits	P	P	P
B6 – Surface soil cracks	S	S	S
B7 – Inundation visible on aerial imagery	P	P	P
B8 – Sparsely vegetated concave surface	S	P	P
B9 – Water-stained leaves	P	P	P
B10 – Drainage patterns	S	S	S
B11 – Salt Crust	P	–	–
B13 – Aquatic Invertebrates/ fauna	P	P	P
14 – True aquatic plants	–	P	–
B15 – Marl Deposits	–	–	P
B16 – Moss Trim Lines	–	–	S
Group C – Evidence of Current or Recent Soil Saturation			
C1 – Hydrogen sulfide odor	P	P	P
C2 – Dry-season water table	P	S	S
C3 – Oxidized rhizospheres along living roots	P/S	P	P
C4 – Presence of reduced iron	P	P	P
C6 – Recent iron reduction in tilled soils	–	P	P
C7 – Thin muck surface	P	P	P
C8 – Crayfish burrows	S	S	S
C9 – Saturation visible on aerial imagery	S	S	S
Group D – Evidence from Other Site Conditions or Data			
D1 – Stunted or stressed plants	–	S	S
D2 – Geomorphic position	S	S	S
D3 – Shallow Aquitard	–	–	S
D4 – Microtopographic Relief	–	–	S
D5 – FAC-neutral test	S	S	S
D7 – Frost-Heave Hummocks	S	–	–
D9 – Gauge or well data	–	P	–



Minnesota Land Resource Regions

F = Great Plains

M = Midwest

K = Northcentral and Northeast

Figure 4: Wetland hydrology indicators in the three Minnesota Land Resource Regions (LRRs). P = primary. S = secondary. P/S = primary (secondary in tilled areas). From Regional Supplements to the Corps of Engineers Wetland Delineation Manual.

4.2. Water level measurements in boreholes

After digging a hole, sufficient time must be allowed for water to infiltrate and to stabilize at the water-table level. The required time will vary depending upon soil texture. In general, it will take longer to equilibrate in finer textured soils than in coarser textured soils, as finer textured soils are less permeable. Also, when digging a borehole with a soil auger in clayey soils, the sides of the borehole may become smeared, blocking water inflow. It may be necessary to scarify the sides of the boring to get an accurate water level (see Appendix A).



Figure 5: Measuring water level in a borehole.



Figure 6: Water glistening on the surface of saturated soil.

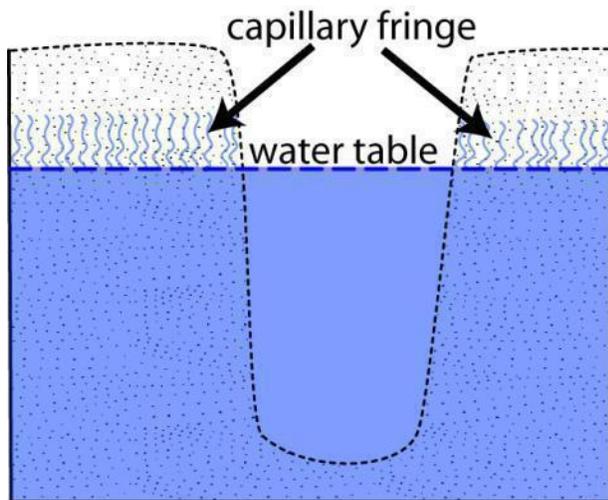


Figure 7: Water table and capillary fringe.

In some cases the water table can be determined by examining the wall of the hole and identifying the upper level at which water is seeping into the hole. Saturated soil conditions are indicated by water glistening on the surfaces and broken interior faces of soil samples (Figure 6). Saturated soil conditions may extend above the water table in a zone known as the **capillary fringe** (Figure 7). The capillary fringe can sometimes be observed in

a borehole as glistening, but the water level observed in the borehole after equilibration is always the **water table**, as it is in equilibrium with atmospheric pressure.

The same open hole should not be used to take multiple measurements over time, as the water level in the hole may change with precipitation or evaporation and may not represent the water table. Also it can be important to make sure measurements are made from the ground surface and do not include the “duff” layer of vegetation. The duff layer should be removed prior to digging the borehole.

If the project requires frequent measurements, precise water level elevations, or is in a remote location, it may be worth the additional effort to install monitoring wells. For many projects, though, periodic observation of water levels or soil saturation in boreholes or soil pits at established reference locations may be a suitable and less labor-intensive alternative to the installation of monitoring wells (**Figure 8**).

Figure 8: Wetland hydrologic monitoring using periodic water level measurements in boreholes

The decision between using periodic observation of water levels in boreholes at established reference locations versus installing monitoring wells may be a matter of logistics. Is there good access to the chosen monitoring points? Is the site not so remote that travel is a problem? Are there personnel available to visit the site regularly? Are the soil conditions such that the water level in the boreholes will equilibrate in a reasonable amount of time?

The wetland restoration site pictured to the right may be a suitable candidate for using borehole water levels for hydrologic monitoring. Access isn't a problem, nor is walking across the site. Personnel are nearby. Water levels in boreholes equilibrate relatively rapidly – in minutes rather than hours. Observation of water levels in boreholes or soil pits may be an acceptable approach.



4.3. Surface Water Level Measurements

Surface water monitoring techniques are used where there are stable access points to surface water and when there is inundation for a significant part of the growing season. These levels are often useful for estimating water table position in adjacent areas that are not inundated, or for establishing a regional base level (**Figure 9**).

Surface water level measurements include measurements of depths, lateral extent of saturation, ponding, or flooding, water level data from staff gauges, culverts, and water control structures, measured manually or using automated data loggers.

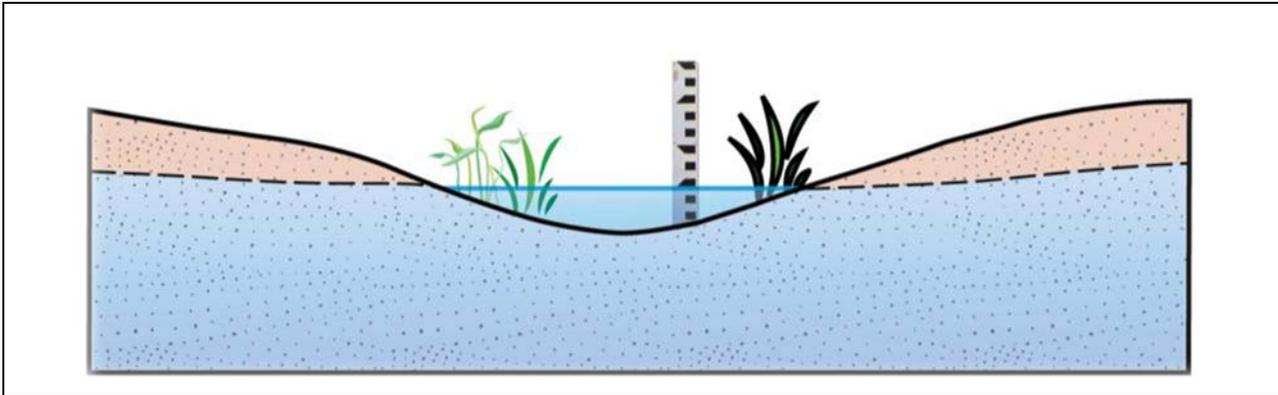


Figure 9: Surface water levels can be useful for estimating water table position in adjacent areas or for establishing a regional base level.

Staff Gauges

Staff gauges are a straightforward way to track surface water levels (**Figure 10**). They are sometimes overlooked tools that can provide valuable information for sites where there is open water. Many types of staff gauges are available commercially. These are typically attached to a fencepost that has been driven into the ground, or to some other stable structure. Staff gauges can be used for reference in water control structures or stilling wells and can be coupled with water level data loggers. **Appendix C** gives specifications for constructing and installing a staff gauge.

Water Control Structures

Some wetlands have water control structures, culverts, or other stable access points to surface water (**Figure 11**). These provide a secure, fixed location for monitoring surface water levels. They can be fitted with a staff gauge or data logger, and are especially useful as monitoring points if they have a reference point with a surveyed elevation.

Stilling wells

Constructed stilling wells, either freestanding or with a staff gauge or water control structure, provide a stable location for surface water level monitoring (**Figures 11, 12**). A stilling well is a pipe or chamber connected by small openings to the main water surface being measured. It serves to dampen transient fluctuations in water level, such as produced by waves or turbulence, allowing measurement of the major fluctuations.



Figure 10: Staff Gauge



Figure 11: Water control structure with stilling well and data logger.

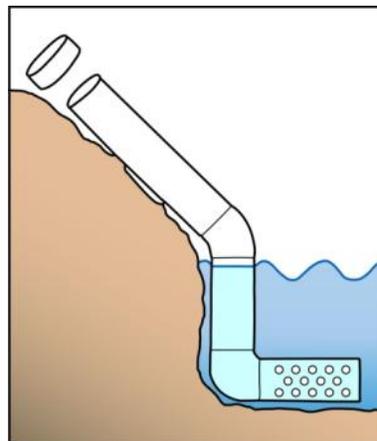
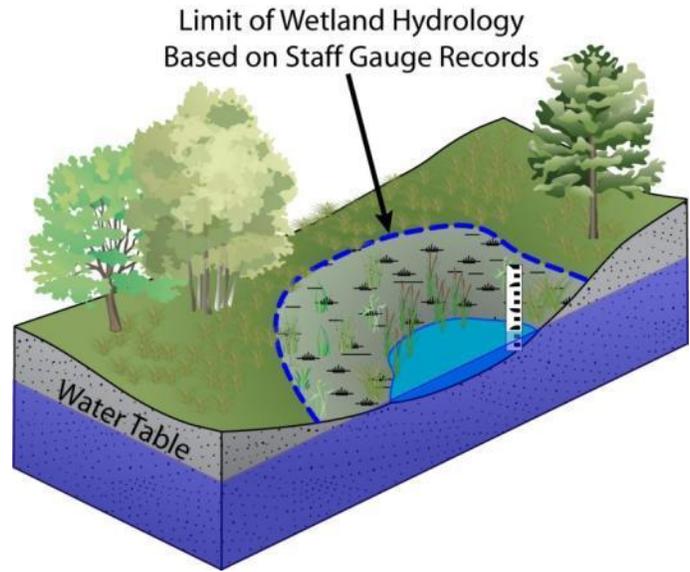


Figure 12: Stilling wells

Figure 13: Example of using surface water level measurements to monitor wetland hydrology.

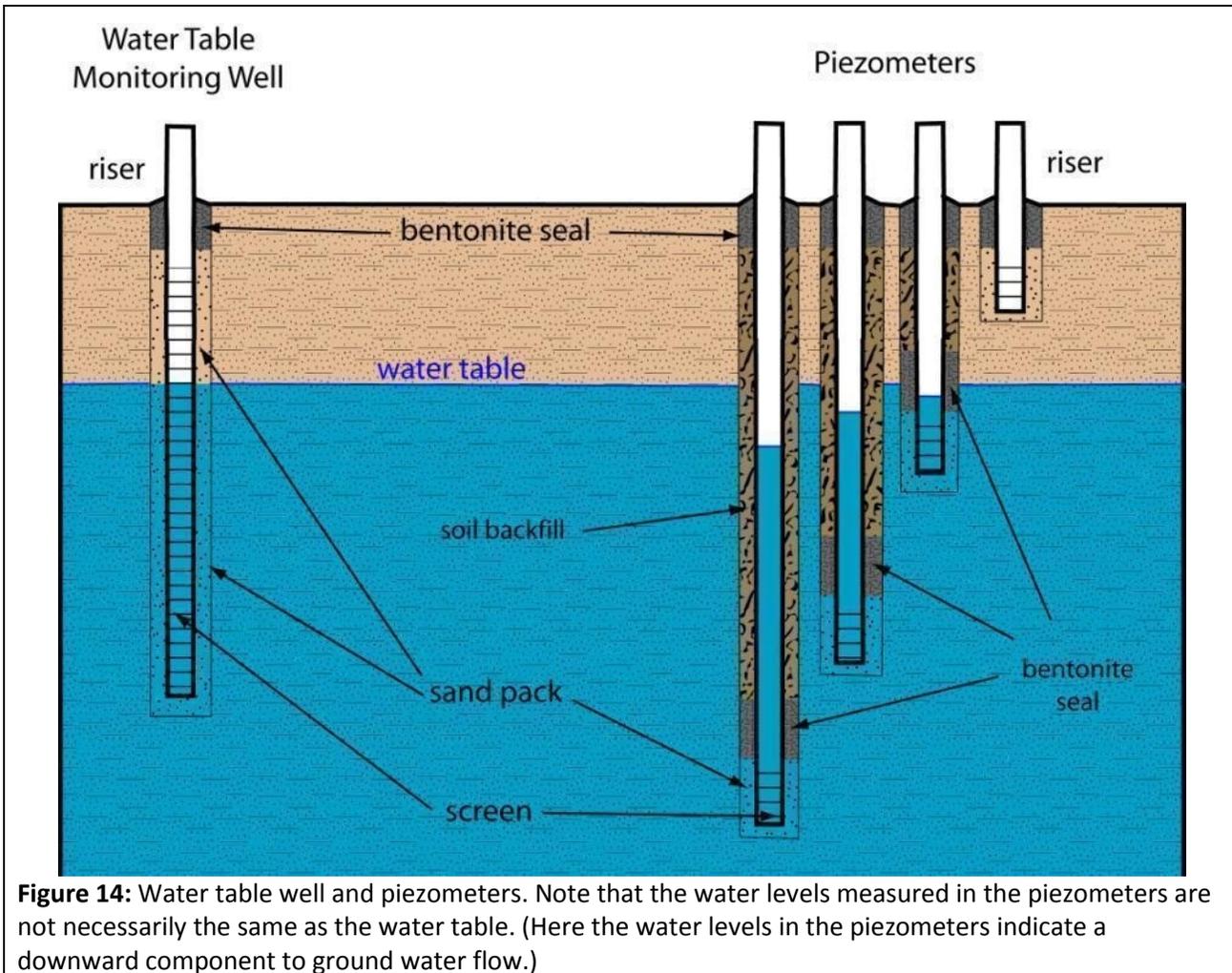
The diagram to the right depicts a ground-water-fed depressional wetland. Water levels in the wetland are controlled mainly by fluctuations in the regional water table – the wetland is “connected” to ground water. If there is good topography data, such as a topographic survey or detailed contour map, this information, together with periodic staff gauge readings, will be sufficient to determine the extent of wetland hydrology.



4.4. Water Table Monitoring Wells and Piezometers

Water-table monitoring wells and **piezometers** are pipes set vertically in the ground. The lower part (“**screen**” or “**screened interval**”) is a slotted well screen or section of perforated pipe. The upper part (“**riser**”) is not perforated.

In this document, we will use the terms “water table monitoring well” and “piezometer” in the context that they are used by soil scientists and wetland scientists. When interacting with those from other backgrounds, or when consulting the literature of the various disciplines that use wells, be aware that terminology varies considerably.



Water-table monitoring wells (also referred to as “**water-table wells**” or simply “**monitoring wells**”) are screened over a longer length – often from just below ground surface to the bottom of the pipe (**Figure 14** - left). They are designed to capture the water table within the screened interval. The water level inside a water-table monitoring well is the elevation of the surface of the groundwater rather than a pressure head at some point deeper than the water-table surface.

Piezometers allow water to enter at the bottom of the pipe only, or have a very small screened interval at the bottom of the pipe (**Figure 14** – right). They are usually installed with a seal above the screened interval so water cannot flow down the outside of the pipe. The water level in a piezometer represents the pressure “head” or potential at the screen, and may be different than the water table level in an adjacent well if there is a vertical component to ground water flow.

Terminology

The terms **monitoring well** and **piezometer** mean different things to different people, depending on line of work or professional background. Other professionals may not use the terms in the same way as soil scientists or wetland scientists, and this can lead to confusion. Both piezometers and water-table monitoring wells are “monitoring wells” in the larger sense – differing only in the screen length. For geotechnical engineers and those doing ground water quality monitoring, a “monitoring well” is a well designed to produce water samples for chemical analysis. The screened interval is designed based on the desired depth of the water sample. In this sense, a “piezometer” is a type of well used for water level measurements only.

Legal Definitions

Minnesota Statutes (1031.005) define a “monitoring well” as “an excavation ... constructed to extract groundwater for physical, chemical, or biological testing”. Minnesota Department of Health (MDH) rules (4725.0100) include “piezometer” in the category of “environmental borehole” - an excavation designed to measure physical and chemical properties “without extracting water.” However the definition of “environmental borehole” requires the excavation to “... penetrate a confining layer or be greater than 25 feet in depth ...” The rules also define a “confining layer” as a layer at least 10 feet in thickness that restricts vertical water movement.

For legal purposes in Minnesota, the shallow devices we routinely call “monitoring wells” and “piezometers” are both defined as “piezometers”, and are not regulated by statute or rule. It is useful to be aware of your audience when using these terms!

Using wells or piezometers

Wells and/or piezometers provide longer-term fixed locations for direct ground water level measurements. They are used to answer questions about the depth, duration, and frequency of near-surface saturation, water table fluctuations, or ground-water movement – using direct measurement. Some examples of reasons to install wells or piezometers include:

- more specific information is needed than can be provided by hydrology indicators
- surface water is not present or is not persistent
- repeated borehole water level measurements are impractical
- site is remote or access is poor
- the *Technical Criterion for Wetland Hydrology* is being used
- information on ground-water flow direction is needed

Appendices A and B provide supplemental information on well installation.

Wells

Water-table wells are the appropriate tool for measuring saturation **depth** or **water table position**. Unless there is a need to determine flow direction or recharge/discharge conditions, water table wells are chosen to answer many of the questions listed in Figure 1.

If the objective is to determine if wetland hydrology is present at a particular point, or to determine the duration and frequency of near-surface saturation, and if there is no need to track water levels when they fall below the critical levels for wetland hydrology, then **shallow water table monitoring wells** of the type described in **U.S. Army Corps of Engineers (2005)** and **Sprecher (2000)** are the tool of choice. If there is a need to track water levels when they are below the critical depth for wetland hydrology, such as for tracking the progression of a wetland restoration, deeper wells are used instead of, or in addition to, the shallow wells (**Figure 15**).

Deeper wells are usually installed deep enough to remain in contact with the water table throughout the year. Data from deeper wells can alert those taking measurements to a rising water table, perhaps triggering more frequent or detailed measurements of near-surface saturation.

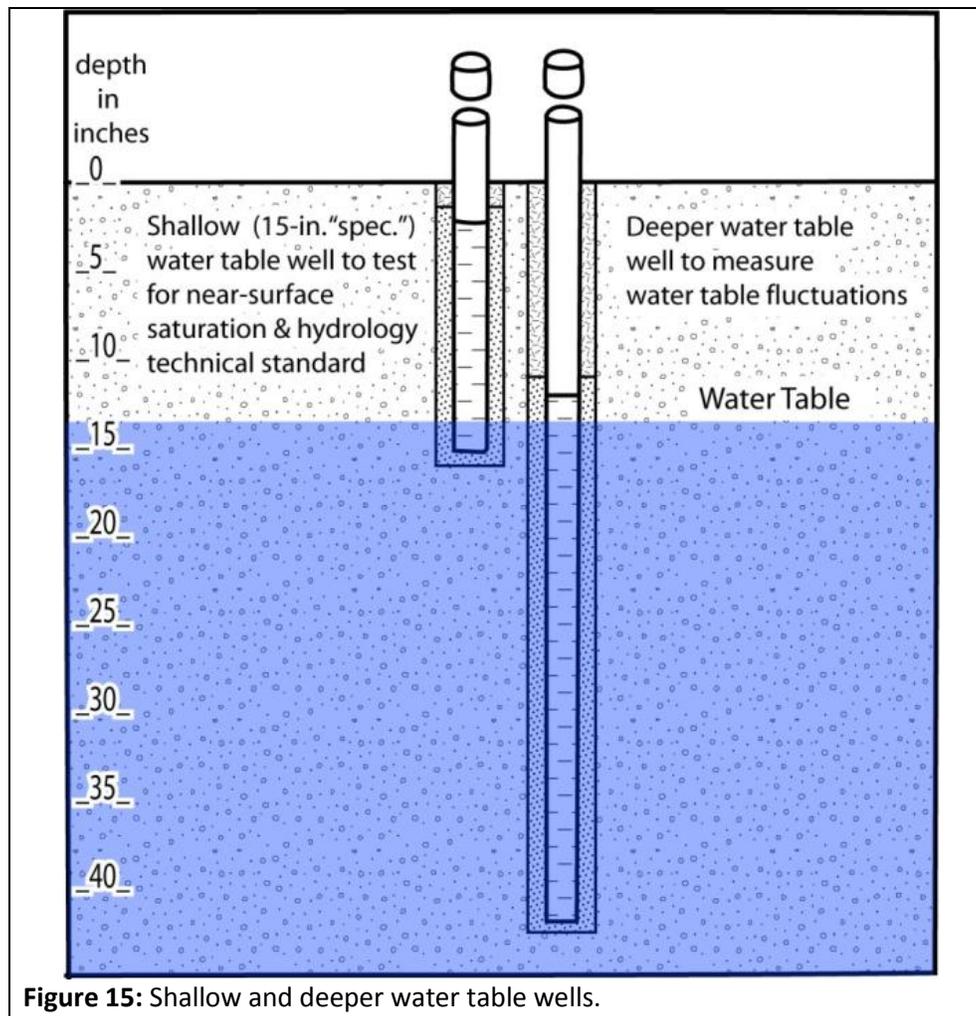


Figure 15: Shallow and deeper water table wells.

Shallow monitoring wells are often the appropriate monitoring strategy in wet meadow or wet prairie settings (**Figure 16**), or where it is necessary to determine the exact nature of a ditch's lateral effect (**Figure 17**).

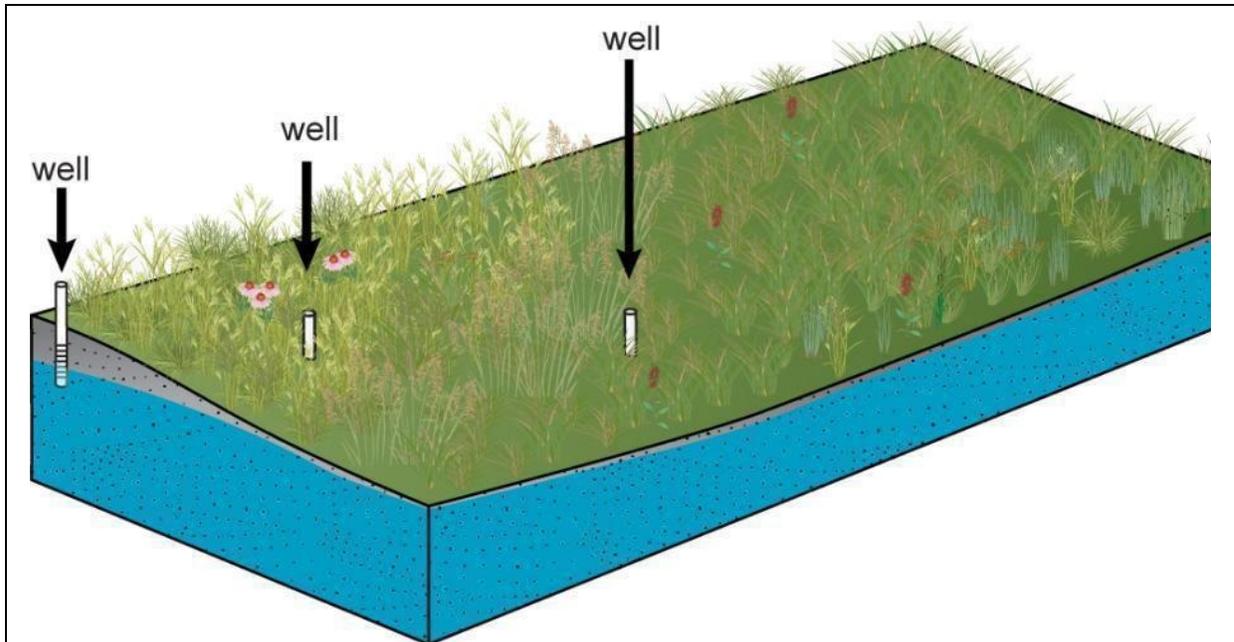


Figure 16: Monitoring using a transect of shallow wells.

The above diagram depicts a wet meadow or wet prairie to the right, with upland to the left. We suspect the wetland portion has a seasonal high water table at the surface to 12 inches below the surface during the early part of the growing season. We wish to define the hydrologic regime and to verify the extent of wetland hydrology with monitoring. The site is remote and access is difficult. The soils are relatively impermeable, so borehole water levels take a long time to equilibrate. The chosen monitoring solution is a transect of shallow monitoring wells, preferably with water level data loggers installed.

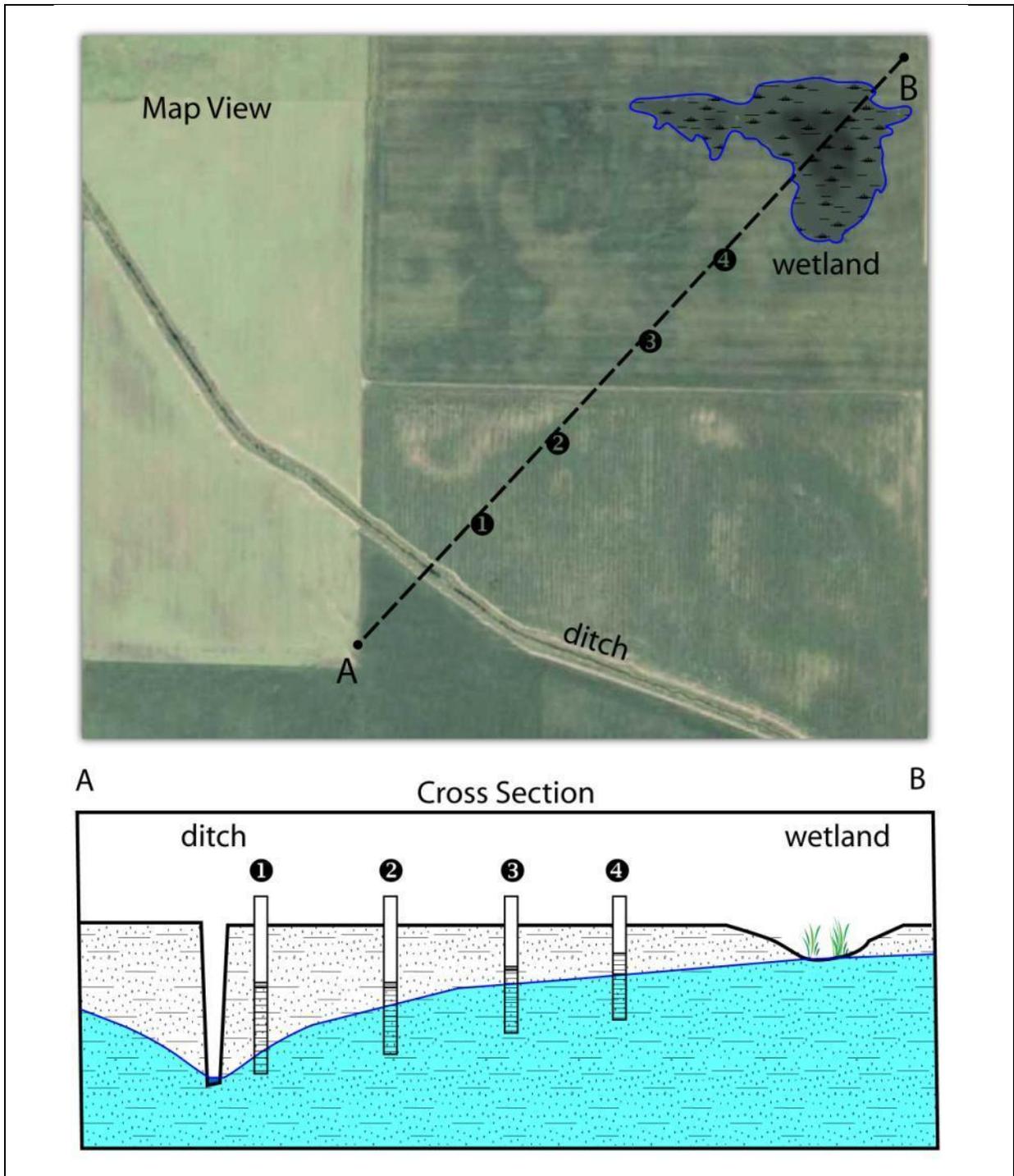


Figure 17: Monitoring the lateral effect of a ditch or drain using a transect of wells

The above diagram depicts a situation in which a ditch is suspected of impacting a wetland. All the involved parties would like to know the exact nature of the ditch’s lateral effect. The agreed-upon monitoring plan involves a transect of monitoring wells perpendicular to the ditch and extending towards the wetland. The wells should be deep enough to extend below the water table under all wetness conditions.

Piezometers

Piezometers are used where depth-specific head measurements are required – usually to characterize the vertical component of ground water flow and to determine recharge and discharge conditions (**Figure 18**). They are also used in determinations and delineations where there is a perched water table, being installed within and below the impermeable layer. They are not typically used in standard wetland investigations where characterizing near-surface saturation is most important.

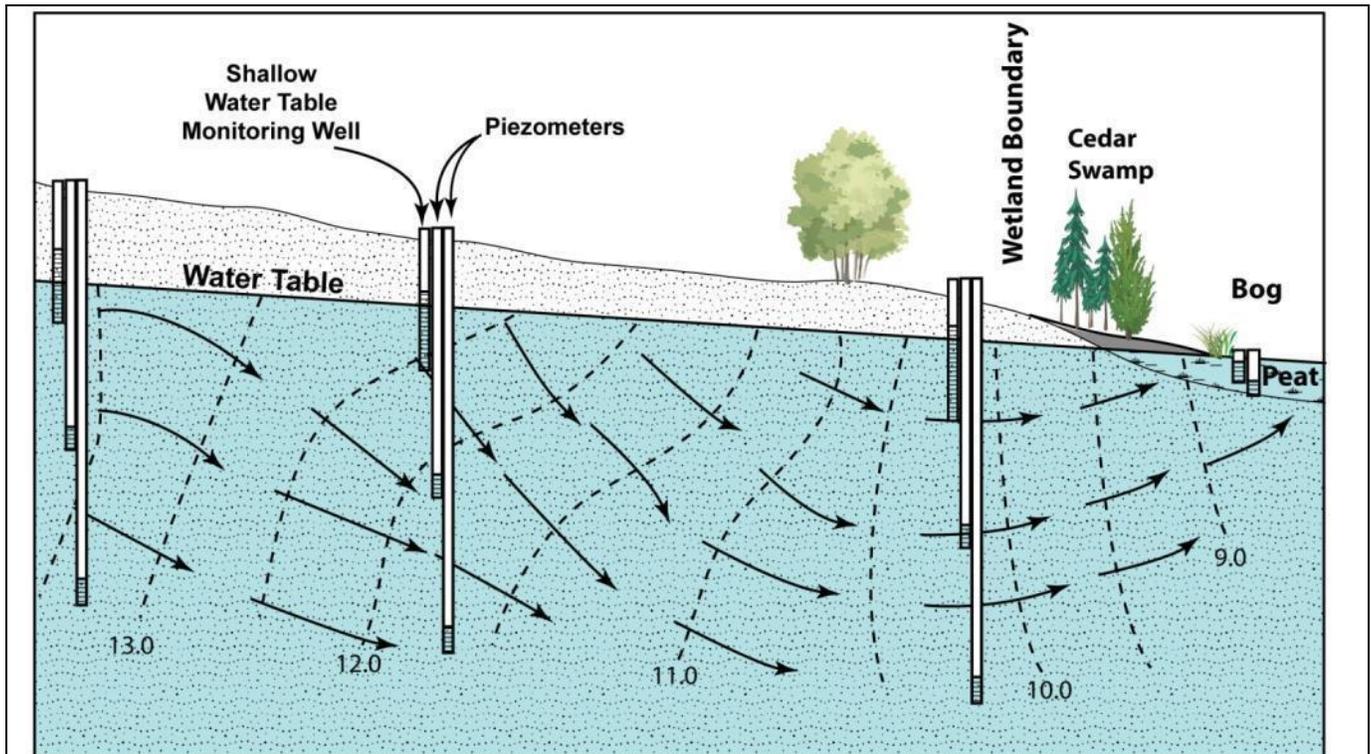


Figure 18: An example transect of shallow monitoring well/ piezometer “nests” as might be installed to investigate ground water flow at a wetland margin. The water levels measured in the piezometers give the hydrostatic pressure or “head” at specific depths. These can be used to construct a “flow net”. Contouring the head data yields lines of equal head (“equipotential” lines – dashed lines in figure), from which localized flow directions can be determined (arrows).

5. Planning a Hydrologic Monitoring Project

Considerations

The nature of the questions, as well as site characteristics and other factors, will determine the monitoring approach and techniques to be used. Planning a monitoring strategy will require considering the following:

- What is the question?
- Hydrology performance criteria
- Site characteristics
 - Landscape position and topography
 - Soil characteristics (texture, permeability, stratigraphy)
 - Hydrologic setting (surface water present? Water table position? Alteration? Inlets & Outlets?)
 - Vegetation (high transpiration rates?)
- Availability of pre-existing data
- Frequency of observations required to answer questions
- Level of accuracy and precision required
- Special circumstances (Controversial, contentious, or sensitive site?)
- Site access and remoteness
- Potential for vandalism
- Available money and time

Agree on reasons, questions, and objectives

The first and most important part of planning for wetland hydrologic monitoring is to agree on the reasons for monitoring and on what questions are intended to be addressed (Figure 1). This will largely determine the approach to monitoring and will ensure that the resulting data are most useful. All subsequent decisions, such as monitoring methods, depth, location, and number of installations, frequency of monitoring, and length of monitoring period, will flow from this agreement. **It is very important that all involved parties agree on the reasons for monitoring, the questions to be answered, and the objectives.**

Hydrology performance criteria

If the reason for monitoring is to evaluate the success of a wetland restoration or creation effort, monitoring will revolve around agreed-upon hydrology performance measures established as part of a restoration or mitigation banking plan. These typically are thresholds for depth, duration, and frequency of saturation, or water level elevations that define desired outcomes. In these cases, monitoring will be designed specifically to measure whether planned outcomes have been achieved.

Choose Monitoring Methods

Many factors affect the choice of monitoring method among the various levels of effort (**Figure 2**). The choice should balance the requirements for repeatability, accuracy, and length of monitoring against the time and money available. Are wells really required? Or can the questions be answered via indicators, surface water measurements, or boreholes? Is the site remote or difficult to access? If so, installing wells with data loggers may in fact be more cost effective than manual monitoring when mobilization costs are considered.

Number of Monitoring Locations

The necessary number of wells or other instruments or locations will be determined by:

- objectives of the study,
- wetland size,
- wetland type(s),
- **site complexity:** topographic relief, vegetative communities, soil types, disturbance,
- ability and willingness to use professional judgment, landscape position, and topography.

Projects involving larger and more complex wetlands, and projects with more demanding questions being asked, will require more wells or other instruments in more locations. Greater use of professional judgment, landscape position, and topography to interpolate between measurement locations can reduce the number of locations.

Depths of Measurements

The depth of hydrologic monitoring (well or piezometer depths, depths of boreholes) will depend on:

- objectives of the study/ questions to be answered:
 - Is there a desire to track water levels when they fall below critical levels?
 - Is there a need to determine recharge/ discharge conditions?
- An understanding of soils across the site:
 - Texture and permeability.
 - Presence of restrictive layers.

If the objective is to determine if wetland hydrology is present at a particular point and if there is no need to track water levels when they fall below the critical levels for wetland hydrology, then soil borings or shallow monitoring wells will be sufficient. To track water levels below the critical depth for wetland hydrology, deeper borings or wells may be necessary (**Figure 15**).

Shallow water table wells provide the most reliable confirmation of saturation in the critical upper 12 inches. The difference between measurements in shallow and deeper water table wells depends on soil conditions and the vertical component of seepage. It has been our experience that the measurements in shallow and deeper water table wells are not significantly different where soils are of relatively uniform texture and where no restrictive layers are penetrated. In these cases, professional judgment may permit eliminating the shallow well of a pair and relying on one, deeper water table well to track water table fluctuations.

Location of Measurements

As with all of these planning decisions, the location of wells or other monitoring measurements will depend on the objectives of the investigation and site characteristics. If the objective is to determine whether wetland hydrology is present at a particular point, a single well or observation point may be sufficient. Multiple locations may be needed on a complex site. Site conditions (e.g. topographic relief, restrictive soil layers) will influence decisions on monitoring locations and depths. Landscape positions most likely to meet wetland hydrology standards (e.g., depressions, floodplains, fringes of lakes and ponds, toes of slopes) should be considered for monitoring.

If the objective is wetland delineation or boundary determination based on water level measurements, then measurements along transects perpendicular to the expected wetland boundary are called for (Figure 12). The number and spacing of measurements along each transect will depend on:

- topographic gradient,
- availability and precision of topographic survey information,
- landscape position,
- proximity to hydrologic alterations (e.g., ditches),
- changes in soil characteristics,
- changes in vegetation,
- willingness to use professional judgment.

Using professional Judgment and Landscape Position in Wetland Monitoring

The use of **landscape position** and **professional judgment** can make for much more efficient hydrologic monitoring. Consider the example in **Figure 19** of a set of monitoring transects perpendicular to an expected wetland boundary. The transects are designed to confirm the wetland boundary based on ground water level measurements. If the well data are the only source of information used to determine the wetland hydrology boundary, then a setup with multiple transects such as pictured in **Figure 19** would be called for.

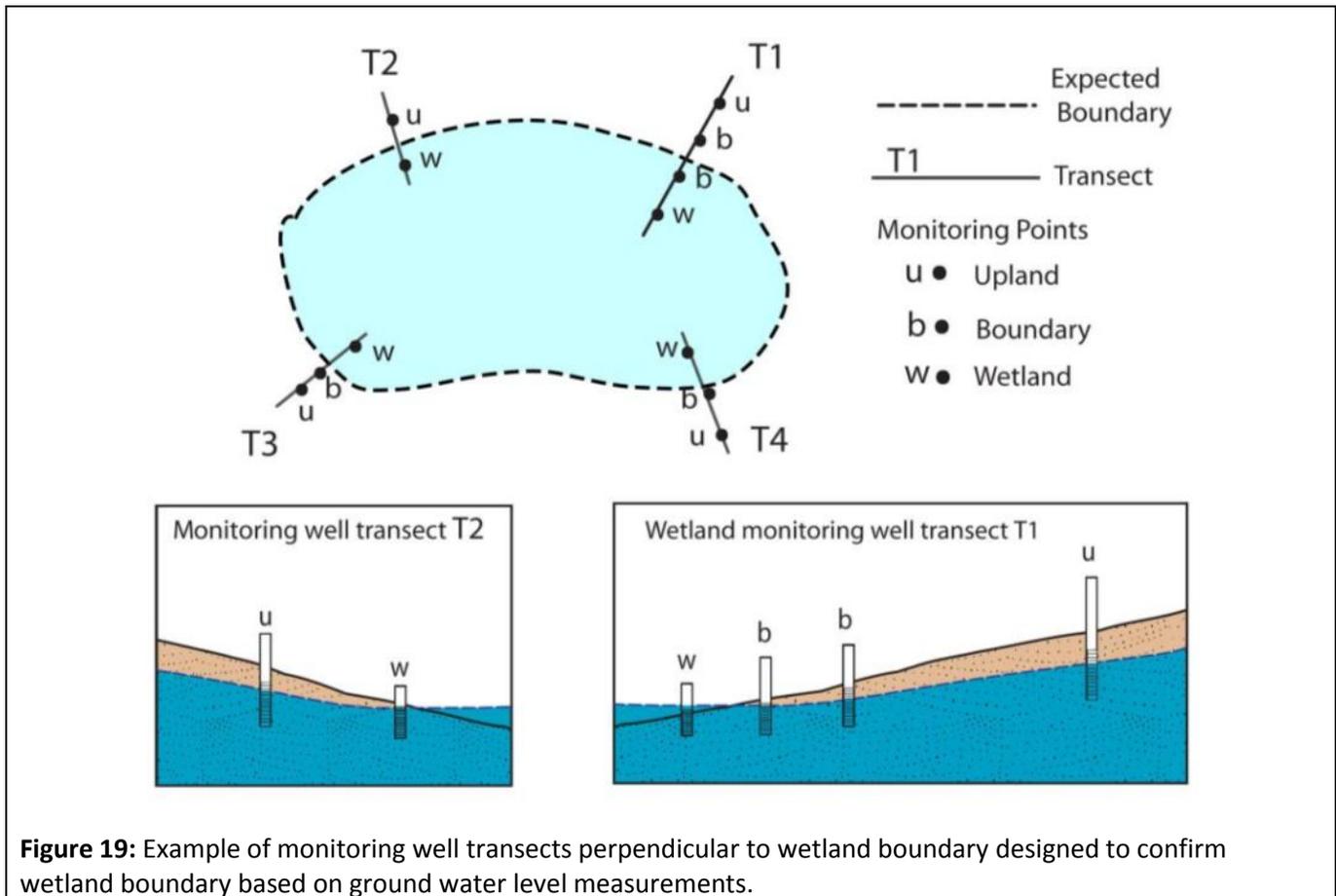
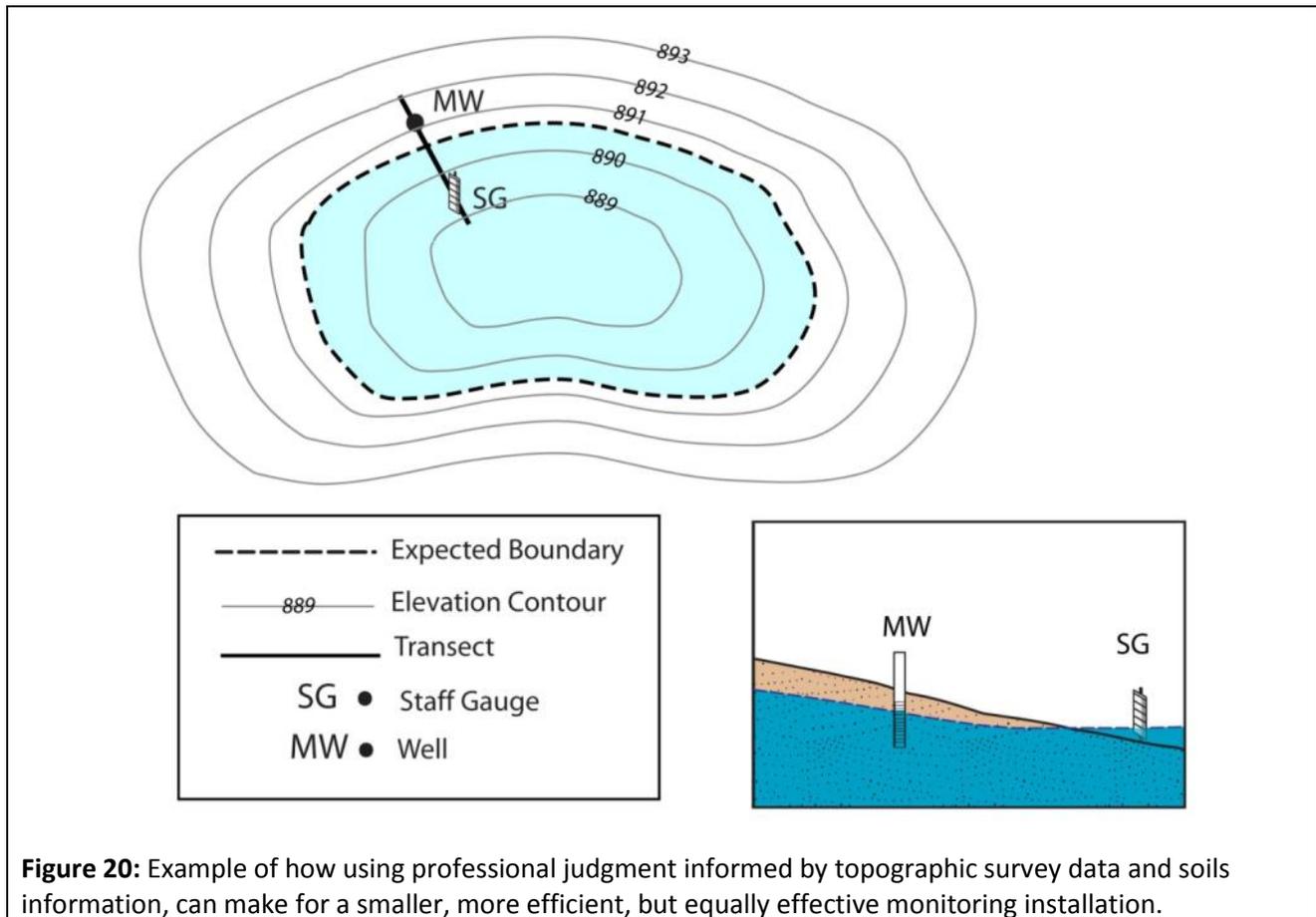


Figure 19: Example of monitoring well transects perpendicular to wetland boundary designed to confirm wetland boundary based on ground water level measurements.

In **Figure 20**, the same expected wetland boundary is pictured. However in this case there is a topographic survey available, as well as soils information from field visits. Based on the landscape and the soils, we are reasonably confident that surface water present in the wetland basin reflects the ground water level, and that

the water table in the vicinity of the expected boundary is relatively flat and at about the same elevation. The monitoring plan pictured below used professional judgment, informed by knowledge of topography and soils, to reduce the number of monitoring points to one well and one staff gauge (**Figure 20**). Based on this professional judgment, we are reasonably confident that the water level data can be extrapolated to the entire basin. This kind of planning can help make more efficient use of limited staff and equipment resources, while not compromising on providing answers to the questions being asked.



Installation

The references cited in the beginning of this document give detailed information on construction of monitoring wells and piezometers for wetland hydrologic monitoring ([Sprecher, S. W., 2000](#); [U.S. Army Corps of Engineers, 2005](#); [Noble, C., 2006](#); [Sprecher, S.W., 2008](#)). **Appendices A** and **B** provide supplemental information on well installation. **Appendix C** gives specifications for constructing and installing a staff gauge of the type used by the DNR lake level monitoring program.

Documentation

Documentation is critically important for putting hydrologic monitoring in place. It applies to all of the hydrologic monitoring methods listed in Section 3 above. Documentation supplies the context necessary to interpret the data; its lack can invalidate measurements. Especially in the case of monitoring wells,

documentation of well installation details and soil conditions is essential for valid interpretation of monitoring well data! Figure 21 summarizes the documentation required for the different hydrologic monitoring methods.

Method	Documentation (● = required; ○ = useful but not necessarily required)
Observation of Wetland Hydrology Indicators	For each location where indicators observed: <ul style="list-style-type: none"> ● List of indicators ● Date indicator observed ● Mapped location or GPS coordinates
Water level measurements in boreholes	For each location where borehole water level measured: <ul style="list-style-type: none"> ● Date and time of measurement ● Soil profile description ● Depth of borehole ● What is being measured (e.g. depth to free water surface, glistening or saturation) ● Reference point (e.g. ground surface) ● Mapped location or GPS coordinates ○ Elevation (approximate or surveyed) of ground surface or other reference point
Manual surface water level measurements	<ul style="list-style-type: none"> ● Date and time of measurement ● Type of measurement (e.g. water depth at a point, water level in control structure, level in stilling well) ● Reference point (e.g. ground surface, top of control structure, absolute elevation) ○ Elevation of reference point
Staff Guages	<ul style="list-style-type: none"> ● Date and time of measurement ● Installation information ● Position of reference point (e.g. “gage 0.0 at ground surface”) ● Surveyed elevation of reference point
Surface water levels-automated measurements (data loggers)	Same as manual surface water measurements (above) as well as: <ul style="list-style-type: none"> ● Data logger calibration information ● Data logger reading at same time as manual reading
Monitoring wells - manual measurements	<ul style="list-style-type: none"> ● Date and time of measurement ● Well construction details: <ul style="list-style-type: none"> ● depth, diameter ● materials ● screened interval ● riser height above ground surface ○ top of riser elevation ● Soil profile description ● Reference point (e.g. top of casing) ○ Elevation of reference point
Monitoring wells - automated measurements (data loggers)	Same as manual well measurements (above) as well as: <ul style="list-style-type: none"> ● Data logger calibration information ● Data logger reading at same time as manual reading

Figure 21: Documentation required for the different hydrologic monitoring methods.

Appendix A

Installing Monitoring Wells for Wetland Hydrologic Monitoring

The references cited in the beginning of this document give detailed information on construction of monitoring wells and piezometers for wetland hydrologic monitoring ([Sprecher, S. W., 2000](#); [U.S. Army Corps of Engineers, 2005](#); [Noble, C., 2006](#); [Sprecher, S.W., 2008](#)).

Included here is information paraphrased from these references (*italicized*), along with additional illustrations and comments based on BWSR staff experience.

MATERIALS

Well Casing

Schedule 40, 1-inch inside diameter PVC pipe is recommended. The diameter of the pipe allows sufficient room for hand measurement of water levels while minimizing well volume and maximizing responsiveness to water-table changes. The small diameter also minimizes auger hole diameter, volume of the filter pack, and the quantity of bentonite needed to seal the bore hole. If required, larger diameter pipe can be substituted. Well stock larger than 2 inches in diameter should be avoided.

We have taken to using 1¼ -inch pipe. It accommodates data loggers, while retaining the benefits of smaller casing diameter mentioned in the official references. Schedule 40 PVC pipe and associated couplings, adapters, and end caps are readily available in hardware stores.

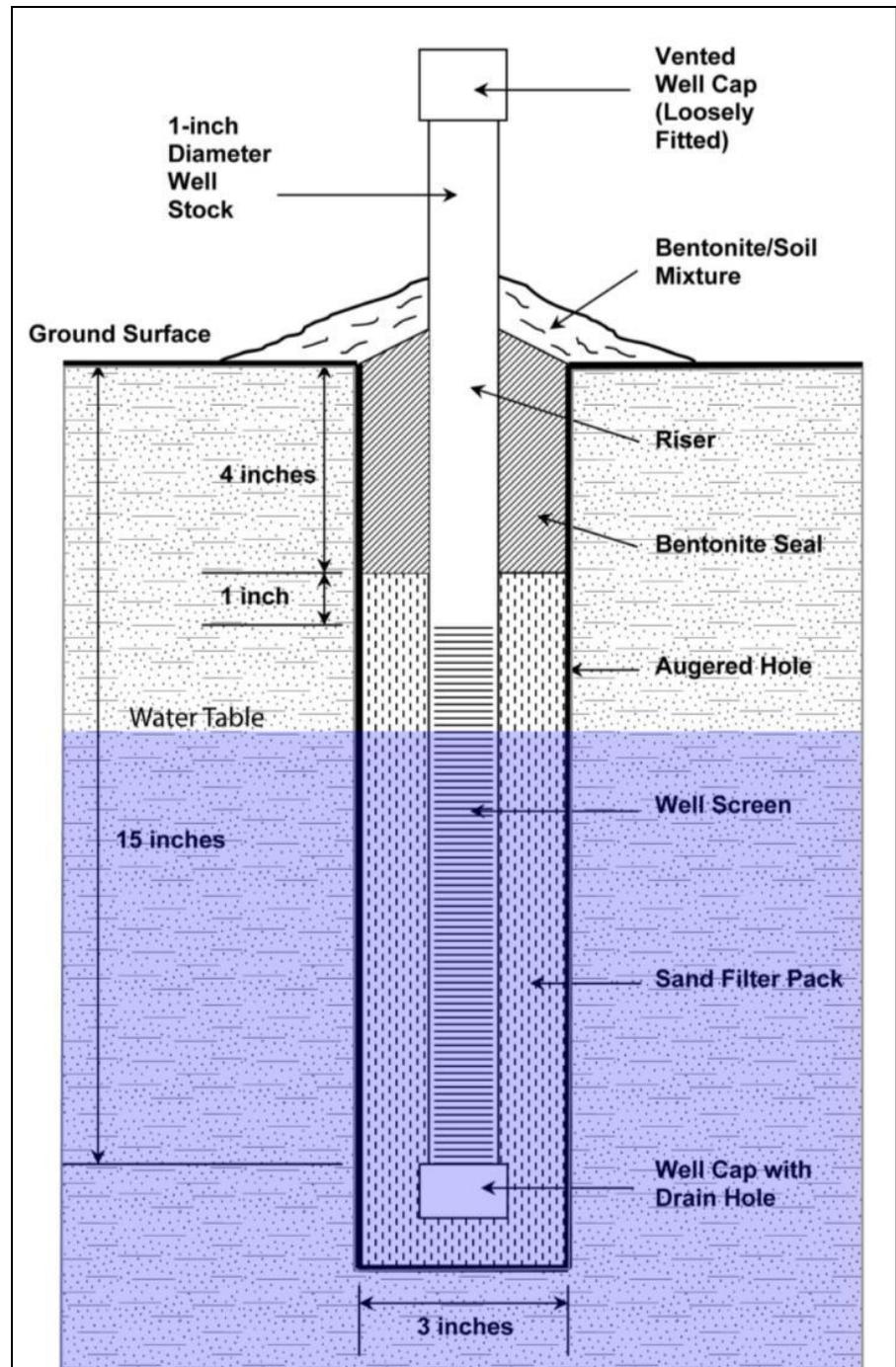


Figure A1:

US Army Corps of Engineers Corps of Engineers specification for standard 15-inch shallow monitoring well ([U.S. Army Corps of Engineers, 2005](#)).

Well Screen and Bottom Cap

Recommended slot opening and slot spacing for the well screen are 0.010 inch and 0.125 inch, respectively. Hand-slotted or drilled well screens should not be used.

This is referred to as “10-slot” screen. PVC 10-slot screen is a specialty item – not readily available in your average hardware store. It is available in Minnesota from suppliers such as the Goodin Company (www.goodinco.com) or directly from manufacturers. Do an internet search on “PVC monitoring well screen”.

Hardware stores often carry 1¼-inch galvanized “sand point” well screens. These are designed for driving into place and are much more expensive than PVC well screens. They can be used to construct driven wells in sand or organic soil, but are “over-engineered” (hence over-priced) for the very shallow wells required in wetland hydrologic monitoring.

One problem with the use of commercial well screen for very shallow monitoring wells is that there often is a length of un-slotted pipe and joint or threads below the screen... This extra length provides a reservoir where water can remain trapped after the outside groundwater has dropped, resulting in the potential of misleading or incorrect readings during water-table drawdown. To avoid this problem, commercial well screen should be cut to the desired length within the slotted portion of the pipe. A PVC cap should be glued at the bottom of the screen and a small drain hole should be drilled in the bottom cap.



Figure A2: 1¼ - inch PVC monitoring well screen with bottom cap.

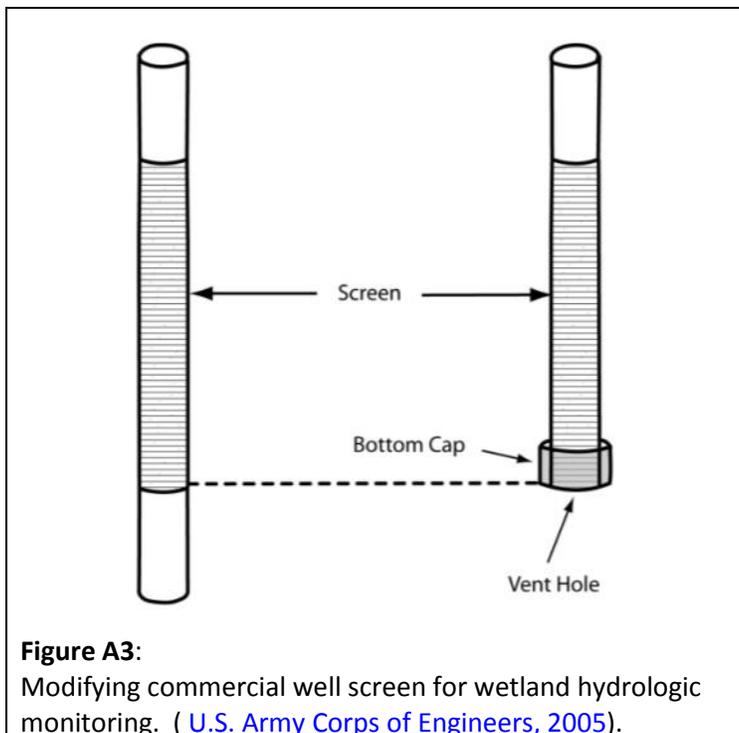


Figure A3: Modifying commercial well screen for wetland hydrologic monitoring. ([U.S. Army Corps of Engineers, 2005](#)).

The vent hole in the bottom cap is extremely important! Without the vent hole the bottom cap can act as a reservoir where water can remain after water levels drop, causing misleading or incorrect readings.

Riser

The riser is the un-slotted PVC pipe that extends from the top of the well screen to above the ground surface (**Figure A1**). The riser should extend far enough above the ground to allow easy access. A longer riser may be needed on inundated sites or where automatic recording devices are used.

We have learned the hard way that unprotected PVC riser above the ground surface can get melted or burned where prescribed burning is used as a vegetation management tool. If burning will occur, we have used two preventative measures to avoid damage to monitoring wells: **1)** Use an outer protective casing or other housing (see next section); or **2)** Use metal riser pipe. Sections of galvanized steel pipe threaded on either end (“nipples”) are readily available in 1-inch and 1 ¼ - inch diameters, and in various length, at plumbing sections of most hardware stores. These can be attached to PVC well screens with adaptors also readily available.

Shallow wells are subject to frost heave between monitoring seasons. The distance that the riser extends above the ground surface (the “stick-up”) should be measured at the beginning of the monitoring season if the well has over-wintered.

A note of caution: in deeper wells, couplings or adaptors too close to the surface can result in breakage by frost action. Deeper wells are more firmly anchored. Couplings near the surface are more susceptible to frost heave than smooth pipe. The combination of a firmly anchored well and the increased “grab” of frost can result in breakage rather than simply frost heave.

Well Top Cap and Surface Completion

A well cap is required to protect the top of the well from contamination and rainfall. Caps should be attached loosely so they can be removed easily without disturbing the well. Tight-fitting caps, either threaded or unthreaded, should be avoided because they may seize to the riser. A suitable well cap can be constructed from a short length of PVC pipe of a larger diameter than the riser, with a glued PVC cap at one end (**Figure A4**). The constructed well cap can be attached loosely to the riser by drilling a hole through both the cap and the riser and connecting the two with a bolt. The cap should be vented to allow equilibration of air pressure inside and outside of the well.

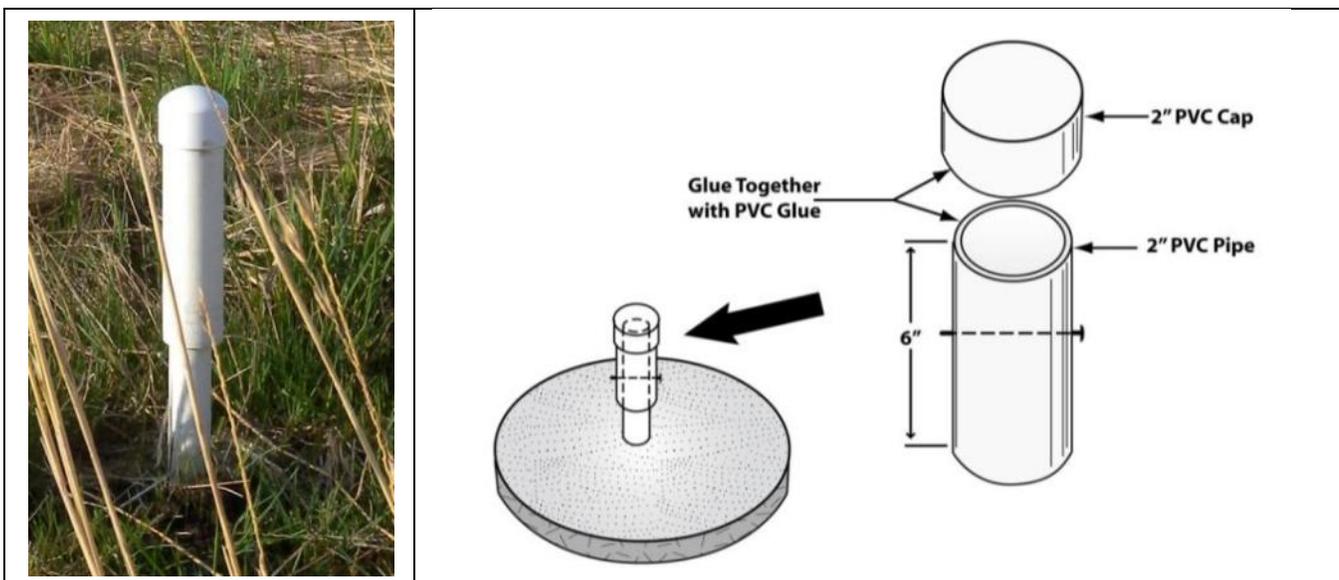


Figure A4: Homemade cap made from oversize PVC pipe and end cap.



Figure A5 Left: steel protective casing and locking cap. Center: Improvised protective housing for water level data logger. Right: Protection posts.

In cases where vandalism is a concern, or where there is the potential for damage from management activities such as prescribed burning or mowing, there may be a need for some sort of surface protection. One approach is a protective housing such as an oversized steel pipe or stovepipe. We have crafted an economical improvised protective housing from a metal garbage can (**Figure A5**). These can be fitted with locks if there is concern about the possibility of vandalism. Locking well caps are also available commercially. Most commercially available protective well casings are designed for much deeper wells and would obstruct the screened interval of the very shallow wells used in wetland monitoring. We have used surplus steel pipe from scrap yards cut into smaller (~2 ft) sections.

If there is a risk of a well being run over by vehicles or equipment, protection posts should be installed – for example driven signposts, angle irons, or wooden fenceposts. These can also help in locating the well in high vegetation.

Filter Pack (“Sand Pack”)

A filter pack is placed around the well screen to remove fine particles and provide a zone of high hydraulic conductivity that promotes water movement toward the well (Figure A1). Filter packs can be classified into two major categories, natural and artificial. Natural packs are created by manually repacking any excavated soil around the well screen, ensuring that large voids are absent. Natural packs are recommended in coarse-textured, sandy soils. In fine-textured soils, an artificial pack should be used. See Table A1 for recommendations on the use of filter packs for soils of different textures.

Commercially available washed sand is recommended for use as artificial pack material and is usually well-sorted, well-rounded, clean, chemically inert, and free of all fine-grained clays, particles, and organic material.

Sand that passes a 20-mesh screen and is retained by a 40-mesh screen (“20-40 sand”) is recommended for well screen with 0.010-inch slots (“10-slot screen”). Washed, graded sand is available from blasting sand or water well supply stores. In a pinch, any sand that does not pass the well screen slots can be used. We have used “play sand” sold in hardware stores, or road sand from local highway departments.

Geotextile Fabric Wrap

In some cases it is advisable to wrap the screen in geotextile fabric in order to prevent clogging. These include:

- Wells in organic soils.
- Wells in very fine-grained soils with high water table where boring creates a messy slurry.

Landscaping fabric available in most hardware or garden stores works well (Figure A6).

Table A1 USDA Soil Texture Classes & Recommendations for Sand Filter Packs	
USDA Soil Texture	Sand Pack
Muck, Mucky Peat, Peat	None
Coarse Sand	None
Medium Sand	None
Fine Sand	None
Loamy Sand	None
Sandy Loam	Recommended
Loam	Recommended
Silt Loam	Recommended
Silt	Recommended
Sandy Clay Loam	Required
Silty Clay Loam	Required
Clay Loam	Required
Sandy Clay	Required
Silty Clay	Required
Clay	Required

From [Sprecher, 2000](#)



Figure A6: Well screen wrapped in geotextile fabric.

Bentonite Seal

Bentonite is a type of clay that absorbs large quantities of water and swells when wetted. It is used in well installation to form a tight seal around the riser to prevent water from running down the outside of the pipe to the well screen. With this protective plug, only groundwater enters the slotted well screen.

When installing a monitoring well, a layer of bentonite should be placed around the riser immediately at and below the ground surface (**Figure A1**). This ring of bentonite rests directly on top of the filter pack around the well screen. Above the bentonite seal, additional bentonite mixed with natural soil material should be mounded slightly and shaped to slope away from the riser so that surface water will run away from the pipe rather than pond around it at the ground surface.

Bentonite is available from well supply companies in powder, pellet, chip, or granular form. The chip or granular forms are easiest to use (**Figure A7**). They can be dropped directly down the annular space above the sand filter pack. If this zone is saturated, the bentonite will absorb water in place, swell tight, and seal off the sand filter from above. If the bentonite is installed into a dry annular space, it should be packed and then water added so the bentonite will swell.



Figure A7: Granular bentonite.

INSTALLATION

Methods

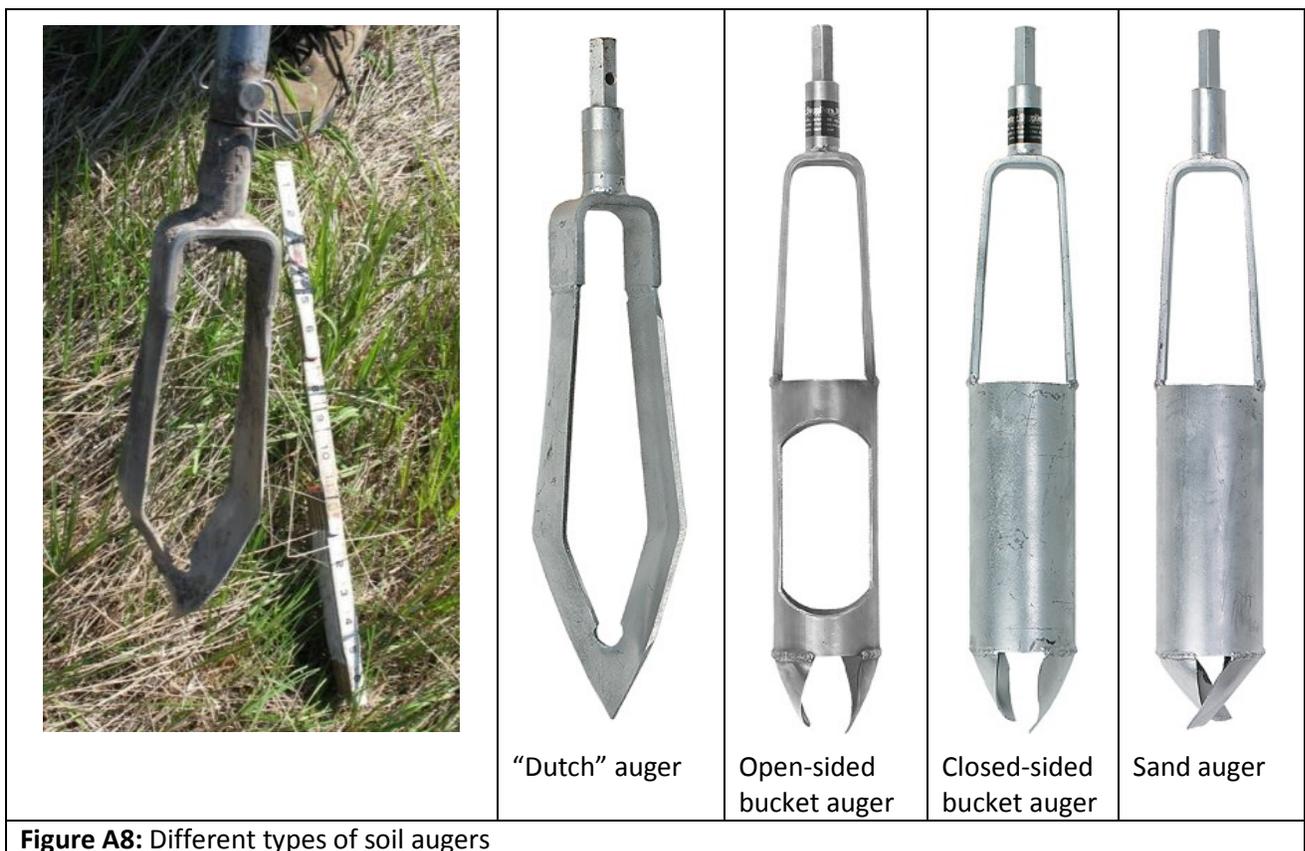
In most cases the recommended method for installing shallow monitoring wells involves using a soil auger (with an outside diameter 2 inches greater than the well diameter) to bore a hole, and then installing the well, sand pack, and seal in the open hole according to the specifications or conditions at hand. As an alternative, wells may be driven or pushed into the ground. Driven wells may be preferred in areas with coarse-grained (sandy) soils, or in saturated organic materials (mucks or peats). Wells should be tested for performance before being used.

Augering

Equipment:

- Soil auger (2 inches larger than the diameter of the well)

A **Dutch auger** or **open-sided bucket auger (Figure A8)** works well for cohesive, finer-textured soils. In loose sands or saturated soils, it can be difficult to retrieve soil with a Dutch auger (it falls out on the way up). A **closed-sided bucket auger** or **sand auger** may work better in these cases.



- Tamping tool – a stake, dowel, or rod for tamping the sand pack and bentonite seal;
- Scarifying tool – for scratching the sides of the hole if it was smeared during augering (**Figure A9**);
- Bentonite chips or granular bentonite;
- Silica sand – (“20-40 sand”) recommended for well screen with 0.010-inch slots;
- Assembled well screen and riser pipe.

Procedure: Well Installation by Augering

1. Auger a hole in the ground to a depth approximately 2 inches deeper than the planned bottom of the well.
2. Scarify the sides of the hole if it was smeared during augering (**Figure A9**).
3. Place 2 to 3 inches of sand in the bottom of the hole.
4. Insert the well into the hole to the proper depth.
5. Pour and tamp sand in the annular space around and at least 1 inch above the top of the screen.
6. Pour and tamp bentonite above the sand to the ground surface (**Figure A10**). If necessary, add water to cause the bentonite sealant to expand.
7. Form a low mound of a soil/bentonite mixture on the ground surface around the base of the riser to prevent water from entering around the pipe.
8. Test the well (to make sure it's not clogged) by either removing water (with a pump or bailer) or adding water, and then monitoring how quickly the water level recovers. The water level in the well should recover at approximately the same rate as it would in a freshly dug hole without a well.



Figure A9: Homemade scarifying tool made with screws and plastic pipe.



Figure A10: Adding (left) and tamping (right) bentonite.

Driving or pushing

Augering does not work well in some soil conditions, such as non-cohesive sandy soils, soils with coarse fragments, and saturated organic soils. In these cases, an alternative is installation by driving or pushing. The equipment is the same as for an augured well, except that a well point is used instead of a bottom cap. The well point should be vented to permit draining. For PVC wells, a driving tool may be needed to install the well without damaging the screen and riser. A commercially available steel drive point may be used, though these are more costly.

A cautionary note: driven or pushed wells are more susceptible to screen clogging during installation, especially in soils with a high organic or clay content.

Equipment:

- Constructed well with vented well point.
- Bentonite chips or granular bentonite.
- Driving device (if necessary).

Procedure:

1. Make a mark on the riser the desired depth of the well above the bottom of the well screen. With the well cap removed, use a driving device to drive the well vertically into the ground until the mark is at the ground surface. In organic soil materials, the well may simply be pushed into the ground.
2. Dig out a ring of soil around the well riser to a depth of 4 inches. Fill this space with bentonite and add water, if necessary, to form a tight seal.
3. Form a low mound of a soil/bentonite mixture on the ground surface around the base of the riser to prevent water from entering around the pipe.

Wells in Organic Soils

Constructing and maintaining monitoring wells in organic soils presents special challenges. Screens are more prone to smearing. Sand packs tend to migrate downward, which can result in bentonite seals moving down and clogging well screens. The Army Corps of Engineers recommends the following further precautions for installing wells in peat or muck:

- Wrap wells in geotextile fabric.
- Wells should be augered in rather than driven (driven wells are more prone to smearing).
- Use peat/muck cuttings rather than sand to backfill around the well.

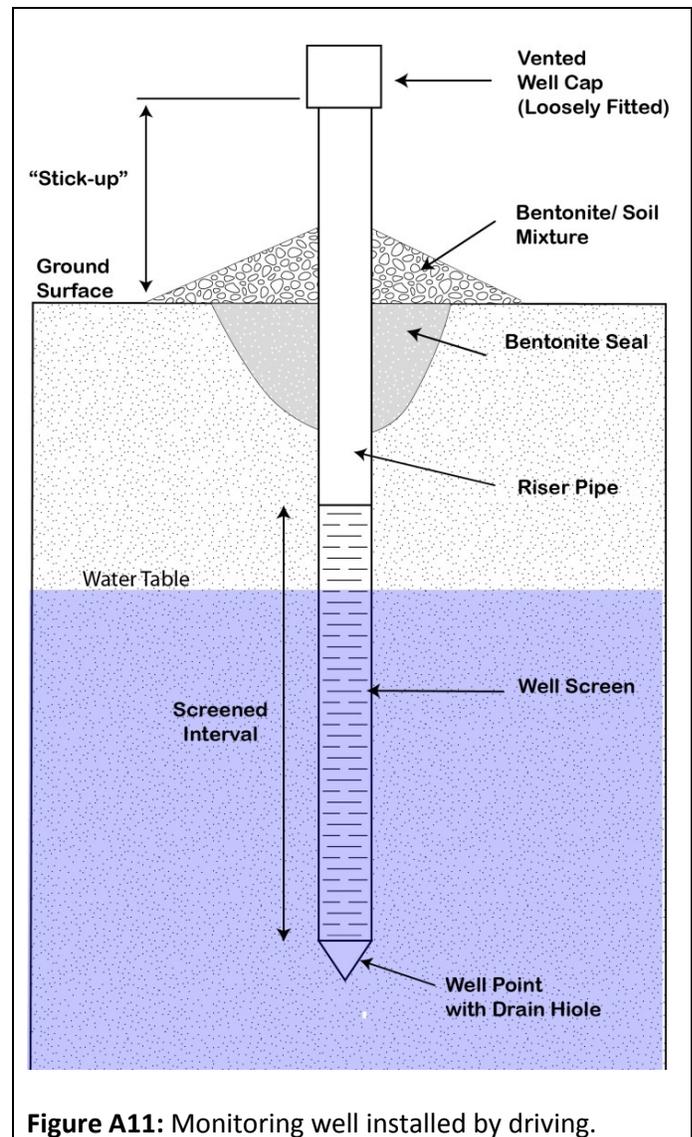


Figure A11: Monitoring well installed by driving.

- Minimize the bentonite seal around the riser to about 2 inches thick (thicker bentonite seals tend to migrate down and clog the well screen).
- Make sure to scarify the sides of the borehole.
- Wells testing for near-surface saturation in organic soils should not penetrate any mineral soil layers beneath.

For monitoring in **calcareous fens**, see **Appendix B**.

Riser Height (“Stick-Up”)

Water-level measurements are usually recorded as the “depth to water” from the top of the well riser. The depth of the water table below the ground surface is determined by subtracting the riser height (“stick-up”) from the “depth to water” measurement. After installing the well, it is important to measure and record the “stick-up.” It is usually desirable to survey the elevation of the top of the well riser and the ground surface elevation. This is useful in correlating water level trends across a site.

TESTING AND MAINTNEANCE

Fine soil particles can clog well screens during installation, impeding or stopping water flow. Well performance can also diminish over time due to a number of reasons including sediment deposition in the well, movement of fine soil particles, bacterial growth, disruption of the bentonite seal, frost heaving, or shrink-swell action.

The performance of the well should be tested after installation and periodically during the monitoring period by either (1) pumping or bailing water out of the well, or (2) adding water to the well, and then monitoring how quickly the water level returns to the initial level. The water level in the well should recover at approximately the same rate as it would in a freshly dug hole. This could take several hours in soils with high clay content. If the water does not return to the initial level in a reasonable amount of time, pull the pipe out of the ground, clean the screen, reinstall it, and retest it. If water levels in the well are questionable, one technique is to auger a hole nearby and compare the water level in the hole to the water level in the well.

Riser heights should be measured after spring thaw and re-checked periodically when water-table measurements are taken or electronic data are downloaded. If the riser height has changed, adjust the data or reset the well.

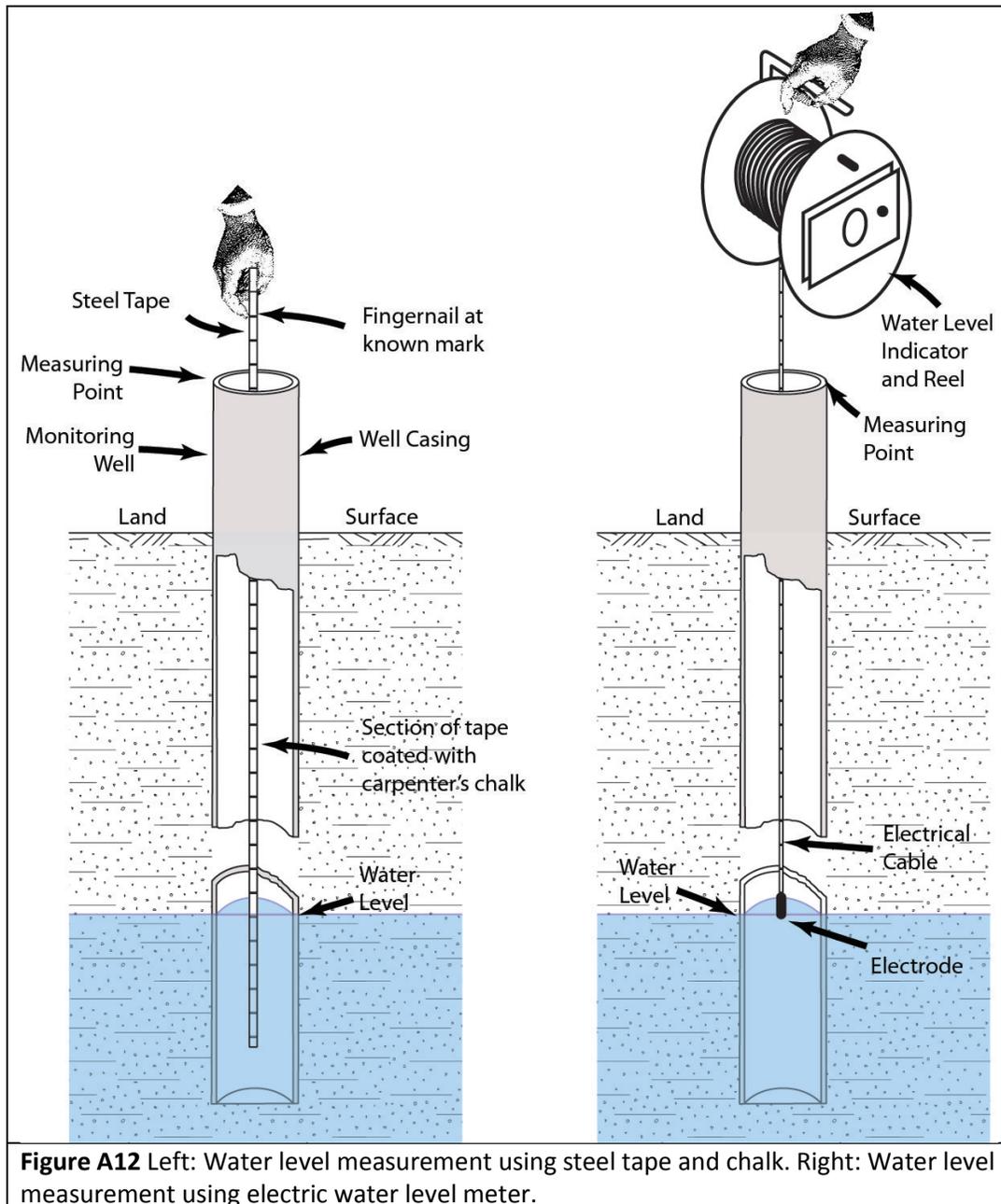
MEASURING WATER LEVELS

Water levels can be measured manually or using automated water level data loggers. Data loggers have the advantage of being able to take frequent measurements without the need for frequent site visits. At sites where the hydrology is highly variable or “flashy”, data loggers clearly provide more useful data. The disadvantage is the initial cost. Manual measurements are accurate and dependable, but require a consistent, uninterrupted schedule of frequent site visits. Depending on site access, personnel costs are a serious consideration. The choice of manual versus automated measurements will depend on logistics, site access, personnel availability, ability to front the initial cost outlay for data loggers, and whether or not there will be future projects requiring data loggers.

Manual Water Level Measurements

A simple and highly accurate way to measure water levels is with a steel measuring tape marked with carpenter’s chalk or a water-soluble marker. Using this technique, it is possible to measure water levels with an

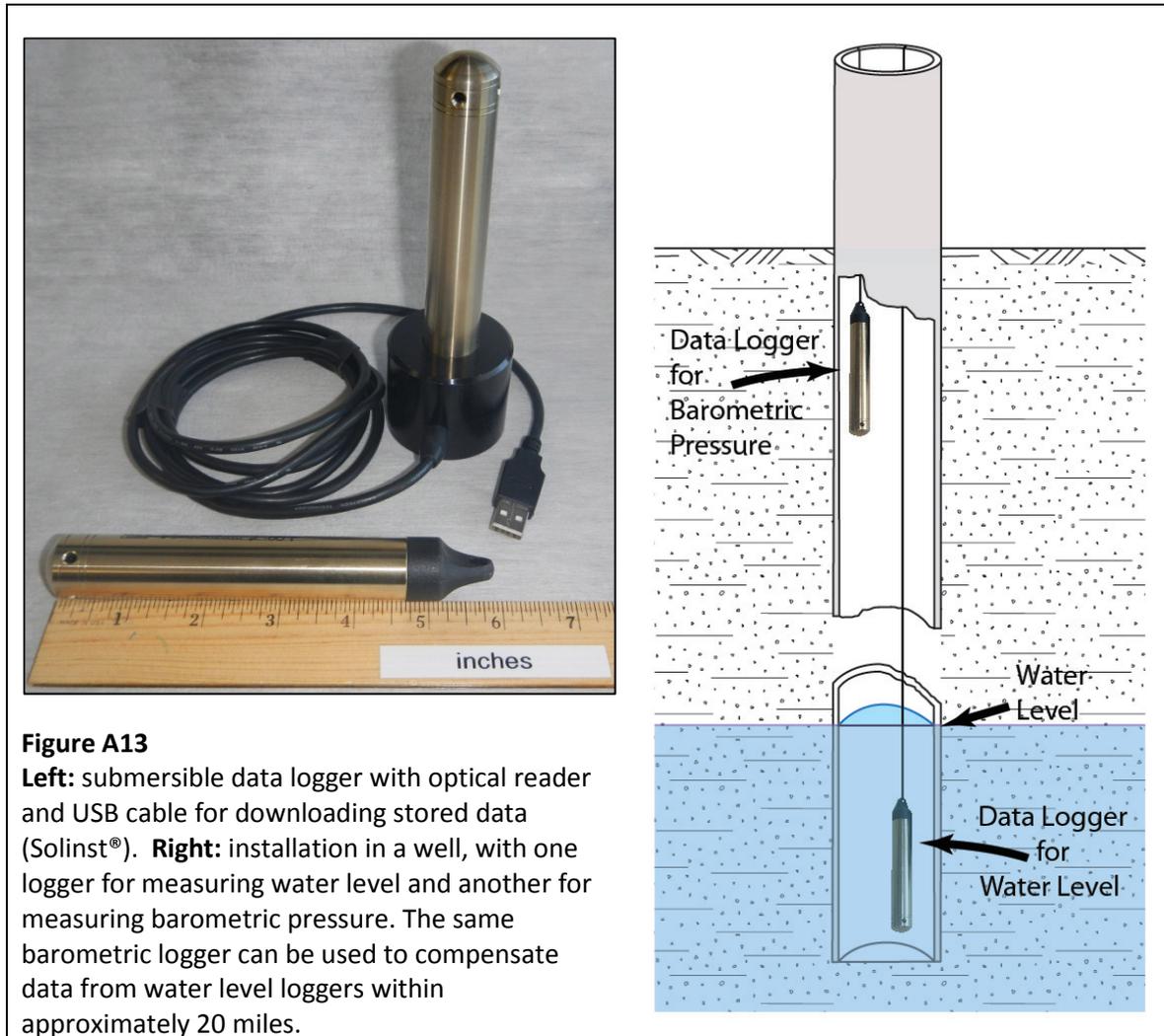
accuracy of ± 0.02 ft ($\sim \frac{1}{4}$ inch or $\sim \frac{1}{2}$ cm). The tape is inserted in the well and held at the measuring point (usually the top of the well riser) at a known mark. The wetted length is then subtracted off to yield the water level depth below the measuring point. Electric water level meters have an electrode attached to the end of a graduated tape. The device makes a sound or flashes when the electrode makes contact with water (**Figure A12**). Measurement devices that displace significant amounts of water (e.g., dowel rods, folding rulers) should not be used.



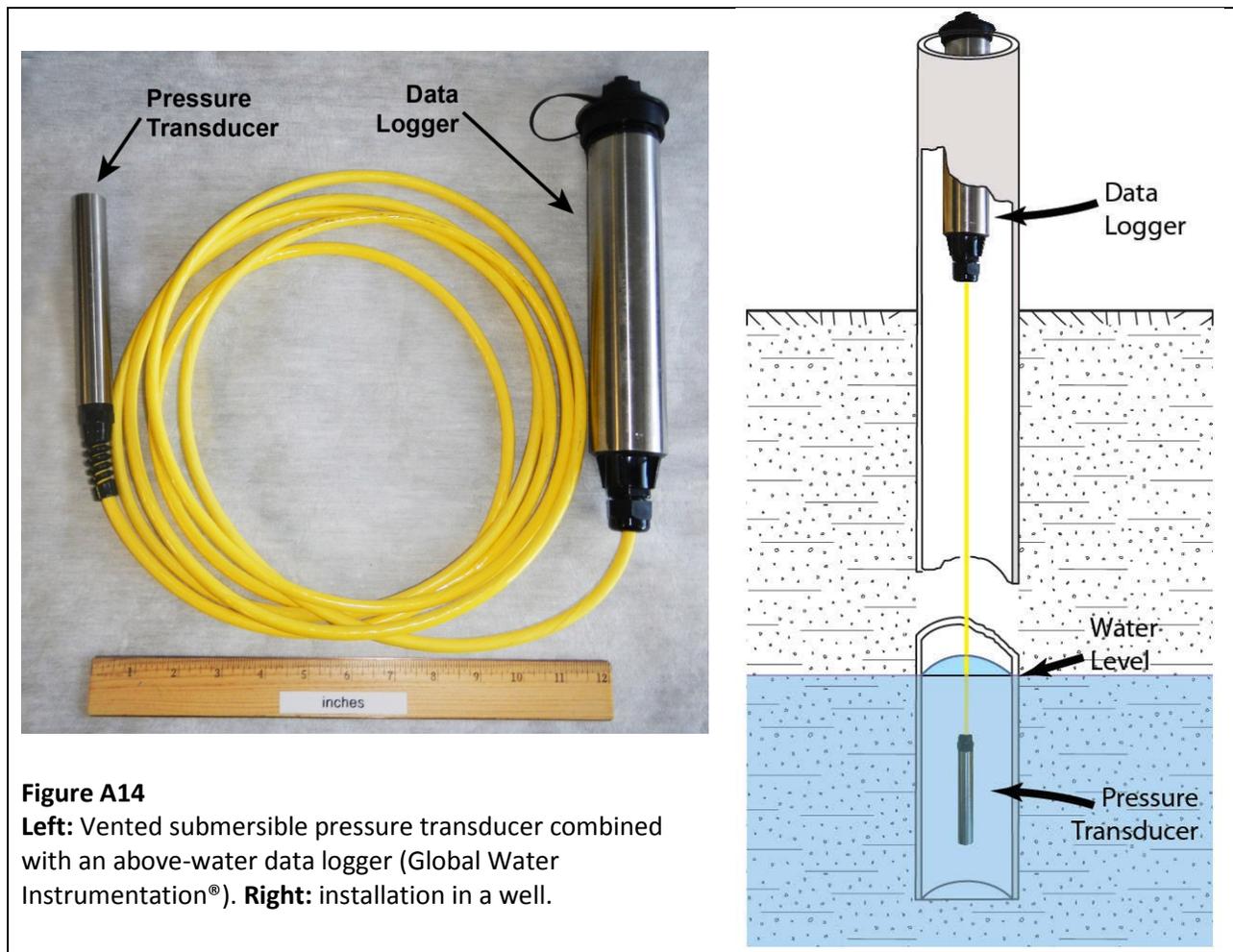
Water-Level Data Loggers

Water level data loggers have a pressure transducer or capacitance-based sensor to measure the water level and memory circuitry to record and store the levels at specified times. Pressure transducers are the most commonly used. There are basically two types of data loggers using pressure transducers:

1. Submersible data loggers (e.g. Solinst[®], Hobo[®]- **Figure A13**). These have the advantage of small size and are easily deployable in small wells. The disadvantage is that they measure absolute pressure and so the readings must be compensated for changes in barometric pressure. This is done either by dedicating a special logger, deployed above the water level, to measure barometric pressure, or by using other available barometric pressure data. One barometric logger can be used to compensate data from water level loggers within approximately 20 miles.



2. Vented submersible pressure transducer combined with an above-water data logger (e.g. Global Water[®] Instrumentation – **Figure A14**). These have the advantage of automatically compensating for changes in barometric pressure. The disadvantage is the larger size of the data logger portion, and the need for some sort of protective housing for the data logger.



Monitoring Period and Frequency of Readings

The period of monitoring and the frequency of readings will be dependent on the monitoring objectives, the performance measures being tested, and the questions being asked. In general, water level measurements are taken throughout the growing season. If wetland hydrology is expected only in the early part of the growing season, readings should be more frequent during that time. Water level measurements are often taken daily, or at least weekly, during the early part of the growing season. In many cases the frequency of readings can be reduced as the growing season progresses and water levels drop during mid-summer.

Appendix B:

DNR Guidance Document (CF1)

MN DNR Calcareous Fen Monitoring Well Requirements

Calcareous fens are identified by hydrology, soil type, water chemistry, and vegetation characteristics. This document describes the identification of necessary hydrology for identifying a calcareous fen. It is assumed that soil type, water chemistry, and vegetation characteristics have already been evaluated.

Calcareous fens can occur in various landscapes. In spring-pond or mound settings actively discharging ground water is evidence of upwelling. In side-slope settings a downward flowpath that intersects the ground surface will also result in the emergence of groundwater at the surface, which we are also classifying as ‘upwelling’. Either of these upwelling situations can take the form of pools or streams that have an obvious ‘bubbling up’ of groundwater. If this is observed, monitoring wells or piezometers are not needed to be installed to establish upwelling groundwater conditions. However, obvious upwelling is not always evident, or long term monitoring of hydrologic conditions in a calcareous fen may be needed. In those cases, installation of wells and piezometers may be required.

Well/piezometer installation in calcareous fens cannot be accomplished using normal well construction methods. To avoid severe damage to the fen, all work must be done by hand. Grouting and subsequent sealing of wells/piezometers cannot follow the normal Minnesota Department of Health Well Construction Code. Variances from the Code may be needed depending on peat and well depth.

Upwelling conditions in a calcareous fen are typically identified by establishing that an upward ground water gradient exists and that an upward ground water flow path also exists. This is done through the installation of at least one sub-peat piezometer and one water table well completed in the peat layer. The piezometer is placed at depth below the peat layer in the mineral soil. The water table well is constructed to bracket the water table that exists within the peat. When the water level elevation is higher in the deep piezometer than the water table well, then an upward gradient exists.

To minimize impacts to the fen, all wells and piezometers should be constructed with PVC or stainless steel and should be installed by hand with minimal disturbance to surrounding vegetation. No bentonite or sand filter packs should be used. Due to the high alkalinity of the groundwater, metal casing is not recommended for long term monitoring. Construction and installation methods for the two well types are described below:

Water Table (Peat) Wells:

Peat depth should be determined before well installation is started. Peat depth can be determined by probing the peat with a metal bar or tile probe. Peat provides little resistance to the bar (unless frozen) while mineral soil is extremely resistant. Once the peat depth is determined the water table well should be constructed on the surface.

Water table wells should be no more than 2 inches in diameter with 1.25 inches preferred to minimize impacts to the fen. Screens should consist of 0.25 mm slotted PVC and should be the length needed to bracket the

anticipated fluctuations in water levels in the peat. If possible, the entire depth of peat should be screened unless measurement of discrete peat layers is required for study. If ponding of water can or does occur on the land surface, then the screen should extend above the land surface to include above land surface expressions of the water table.

A stabilization sump (sump) should be installed below the screen. This sump consists of un-slotted casing with an unvented well cap glued onto the base and a coupling glued at the top to connect to the well screen. The sump should be of sufficient length to allow for installation of the sump into the mineral soil below the peat (see **Figure B1**-stabilization sump). DNR experience with calcareous fen monitoring has shown construction of this stabilization sump to be the best method for stable water table well installation where groundwater upwelling occurs in peat. Other well installation methods can be used but unless the well is anchored to the mineral soil, it will move and no longer provide accurate and comparable water levels.

To install the water table well, an auger the same diameter as the well or slightly smaller should be used to auger through the peat to the mineral soil. Never use a larger diameter auger than the diameter of your casing. Working quickly, stabilization sump and well screen should be pushed down into the peat by hand. This may require the temporary use of a cap on top of the well screen to install the well. The top of the screen should be at the land surface and may need to be cut off prior to installing the PVC standpipe casing depending on accurate measurements.

The PVC standpipe should be installed by gluing the necessary length to the top of the well screen with a coupling. The standpipe is generally 2-3 feet above land surface. The measuring point should be surveyed in to allow direct comparison to the deep piezometer groundwater levels. A vented cap should be placed on top of the well. If accurate measurements of peat depth are taken, the standpipe can be glued onto the well screen prior to well installation and the entire well can be installed at once.

Sub-peat Piezometers:

Sub-peat piezometers are used to measure the groundwater levels in the mineral soil beneath the peat. These piezometers are constructed with schedule 40 PVC threaded casing and 0.25 mm slot, 6 inch stainless steel screen (see **Figure B2**). These wells are driven with a small diameter steel pipe inserted inside the PVC casing and placed on the drive plate inside the stainless steel screen.

To better understand the hydraulic connection between the peat and the mineral soil it is necessary to take soil samples of the upper portions of the mineral soil. This is to help identify any confining layers (silt or clay) that might be present below the peat and above the mineral soil. Use a hand auger with enough rod length to drill into the mineral soil and examine the material removed. Once you have sampled the mineral soil you can decide a target depth to set your screen. It is important to make sure the screen is set completely in the mineral soil and below any confining layers that may exist on top of the mineral soil.

A post-hole driver or similar is necessary to drive the well into the mineral soil. A sacrificial coupling may be installed on top of the well if the post-hole driver hits the top of the well casing.

Once installed, the measuring point should be surveyed in to allow direct comparison to the shallow water table groundwater levels. A vented cap should be placed on top of the well.

All wells should be logged with both construction and stratigraphy information and unique identifiers should be assigned. If possible, Minnesota Department of Health unique well numbers should be assigned.

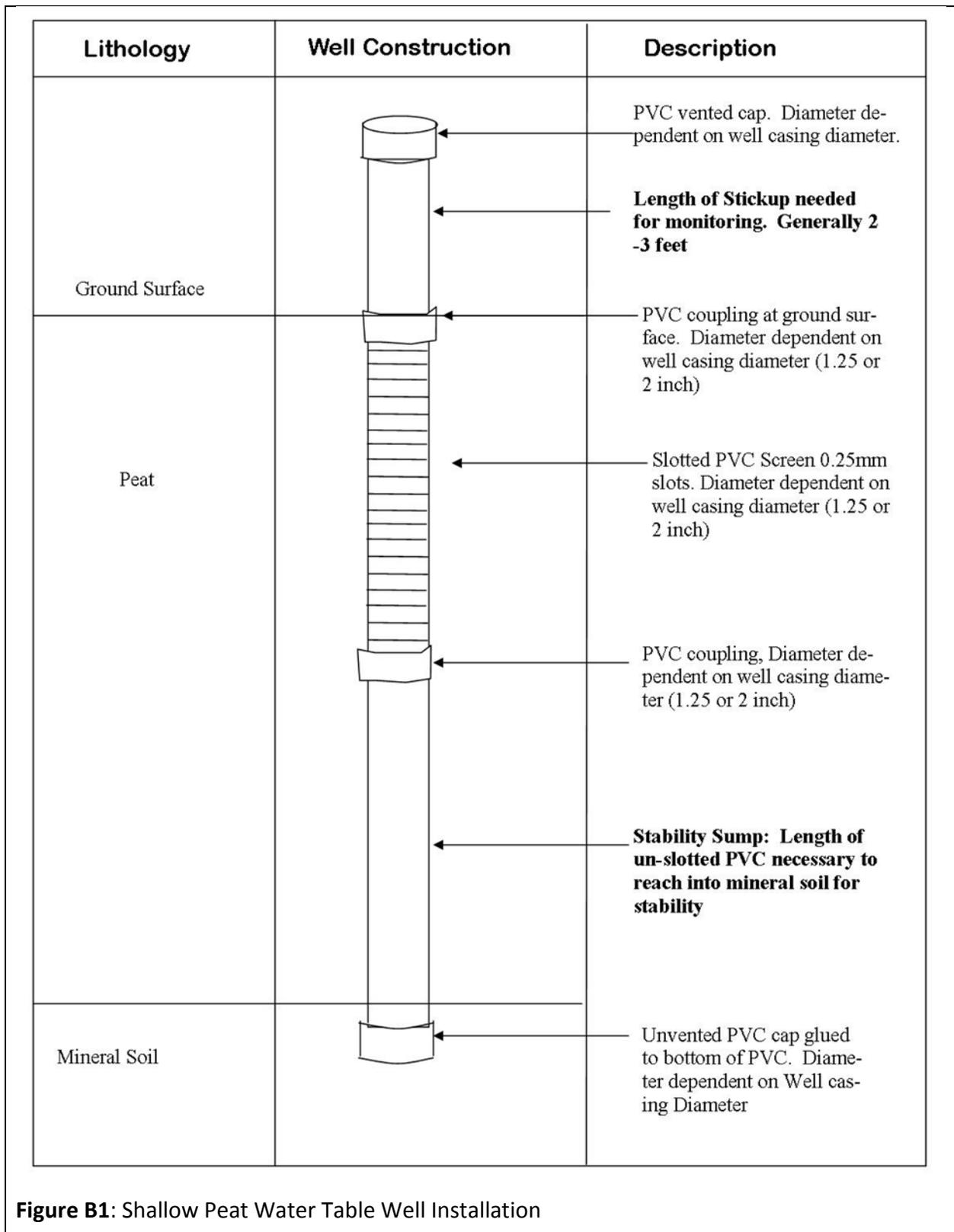


Figure B1: Shallow Peat Water Table Well Installation

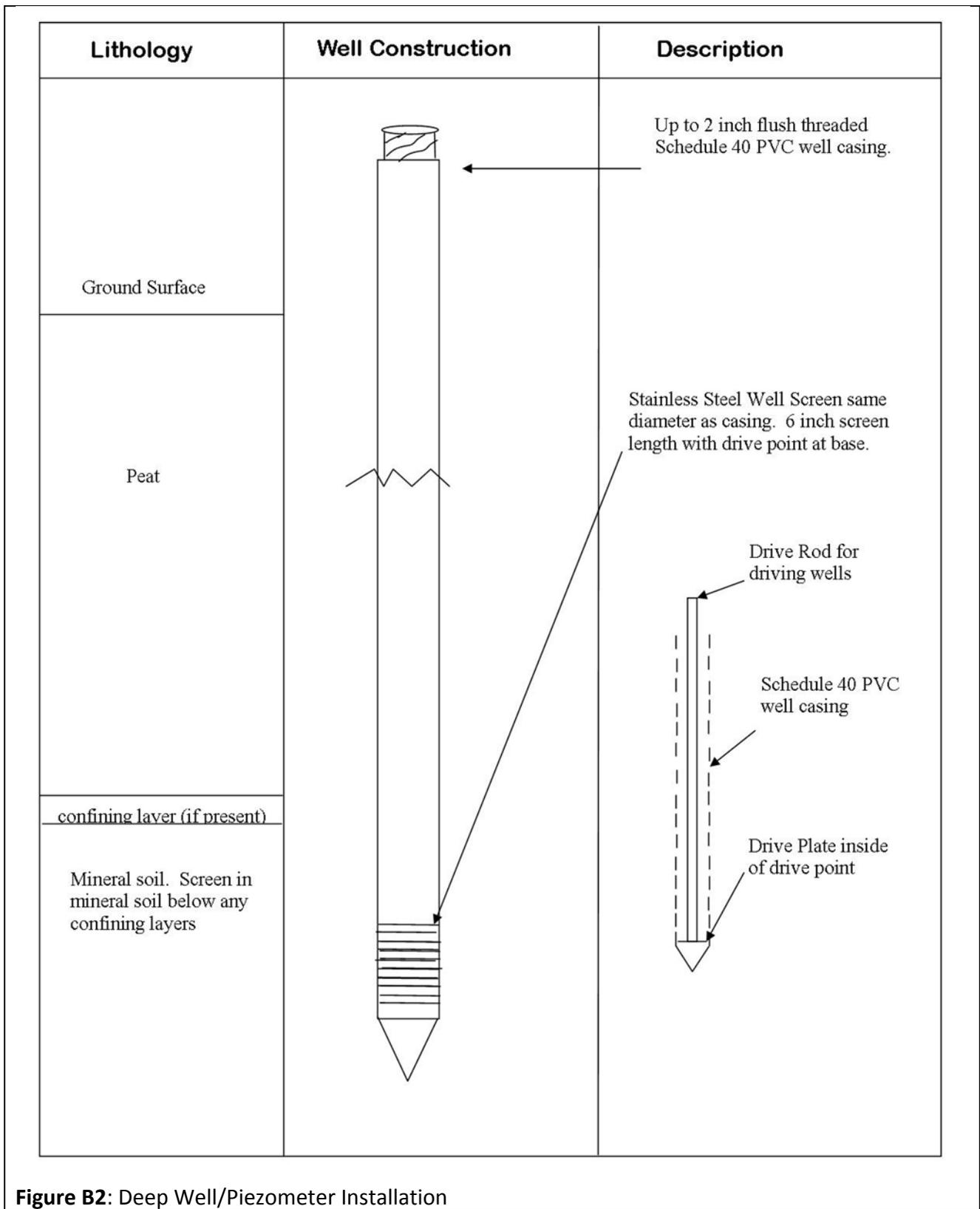


Figure B2: Deep Well/Piezometer Installation

Appendix C:

Constructing a Staff Gauge

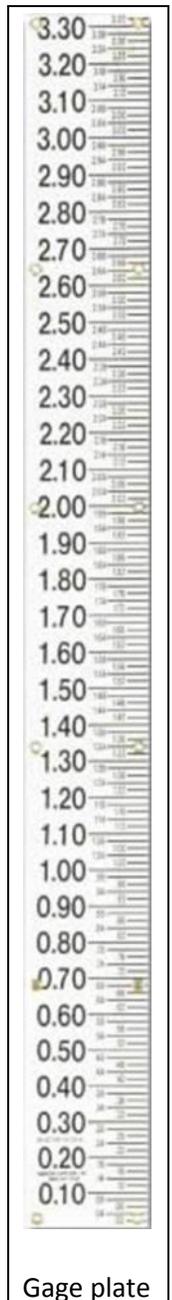
The following guidance on constructing a temporary gauge is courtesy of the Minnesota Department of Natural Resources (DNR), Ecological and Water Resources Division, Lake Level MN Program:

www.dnr.state.mn.us/climate/waterlevels/lakes. Reference to particular vendors is for example; it does not imply endorsement by the State of Minnesota.

1. Start with a **gage plate** – for example (pictured):
Forestry Suppliers, Inc., Style A gage plate, 0' - 3.33'
(or equivalent from any number of suppliers).
2. Center gage plate and attach to a:
2" x 6" x 4' long green treated board with
1 1/2" galvanized roofing nails
3. Get a **7' long, 2.0 lb/ft. steel U-channel post fence post**
for example:
<http://www.gophersign.com/ProductDetail.asp?idproduct=7338&idCategory=729>
4. Drill bolt holes in the top and the bottom of the board, about ½ foot from the ends, in line with the holes in the post.
5. Attach both the top and bottom of the board to the fence post using the following hardware:
 - hex. bolt (3 1/2" x 5/16")
 - hex. nut (5/16")
 - flat washer
 - lock washer (5/16")
6. Depending on the location, it may be easier to drive in the fence post first, and then attach the gauge/board to the post.

If installing in deeper water, it may be easier to:

- 1st: attach the lower end of the board to the post,
- 2nd: with the gauge/board rotated away from the post, drive in the fence post
- 3rd: finally, rotate the top of the board into place and attach



Gage plate



Appendix D:

Interpreting Monitoring Data

Establishing Context: Evaluating Antecedent Precipitation Conditions

Monitoring data must always be interpreted in the context of the wetness conditions preceding the monitoring period. Is the monitoring data over a particular period of time representative of normal, wet, or dry conditions?

The publications *Accessing and Using Meteorological Data to Evaluate Wetland Hydrology* (Sprecher and Warne, 2000), and *NRCS Engineering Field Handbook – Chapter 19 – Hydrology Tools for Wetland Determination* (NRCS, 1997), are important resources for nationwide application. They describe procedures for evaluating whether precipitation prior to a particular date was within the range of normal.

In Minnesota, we have the additional benefit of climate data and tools readily available via the web from the State Climatology Office (at <http://climate.umn.edu>) – greatly enhancing the application of these procedures. Together with the capabilities of spreadsheets (such as Microsoft Excel), the State Climatology Office data and tools make the procedures accessible and straightforward. A guidance document available on the BWSR web site describes procedures to evaluate antecedent precipitation utilizing State Climatology Office data and tools: <http://www.bwsr.state.mn.us/wetlands/wca/antecedent-precip.pdf>.

A useful technique described in this guidance is way of presenting precipitation data that includes daily precipitation, monthly precipitation, the 30-day rolling sum, and the range of normal conditions on the same graph (**Figure D1**).

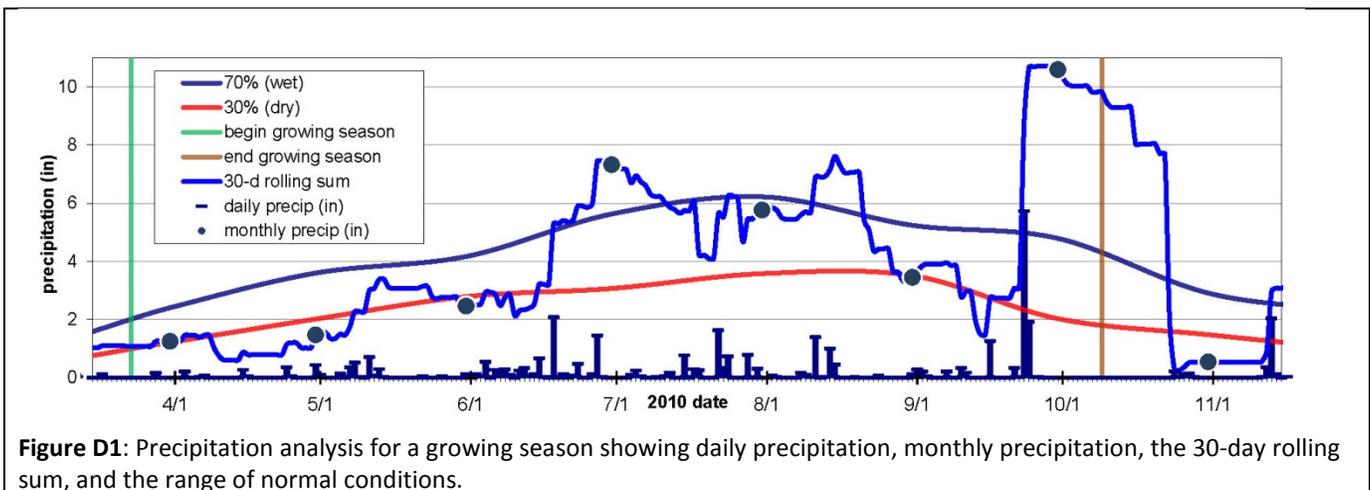
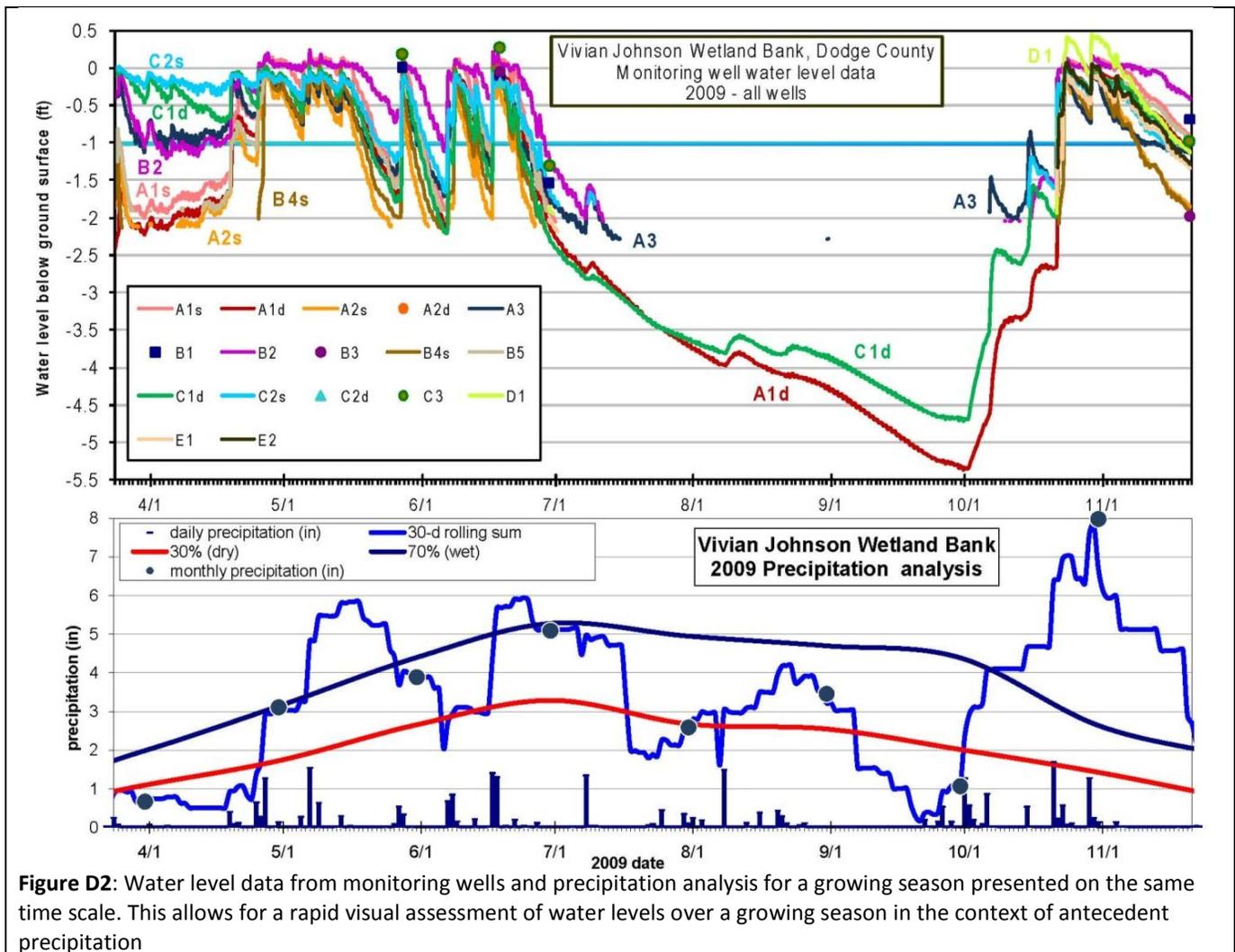


Figure D1: Precipitation analysis for a growing season showing daily precipitation, monthly precipitation, the 30-day rolling sum, and the range of normal conditions.

Presentation of Monitoring Data

Monitoring data can be presented in tabular form, but are much easier to understand and interpret when presented graphically. Graphical presentations of monitoring data are easy to generate using computer spreadsheets. A particularly useful way of presenting monitoring data is to graph water levels and precipitation data analysis such as Figure D1 on the same time scale (**Figure D2**). This allows for a rapid visual assessment of water levels over a growing season in the context of antecedent precipitation.



If water level measuring points have been tied in to absolute elevation (very useful) then water level data can be presented not only in terms of depth below ground surface, but also in terms of elevation (**Figure D3**). This is very useful if the site has a topographic survey. Water level elevation data can then be used to delineate areas meeting defined water level depth and duration criteria (**Figure D4**).

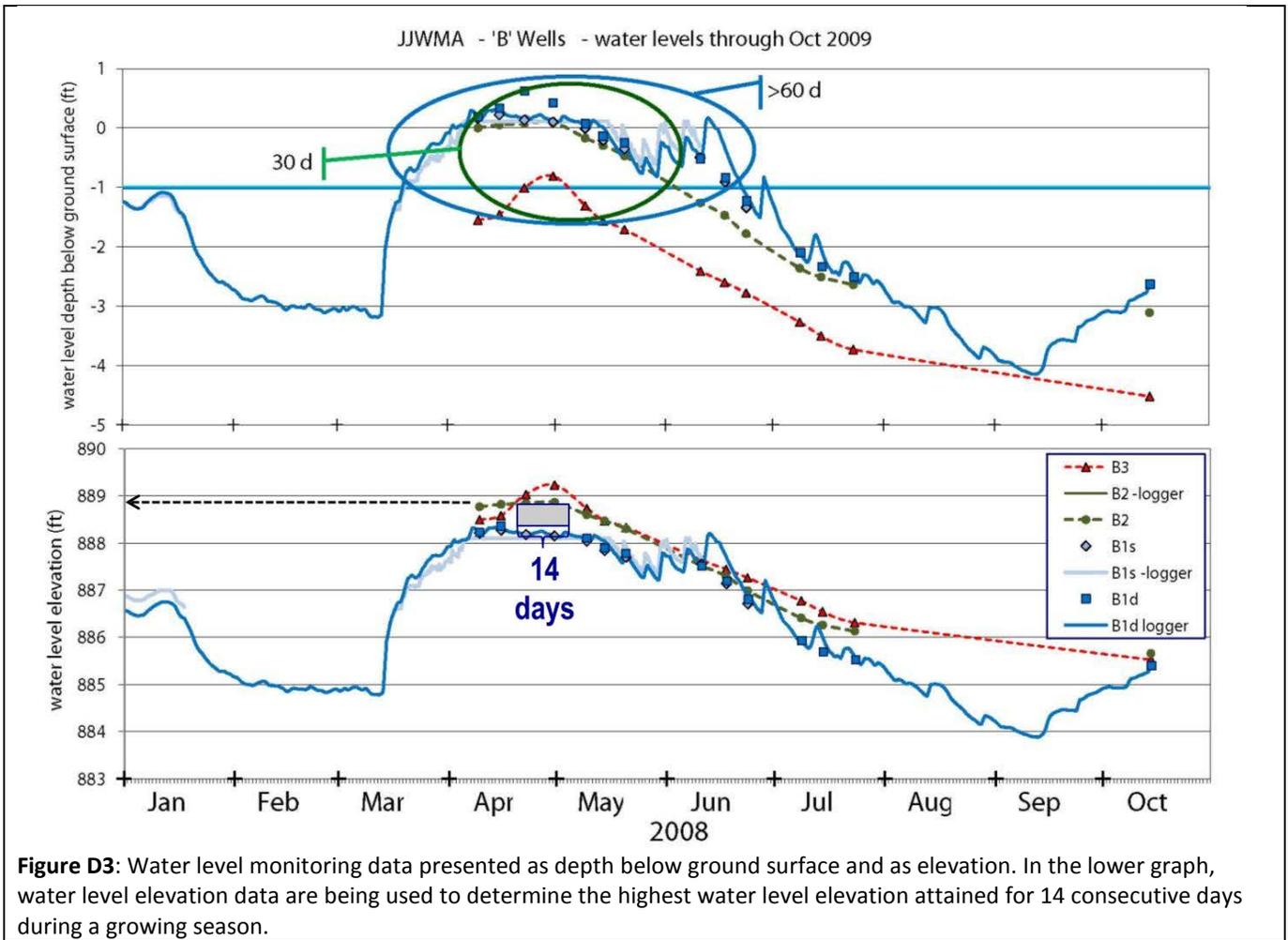


Figure D3: Water level monitoring data presented as depth below ground surface and as elevation. In the lower graph, water level elevation data are being used to determine the highest water level elevation attained for 14 consecutive days during a growing season.

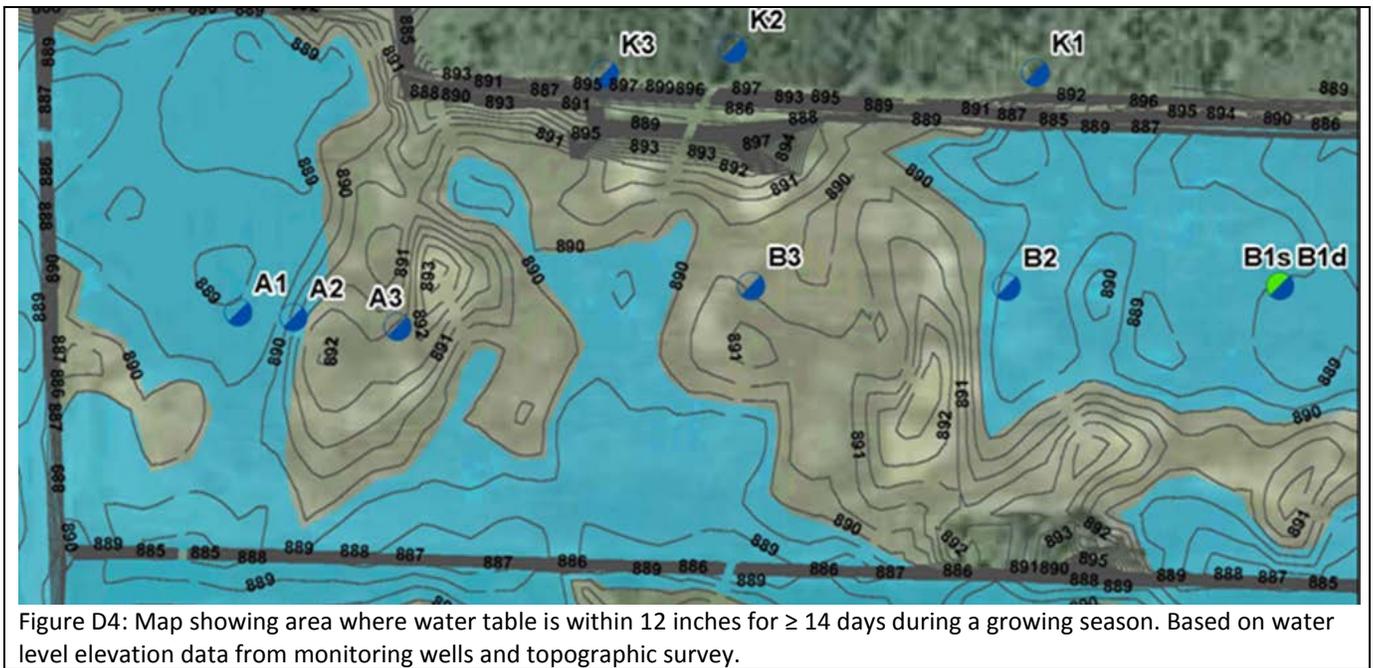


Figure D4: Map showing area where water table is within 12 inches for ≥ 14 days during a growing season. Based on water level elevation data from monitoring wells and topographic survey.