Technical Standard for Water-Table Monitoring of Potential Wetland Sites

by U.S. Army Corps of Engineers

PURPOSE: This technical note describes national standards for the collection, analysis, interpretation, and reporting of hydrologic data, which may be used to help determine whether wetlands are present on disturbed or problematic sites that may be subject to Clean Water Act regulatory jurisdiction. These standards may be supplemented or superseded by locally or regionally developed standards at the discretion of the appropriate Corps of Engineers District.

BACKGROUND: Wetland determinations in the majority of cases are based on the presence of readily observable field indicators of hydrophytic vegetation, hydric soils, and wetland hydrology, according to procedures given in the *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) (hereafter called the Corps Manual). These three characteristics are the best available evidence that an area has performed in the past, and continues to perform, the functions associated with wetland ecosystems.

The Corps Manual (Part IV, Section F, Atypical Situations) recognizes that wetland determinations on some sites may be difficult because of human disturbance that may have altered or destroyed wetland indicators. In addition, some naturally occurring wetland types may lack indicators or may have indicators present only at certain times of year or during certain years in a multi-year cycle (Part IV, Section G, Problem Areas). Wetland determinations in these atypical and problem situations increasingly involve the use of direct hydrologic monitoring to confirm the presence of wetlands in cases where soils or vegetation have been significantly disturbed or are naturally problematic, or where the hydrology of the site has been altered recently such that soil and vegetation indicators may give a misleading impression of the site's current wetland status.

The Corps Manual provides only a general discussion of wetland hydrology concepts and does not provide a suitable standard that can be used to design a hydrologic monitoring study or interpret hydrologic data, particularly in cases where groundwater is an important water source. Therefore, the purpose of this Technical Standard is to provide a minimum standard for the design, construction, and installation of water-table monitoring wells, and for the collection and interpretation of groundwater monitoring data, in cases where direct hydrologic measurements are needed to determine whether wetlands are present on highly disturbed or problematic sites.

USE OF THE TECHNICAL STANDARD: The Technical Standard is intended for use in atypical and problem situations as described in the Corps Manual. Atypical situations are broadly defined as any wetlands where indicators of hydrophytic vegetation, hydric soil, or wetland hydrology may be lacking due to recent human activities or natural events. Problem areas are wetlands that may lack wetland indicators at certain times due to normal variations in environmental conditions. This standard is designed to determine a site's current hydrologic status and may not be appropriate for evaluating past or pre-disturbance conditions.

This standard should not be used to overrule a wetland determination based on indicators of hydrophytic vegetation, hydric soil, and wetland hydrology on sites that are not significantly disturbed or problematic. Wetland indicators reflect natural processes that occur in wetlands and generally provide the best evidence that functioning wetlands are present on a site. The actual hydrologic regime required to produce and maintain a wetland may vary locally and regionally due to climate, landforms, geology, soils, and plant and animal adaptations. Therefore, any wetland hydrologic standard is necessarily an approximation and should be used only when an indicator-based wetland determination is not possible or would give misleading results.

In addition, this standard is not intended to overrule other scientific evidence that particular regional or local wetland types may be associated with hydrologic conditions different from those described here, including the seasonal timing, depth, duration, and frequency of saturation. Standards used to verify wetland hydrology in such cases should be based on the best available scientific information concerning a particular local or regional wetland type.

The Technical Standard is designed solely to determine the location of the water table for wetland jurisdictional purposes. It should not be used for water-quality monitoring or other purposes. This national standard may be supplemented or superseded by locally or regionally developed standards at the discretion of the District, and well-documented and justified deviations from the standard are acceptable with the approval of the District. It is always good practice to discuss the goals and design of the monitoring study with Corps regulatory personnel before initiating work. This may help to avoid disagreements and problems of interpretation later. This standard is subject to periodic review and revision as better scientific information becomes available.

SITE CHARACTERIZATION: A detailed site characterization should be completed before initiating the groundwater monitoring program. Site information is needed to determine appropriate well locations, installation depths, and other design features. The site characterization should begin with a review of all pertinent off-site information including county soil surveys, topographic maps, aerial photographs, and National Wetland Inventory (NWI) maps, if available. This review should be followed by a field investigation to verify the off-site information and gather additional data. At a minimum, the following site information should be collected (see Warne and Wakeley (2000) for detailed guidance):

- Detailed site map showing the location of property and project-area boundaries (determine coordinates of boundary points and landmarks, if possible).

- Topographic map showing the watershed boundary, water features (e.g., lakes, streams, minor drainages), and direction of water movement across the site.

- Current vegetation and land use.

- Detailed description of any modifications to site hydrology (e.g., water diversions or additions including ditches, subsurface drains, dams, berms, channelized streams, irrigation, modified surface topography, etc.).

- Soil profile descriptions including locations of soil test pits (indicate on site map and determine coordinates, if possible).

Soil profile descriptions are an important part of the site characterization because they may dictate appropriate depths for installation of water-table monitoring wells. Of critical importance is the identification of soil strata that can restrict downward water movement and create a perched water table. Examples of soil strata that may produce perched water tables include fragipans, spodic horizons, argillic horizons, and shallow bedrock. If a shallow restrictive soil layer is identified, care must be taken during well installation to ensure that the layer is not penetrated. Penetration of the restrictive layer may result in misleading water-level readings.

Soil profile descriptions should include horizon depths and (for each horizon) information about texture, color, induration (cementation), redoximorphic features, and roots, so that significant differences in permeability can be evaluated (Sprecher 2000). A blank Soil Characterization Data Form is provided for this purpose (Appendix A). Soil profiles must be described at least to the anticipated installation depth of the wells; profile descriptions to 24 in. or more are recommended. Several soil characteristics indicate that downward water flow may be impeded and that perched water tables may exist. Features to note include the following (Sprecher 2000):

- Abrupt change from many roots to few or no roots.
- Abrupt change in soil texture.
- Abrupt change in ease of excavation.
- Abrupt change in water content, such as presence of saturated soil horizons immediately above soil horizons that are dry or only moist.
- Redoximorphic features at any of the distinct boundaries listed above.

WELL PLACEMENT: A detailed discussion of monitoring well placement within the project site is beyond the scope of this Technical Standard. In general, well placement depends on the objectives of the investigation and characteristics of the site. If the objective is to determine whether wetland hydrology is present at a particular point, a single well may be sufficient. However, multiple wells may be necessary to determine if wetland hydrology occurs on a complex site where topography and human alterations (e.g., road construction, ditching) have produced considerable hydrologic variation. Well locations and depths are dictated by site conditions including topographic relief and the depth and continuity of restrictive soil layers. Portions of a site that are most likely to meet wetland hydrology standards (e.g., low-lying areas such as depressions, floodplain backwaters, swales and washes, fringes of lakes and ponds, toes of slopes, or other areas with shallow restrictive soil layers) should be identified during site characterization and considered for well placement.

If the objective is to confirm wetland boundaries based on groundwater measurements, then multiple wells installed along transects perpendicular to the expected wetland boundary are needed (Figure 1). The number and spacing of wells along each transect depend on the topographic gradient and the precision needed in defining the wetland boundary. Other site information that may help in placing wells and identifying boundaries includes changes in topographic gradient, proximity to hydrologic alterations (e.g., ditches), and changes in soil characteristics or vegetation.

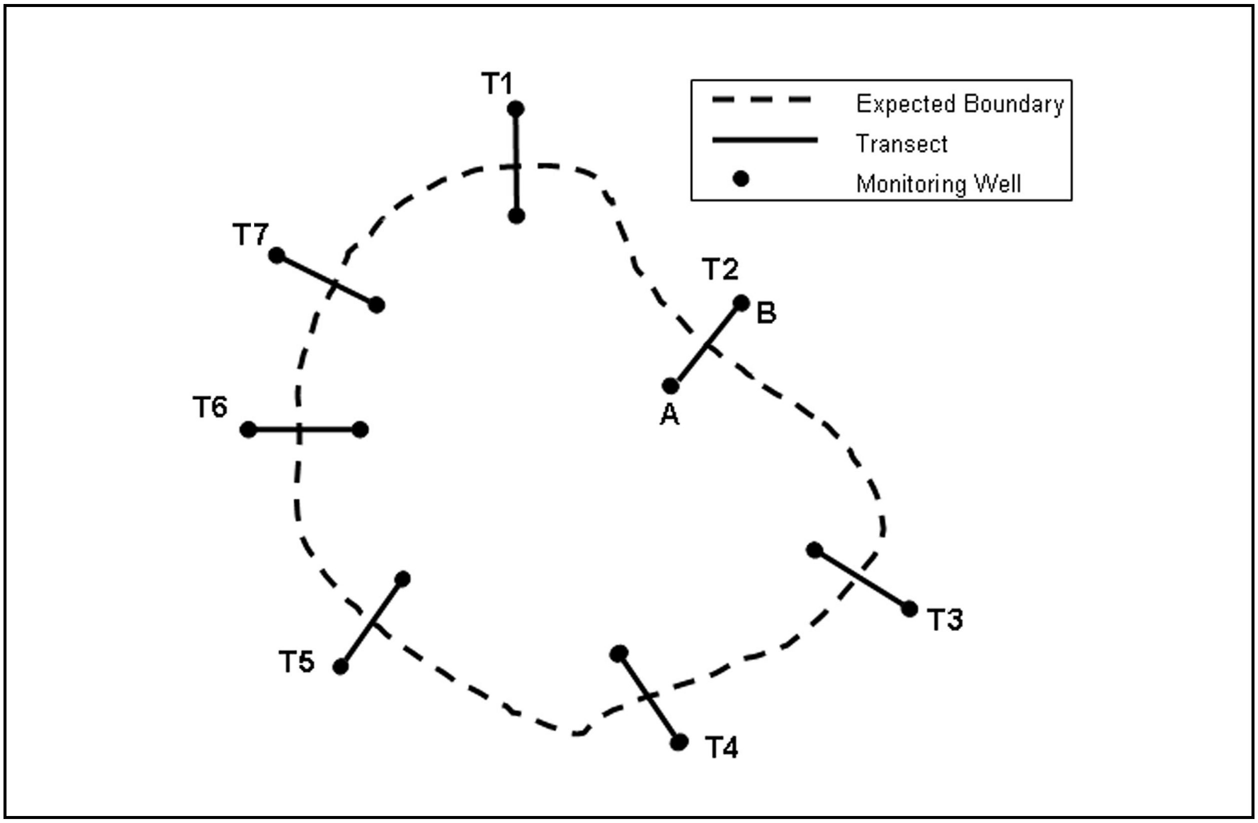

Figure 1. Example of monitoring wells located along transects across the expected wetland boundary. Transects extend from obvious upland to obvious wetland. Two or more wells are needed along each transect (e.g., at locations A and B).

MONITORING WELL CONSTRUCTION: In most cases, a standard monitoring well installed to a depth of 15 in. below the soil surface should be used to measure water-table depth on potential wetland sites. Shallower installation depths may be needed if restrictive soil layers exist within 15 in. of the surface. Monitoring wells must not penetrate any such restrictive layer. The standard design is for a well installed by augering. Depending upon site conditions, wells installed by driving may also be acceptable (see the section on Monitoring Well Installation). Installation of one or more additional deeper (4-5 ft) wells at each site is also encouraged to help in interpreting water-table fluctuations and warn of sudden changes in water-table depth. Deeper wells are not required but, if used, should not penetrate any restrictive soil layers. The performance of all wells must be tested and verified before use.

Monitoring Well Components. A standard monitoring well installed by augering is shown in Figure 2 and consists of the following main components: well screen, riser, well caps, sand filter pack, and bentonite sealant. Specifications for each of these components are given below.

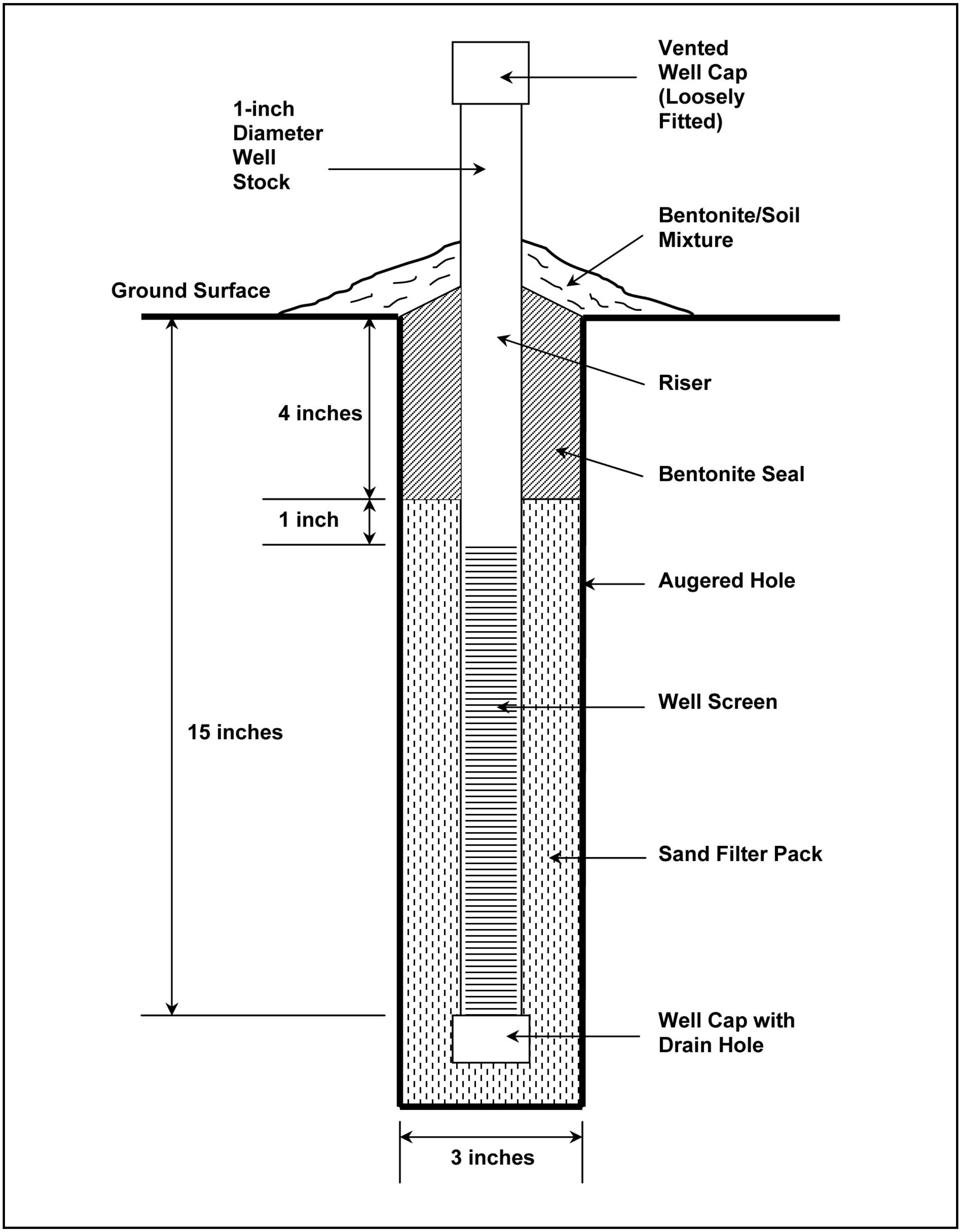

Figure 2. Standard 15-in. monitoring well installed by augering

Well Stock. Shallow monitoring wells should be made from commercially manufactured well stock. Schedule 40, 1-in. 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. However, if required by automated water-level recorders, then 2-in.-diam pipes can be substituted. Well stock larger than 2 in. in diameter should be avoided.

Well Screen and Bottom Cap. Recommended slot opening and slot spacing for the well screen are 0.010 in. and 0.125 in., respectively. The slotted screen should extend from approximately 5 in. below the ground surface down to the bottom of the well. Hand-slotted or drilled well screens should not be used.

One problem with the use of commercial well screen for very shallow monitoring wells is that there often is a length of unslotted pipe and joint or threads below the screen. In shallow monitoring situations, this extra length often must be inserted into underlying soil material that should be left undisturbed. In combination with a commercial well point, this extra length also 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 2).

Riser. The riser is the unslotted PVC pipe that extends from the top of the well screen to above the ground surface (Figure 2). The riser should extend far enough above the ground to allow easy access but not so high that the leverage of normal handling will crack below-ground seals. In locations that do not pond or flood, 9 to 12 in. above the ground surface is usually sufficient. A longer riser may be needed on inundated sites or where automatic recording devices are used.

Well Top Cap. 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 jarring or dislodging the well, or cracking the bentonite seal. Tight-fitting caps, either threaded or unthreaded, should be avoided because they may seize to the riser and require rough handling to remove. 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 (Sprecher 2000). 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 wire lock pin. The cap should be vented to allow equilibration of air pressure inside and outside of the well.

Filter 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 2). 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 1 for recommendations on the use of filter packs for soils of different textures.

Commercially available silica 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. Silica sand is available from water-well supply houses in uniformly graded sizes. Sand that passes a 20-mesh screen and is retained by a 40-mesh screen (20-40 sand) is recommended with a 0.010-in. well screen.

Table 1
USDA Soil Texture Classes and 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

Bentonite Sealant. 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, 4 in. of bentonite should be placed around the riser immediately at and below the ground surface (Figure 2). This 4-in. ring of bentonite rests directly on top of the filter pack around the well screen. Above the bentonite ring, 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 drilling supply companies in powder, chip, or pellet form. Chips are easiest to use in the field. They can be dropped directly down the annular space above the sand filter pack. If this zone is already saturated with water, the chips will absorb water in place, swell tight, and seal off the sand filter from above. If the bentonite chips are dropped into a dry annular space, they should be packed dry and then water should be added down the annular space so the clay can swell shut.

Modified Well Design for Clay Soils. In heavy clay soils, such as Vertisols, water movement occurs preferentially along cracks and interconnected large pores. These cracks may deliver water to a standard monitoring well through its vertical, slotted walls. Even when the surrounding soil is unsaturated, water may remain in the well for days due to impeded drainage into the slowly permeable clay. This problem can be reduced, but not eliminated, by using a well that is slotted or open only at the bottom. In addition, the sand filter pack should be installed only around the immediate well opening and should not extend up the riser. The annular space around the riser should be packed with the natural clay soil material or filled with bentonite.

Because Vertisols in wetland situations tend to be episaturated (i.e., they perch water at or near the surface but may remain unsaturated below), monitoring should focus on detection of surface ponding and saturation in the upper few inches of the soil. For this purpose, wells shorter than 15 in. may be needed.

MONITORING WELL INSTALLATION

Installation Methods. The recommended method for installing shallow monitoring wells involves the use of a bucket auger with an outside diameter 2 in. greater than the well diameter (e.g., 3 in. for a standard 1-in. well). As an alternative, wells may be installed by driving them into the ground. Driven wells may be preferred in areas with noncohesive coarse-grained (sandy) soils, rocky soils (e.g., glacial tills), or in saturated organic materials (i.e., mucks or peats). Procedures for both installation methods are given below. No matter which installation method is selected, wells must be tested for performance before being used. These procedures assume that the soil profile at the well location has already been described and that the appropriate well depth (i.e., 15 in. or less) has been determined based on the presence or absence of restrictive soil layers. A Monitoring Well Installation Data Form (Appendix B) should be completed to document the design and installation of each well (Sprecher 2000).

Augering. Recommended equipment includes a bucket auger 2 in. larger than the diameter of the well being installed, a tamping tool (e.g., wooden or metal rod), bentonite chips, silica sand, and the constructed monitoring well. A pump or bailer may be needed to test the well after installation. The following procedure is used to install the well:

1. Auger a hole in the ground to a depth approximately 2 in. deeper than the bottom of the well. Be sure the hole is vertical.

2. Scarify the sides of the hole if it was smeared during augering.

3. Place 2 to 3 in. of silica sand in the bottom of the hole.

4. For a 15-in. well with 10 in. of well screen, make a permanent mark on the well riser 5 in. above the top of the screen. Insert the well into the hole to the proper depth; the permanent mark on the riser should be even with the soil surface. Do not insert through the sand.

5. Pour and gently tamp more of the same sand in the annular space around the screen and 1 in. above the screen.

6. Pour and gently tamp 4 in. of bentonite chips above the sand to the ground surface. 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 surface water from puddling around the pipe.

Driving. Well installation by driving is recommended when site conditions prevent augering (e.g., noncohesive sandy soils, soils with many coarse fragments, saturated organic soils). In addition, driven wells are acceptable whenever their performance can be shown to be equivalent to that of an augered well. Plans to use driven wells for regulatory purposes should be discussed in advance with the appropriate Corps of Engineers District office.

A driven well is similar in design and construction to the augered well described previously, with the addition of a well point in place of the bottom cap (Figure 3). Well points are commercially available and can be vented to permit draining by drilling a hole in the bottom. A special driving tool may be needed to install the well without damaging the PVC pipe.

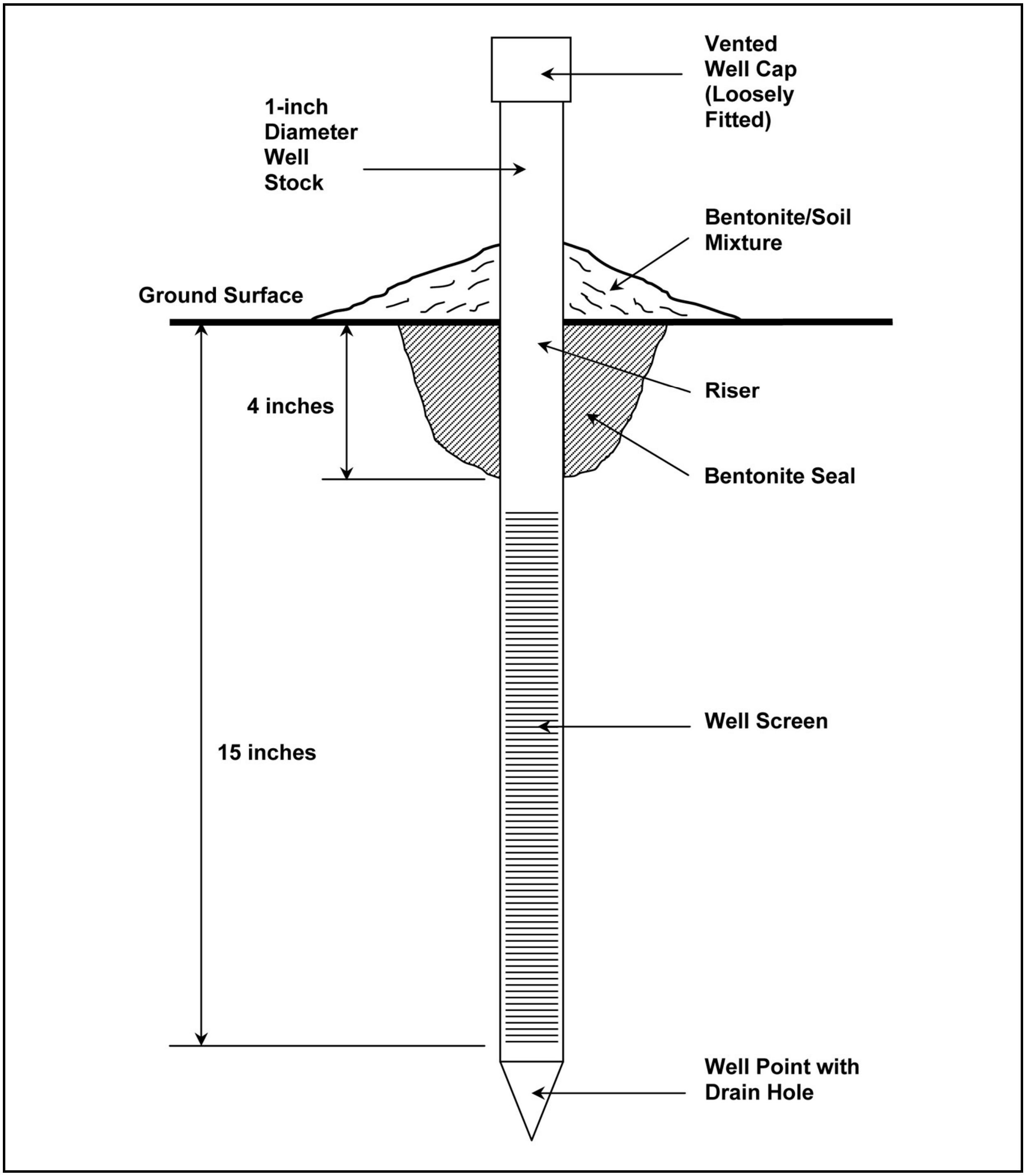

Figure 3. Standard 15-in. monitoring well installed by driving

Required materials include bentonite chips and the constructed monitoring well with vented well point. A pump or bailer may be needed to test the well after installation and, depending on site conditions, a driving device may be required. The following procedure is used to install the well:

1. For a standard 15-in. well, make a permanent mark on the riser 15 in. 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 in. Fill this space with bentonite chips 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 surface water from puddling around the pipe.

Establishing Riser Height. Water-level measurements are typically 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 from the “depth to water” measurement. Therefore, after installing the well, measure and permanently record the height of the riser above the ground surface. If automated water-level recording devices are used, follow the manufacturer’s instructions for calibration of water-level readings relative to the ground surface. Riser height should be checked after soils have thawed in spring, and should be re-checked periodically when water-table measurements are taken or electronic data are downloaded.

Surface Water. In areas subject to flooding or ponding, a separate staff gauge or automated device is required to measure the depth of surface water.

MONITORING WELL TESTING AND MAINTENANCE: During well installation, particularly with driven wells, fine soil particles may clog the well screen, impeding water flow and increasing the response time of the well. The performance of the well should be tested by (1) emptying the well by pumping or bailing and monitoring how quickly the water level returns to the initial level, or (2) if the well is dry, filling it with water and monitoring the rate of outflow. The water level in the well should reestablish itself at approximately the same rate as it would in a freshly dug hole without any pipe. In soils with a high percentage of clay, this could require several hours. If the water does not return to the initial level in a reasonable amount of time, pull the instrument out of the ground, clean it, reinstall it, and retest it. If water-table readings are questionable at any time during the monitoring period, one option is to move some distance away from the well location, auger to the depth in question, and determine whether the water level in the auger hole is the same as that indicated by the monitoring well.

Routine Maintenance. Monitoring well responsiveness should be tested at the beginning of the monitoring period and at least every 2-3 months thereafter by the procedure described above, because wells can plug over time due to bacterial growth and movement of fine soil particles. Well performance can also be affected by cracking of the bentonite seal, sediment deposition in the well, and movement of the ground surface and/or monitoring well due to frost heaving or shrink-swell action. To ensure accurate water-level readings, check for vertical displacement of the well after spring thaw and periodically during sampling by re-measuring the height of the riser above the ground surface and adjusting water-table measurements or resetting the well, as needed.

MAKING WATER-LEVEL MEASUREMENTS: Water levels in monitoring wells should be measured with an accuracy of ±0.25 in., if possible. Measurements may be made manually or with automated equipment. The use of automated water-level recorders is recommended unless an uninterrupted schedule of frequent site visits can be maintained. Automated recorders are also recommended in areas with highly variable or flashy hydrology. Whichever method is selected, it should be used consistently throughout the duration of the monitoring study.

Manual Readings. Water-level measurements can be made easily with a steel measuring tape marked with chalk or a water-soluble marker. Another approach is to use an electric device that sounds or flashes when the sensor, attached to the end of a graduated tape, makes contact with the water. Measurement devices that displace large amounts of water (e.g., dowel rods) should not be used.

Automated Readings. Automated recording devices record water levels with down-well transducers or capacitance-based sensors. An important consideration when purchasing automatic recording devices is the ability to compensate internally for variations in barometric pressure. These variations can be significant in wetland determinations. Automated equipment is more costly than hand measurement, but the devices can be used again in future studies. The credibility of monitoring results is enhanced with the high frequency of water-level readings that automated wells allow. Automated water-level recorders should be checked frequently for accuracy by comparison with manual readings. If automated readings are not within instrument specifications, the device should be recalibrated.

Required Timing, Frequency, and Duration of Readings. Water-level measurements must be taken at least once each day, beginning 5-7 days before the first day of the growing season and continuing until the end of the growing season or until the minimum standard for wetland hydrology is met that year. If automated recorders are used, readings four times per day are recommended (use the lowest reading each day). On sites subject to flooding or ponding, depth of surface water must be measured each day that water-table readings are made.

Growing season beginning and ending dates shall be based on the median dates (i.e., 5 years in 10, or 50 percent probability) of 28 °F air temperatures in spring and fall as reported in WETS tables provided by the USDA-NRCS National Water and Climate Center. WETS tables are based on long-term temperature data collected at National Weather Service (NWS) cooperative weather stations throughout the United States and are available on the Internet at http://www.wcc.nrcs.usda.gov/climate/wetlands.html. For a particular project site, growing season information from the nearest available weather station should be used unless, due to elevation or other factors, a more distant weather station is considered to be more representative of conditions at the project site. Alternative local or regional procedures for determining growing season dates may be used at the District's discretion.

Because hydrologic conditions are naturally variable, many years of groundwater monitoring data may be needed to establish what is typical for a given site. This is particularly true in the arid western United States where rainfall can be sparse, unpredictable, and highly localized. In general, ten or more years of water-table monitoring data may be needed to determine whether minimum standards for water-table depth, duration, and frequency in wetlands are met. However, because long-term monitoring is often impractical in a regulatory context, short-term studies may provide sufficient information if the normality of precipitation during the monitoring period is considered. Determining “normal” rainfall is addressed in the following section.

ANALYSIS AND INTERPRETATION OF MONITORING DATA

Technical Standard for Wetland Hydrology. Wetland hydrology is considered to be present on an atypical or problem site if the following standard is met:

> *The site is inundated (flooded or ponded) or the water table is ≤12 inches below the soil surface for ≥14 consecutive days during the growing season at a minimum frequency of 5 years in 10 (≥50% probability). Any combination of inundation or shallow water table is acceptable in meeting the 14-day minimum requirement. Short-term monitoring data may be used to address the frequency requirement if the normality of rainfall occurring prior to and during the monitoring period each year is considered.*

The Corps Manual discusses wetland hydrology in general, but does not provide a wetland hydrology criterion suitable for use in interpreting monitoring well data. The standard given above is based on recommendations by the National Academy of Sciences (National Research Council 1995). By requiring a water table within 12 in. of the surface, this standard ensures that saturation by free water or the capillary fringe occurs within the “major portion of the root zone” described in the Manual. A 14-day minimum duration standard is assumed to apply nationwide unless Corps Districts have adopted a different standard at the local or regional level. The Corps Manual addresses the need for long-term data (10 or more years) in analyses of stream-gauge data but does not consider the use of short-term data in wetland determinations, nor does it address the frequency issue in relation to water-table monitoring. This Technical Standard allows the use of short-term monitoring data to address the frequency requirement for wetland hydrology, if the normality of rainfall is considered.

The depth to saturation depends both on the position of the water table and the height of the tension-saturated capillary fringe (National Research Council 1995). While its presence has an influence on both plant growth and soil features, the upper limit of the capillary fringe is difficult to measure in the field and impractical as a basis for hydrologic monitoring. The Technical Standard for Wetland Hydrology is based on the depth of the water table because, in most cases, water-table depth can be monitored readily and consistently through the use of shallow wells with either manual or automated data collection. Water-table measurements should not be corrected for a capillary fringe unless other evidence, such as tensiometer readings, laboratory analysis of soil water content, or evidence of soil anoxia, indicates that the height of the saturated capillary fringe is greater than a few inches.

Determining Normal Precipitation. Short-term water-table monitoring data (i.e., <10 years) must be interpreted in relation to the amount of precipitation that fell during and for at least 3 months prior to the monitoring period each year. This is done by comparing the precipitation record for a given year with the normal range of precipitation based on long-term records collected at the nearest appropriate NWS cooperative weather station. The USDA-NRCS National Water and Climate Center calculates normal precipitation ranges for each month (defined as between the 30th and 70th percentiles of monthly precipitation totals) for NWS stations throughout the United States. The information is published in WETS tables available on the Internet (http://www.wcc.nrcs.usda.gov/climate/wetlands.html).

Sprecher and Warne (2000, Chapter 4) describe three methods for evaluating precipitation normality within a given year. The first method is taken from the NRCS Engineering Field Handbook (Natural Resources Conservation Service 1997) and involves the direct application of WETS tables in relation to monthly rainfall totals at the project site. At a minimum, this method shall be used to determine whether rainfall was normal immediately before and during a groundwater monitoring study. The analysis should focus on the period leading up to and during the time when water tables are usually high in that climatic region. In many parts of the country, this is at the beginning of the growing season, when precipitation is abundant and evapotranspiration is relatively low. The second method described by Sprecher and Warne (2000) evaluates daily precipitation data on the basis of 30-day rolling sums, and the third method combines the two procedures. If daily precipitation data are available, the combined method is recommended. The evaluation of precipitation normality should include the three months prior to the start of the growing season and extend throughout the entire monitoring period each year.

For many wetlands, water tables in a given year may be affected by precipitation that occurred in previous years, especially if monitoring occurs after an extended period of drought or precipitation excess. After a series of dry years, for example, it may take several years of normal or above-normal rainfall to recharge groundwater and return water tables to normal levels. Therefore, in evaluating wetland hydrology based on short-term monitoring, it is necessary to consider the normality of rainfall over a period of years prior to the groundwater study. Recent precipitation trends can be determined by comparing annual rainfall totals at the monitoring site with the normal range given in WETS tables for two or more years prior to the monitoring study, or by examining trends in drought indices, such as the Palmer Drought Severity Index (Sprecher and Warne 2000). This issue may not be important in soils with perched water tables that respond to the current year's rainfall and dry out seasonally.

Interpreting Results. If ten or more years of water-table monitoring data are available for a site, the long-term record probably includes years of normal, below normal, and above normal precipitation and thus reflects the average hydrologic conditions on the site. Therefore, wetland hydrology can be evaluated directly by the following procedure:

1. For each year, determine the maximum number of consecutive days that the site was either inundated or the water table was ≤12 in. from the ground surface during the growing season. Wetland hydrology occurred in a given year if the number of consecutive days of inundation or shallow water tables was ≥14 days.

2. The Technical Standard for Wetland Hydrology was met if wetland hydrology occurred in at least 50 percent of years (i.e., ≥5 years in 10).

This procedure may not be appropriate during extended periods of drought or precipitation excess. Furthermore, in some regions with highly variable precipitation patterns (e.g., the arid West) more than ten years of groundwater monitoring data may be needed to capture the typical hydrologic conditions on a site.

If fewer than ten years of water-table data are available, then the normality of precipitation preceding and during the monitoring period must be considered. One option is to apply the procedures described in the section on "Determining Normal Precipitation" for each year that water tables were monitored. In addition, annual precipitation or drought severity indices should be evaluated for two or more years prior to the monitoring period on any site that lacks a perched water table. Wetland hydrology can then be evaluated by the following procedure:

1. Select those years of monitoring data when precipitation was normal, or select an equal number of wetter-than-normal and drier-than-normal years.

2. If wetland hydrology (i.e., any combination of inundation or water table ≤12 in. from the surface for ≥14 consecutive days during the growing season) occurred in ≥50 percent of years (e.g., 3 years in 5), then the site most likely meets the Technical Standard for Wetland Hydrology.

It is important to remember that, even in normal rainfall years, many wetlands will lack wetland hydrology in some years due to annual differences in air temperatures (which affect evapotranspiration rates) and the daily distribution of rainfall that are not considered in this analysis. This is particularly true of borderline wetlands that may have shallow water tables in only 50-60 percent of years. Therefore, this procedure may fail to identify some marginal wetlands.

Another option, particularly for very short-duration monitoring studies (e.g., ≤3 years), is to evaluate water-table measurements in conjunction with groundwater modeling. Hunt et al. (2001) described one such approach, called the Threshold Wetland Simulation (TWS), which uses the DRAINMOD model. Actual water-table measurements in a given year are compared with those of a simulated, threshold wetland (i.e., one that meets wetland hydrology requirements in exactly 50 percent of years). The TWS approach requires detailed long-term precipitation and temperature data, soil characteristics, and considerable expertise with the DRAINMOD program.

No method to determine wetland hydrology based on short-term water-table measurements is entirely reliable or free of assumptions. Therefore, ultimate responsibility for the interpretation of water-table monitoring data rests with the appropriate Corps District.

REPORTING OF RESULTS: Warne and Wakeley (2000) provided a comprehensive checklist of information that should be included in the report of a groundwater monitoring study. The report should also include a justification for any deviations from procedures given in this Technical Standard.

The report should include a clear, graphical presentation of daily water-table levels at each well plotted over time and shown in relation to the soil surface and the 12-in. depth, the depth of the monitoring well, growing season starting and ending dates, local precipitation that year, and normal precipitation ranges based on WETS tables. Another useful feature is a diagram of the soil profile at the well location including depths and textures of each major horizon. An example graph with many of these features is shown in Figure 4 (Sprecher 2000).

ACKNOWLEDGMENTS: The initial outline for this Technical Standard was developed at a workshop in Decatur, GA, in September 2003. Participants (in alphabetical order) were Mr. William Ainslie, U. S. Environmental Protection Agency (USEPA), Region 4; Mr. Bradley Cook, Minnesota State University, Mankato; Mr. Jason Hill, Tennessee Tech University (TTU); Ms. Julie Kelley, Geotechnical and Structures Laboratory (GSL), U. S. Army Engineer Research and Development Center (ERDC); Dr. Barbara Kleiss, Environmental Laboratory (EL), ERDC; Dr. Vincent Neary, TTU; Mr. Chris Noble, EL-ERDC; Dr. Bruce Pruitt, Nutter and Associates, Inc.; Dr. Thomas Roberts, TTU; Mr. Paul Rodrigue, USDA Natural Resources Conservation Service (NRCS);

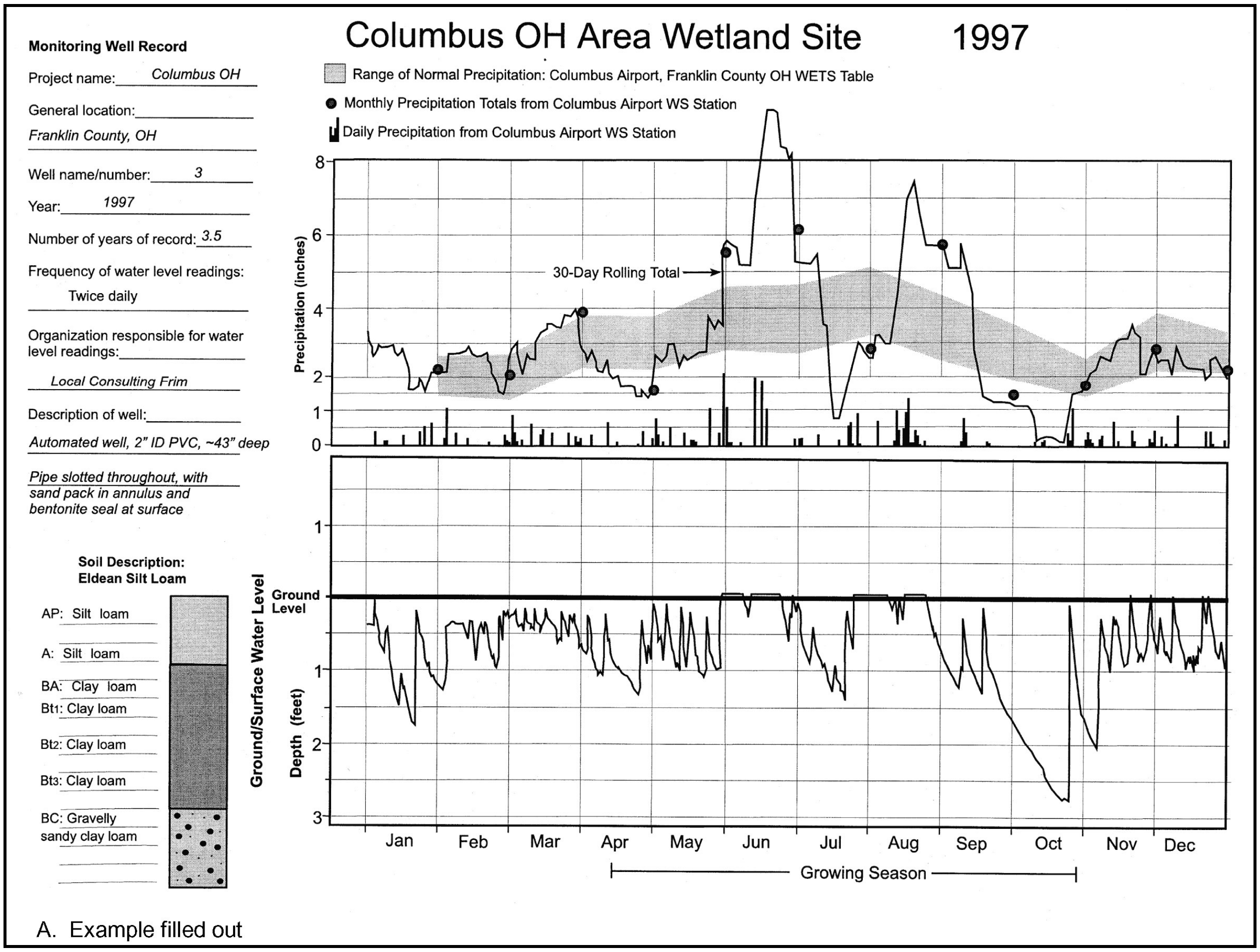

Figure 4. Example of graphical presentation of water-table monitoring data (Note that this example uses a deeper well than the 15 in. specified in this Technical Standard)

Dr. Steven Sprecher, U. S. Army Engineer (USAE) District, Detroit; and Dr. James Wakeley, EL-ERDC. The first draft was written by Drs. Neary and Wakeley and Messrs. Hill and Noble. Technical reviewers included Harry Baij, Jr., USAE District, Anchorage; Mark Clark, NRCS; David D'Amore, U. S. Forest Service (USFS); Jackie DeMontigny, USFS; Michiel Holley, USAE District, Anchorage; Wesley Miller, NRCS; James Miner, Illinois State Geological Survey; Joe Moore, NRCS; Dr. Chien-Lu Ping, University of Alaska, Fairbanks; Ann Puffer, USFS; and Ralph Rogers, USEPA Region 10. A subcommittee of the National Technical Committee for Hydric Soils (NTCHS) provided an independent peer review in accordance with Office of Management and Budget guidelines. The authors are grateful to NTCHS members Drs. Michael Vepraskas and R. Wayne Skaggs, North Carolina State University; and Mr. Ed Blake, Mr. P. Michael Whited, Ms. Lenore Vasilas, and Mr. G. Wade Hurt, NRCS, for their comments and suggestions. The work was supported by Headquarters, U. S. Army Corps of Engineers through the Wetlands Regulatory Assistance Program (WRAP).

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Assistance Program, Mr. Bob Lazor (601-634-2935, *Bob.L.Lazor@erdc.usace.army.mil*). This technical note should be cited as follows:

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APPENDIX A. SOIL CHARACTERIZATION DATA FORM

Soil Characterization Data Form

Project Name________________________________ Date________________________
Personnel___________________________________ Soil Pit ID____________________

Horizon Depths (inches)	Texture	Matrix Color (Munsell moist)	Redoximorphic Features		Induration (none, weak, strong)	Roots
			Color	Abundance		

Comments:

APPENDIX B. MONITORING WELL INSTALLATION DATA FORM

Monitoring Well Installation Data Form

Project Name ______________________________ Date of Installation _______________
Project Location ____________________________ Personnel _______________________
Well Identification Code _____________________
Attach map of project, showing well locations and significant topographic and hydrologic features.

Characteristics of Instrument:
Source of instrument/well stock____
Material of well stock ______________________ Diameter of pipe _________________
Slot width_______________________________ Slot spacing _____________________
Kind of well cap ___________________________ Kind of well point/end plug _________
Installation:
Was well installed by augering or driving? ____
Kind of filter sand_________________________ Kind of bentonite_________________
Depth to lowest screen slots _______________ Riser height above ground _________
Was bentonite wetted for expansion? ____
Method of measuring water levels in instrument ____
How was instrument checked for clogging after installation?________________________________

	Soil Characteristics					
			Redoximorphic Features			
Instrument Diagram[a]	Texture	Matrix Color	Color	Abundance	Induration (none, weak, strong)	Roots

[a]Show depths (heights) of riser, well screen, sand pack, and bentonite in relation to soil horizons.