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Effects of Headcutting on Groundwater Levels in Bottomland Hardwood Wetlands of the Wolf River, Tennessee

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PURPOSE: The Wolf River in western Tennessee has experienced severe channel erosion in the form of headcutting and downcutting that has extended 17 km upstream from the location at which channelization ceased in 1964. A previous study (Wiens and Roberts 2003) indicated that groundwater levels in the bottomland hardwood (BLH) wetlands adjacent to the headcut reaches may be significantly lower than in unaltered reaches. The primary goal of the study documented herein was to determine if the groundwater hydrology of BLH forests adjacent to areas of the Wolf River in which headcutting has occurred have been altered such that substantial portions of the floodplain will no longer delineate as wetlands. A secondary objective was to compare the efficacy of two less rigorous techniques for monitoring shallow groundwater with the technique of installing standard groundwater monitoring wells (Figure 1). The current study will also provide quantitative baseline data for further research and for monitoring the progress or success of any future restoration programs.

Figure1. Groundwater monitoring along the Wolf River

BACKGROUND: Riparian forests and deepwater swamps represent the largest class of wetlands in the United States, with bottomland hardwood (BLH) forests accounting for most of the riparian wetland systems in the Southeast (Mitsch and Gosselink 1993). Large tracts of BLH wetlands were drained and cleared following European settlement (Dahl and Johnson 1991, Hefner et al. 1994). Of the estimated 8.5 million hectares of historic BLH in the lower Mississippi Valley (LMV), approximately 2 million hectares remain (Dahl 1990, The Nature Conservancy 1992). Nearly 60 percent of Tennessee's original wetland resources have been lost as a direct result of human activities (Fretwell et al. 1996) and the majority of those losses have been BLH forests in western Tennessee (Governor's Interagency Wetlands Committee and Technical Working Group 1998).

In the Southeast, most BLH wetlands have been hydrologically altered by the construction of levees and drainage ditches, the deepening and straightening of river channels (channelization), and/or the conversion of forests to non-forest uses such as agriculture. Often, the result of these hydrologic modifications is the loss or eventual loss of the naturally functioning wetland system (Fredrickson 1979, Maki et al. 1980, Wiens and Roberts 2003). BLH wetlands that remain are threatened by human expansion and development in nearly every location where they occur (Shankman 1999).

Large-scale conversion of BLH forests to agriculture and other non-forest uses produces dramatic increases in runoff and erosion of the adjacent bottomlands (Barnhardt 1988). The resulting sediment and debris are deposited downstream and fill the river channels, often causing blockages, which lead to increased flooding (Hupp 1992). In an attempt to "reclaim" the rivers and their floodplains, flood control efforts such as channelization were begun in the early 1900s (Simon and Robbins 1987, Hupp 1992). With the passage of the 1948 Flood Control Act, several federal programs were implemented to aid with flood control efforts and to promote the economic and agricultural development of the LMV (Newling 1998).

One initiative, the West Tennessee Tributaries Project (WTTP), coordinated channelization efforts in western Tennessee under the auspices of the U.S. Army Corps of Engineers (USACE) (Shankman and Samson 1991, State of Tennessee 1994). A primary objective of channelization was to control flooding and facilitate cultivation or development of the river valleys (Shankman and Samson 1991). Although flooding along the upper reaches of streams may have been reduced, the increased gradient of the straightened channels produced increases in both the frequency and magnitude of flooding along the downstream reaches (Shankman and Pugh 1992). The WTTP was halted by court order in 1970 (Shankman and Samson 1991, State of Tennessee 1994); however, the effects of the project have impacted nearly every river system in western Tennessee (Wilder 1998).

The extensive channelization efforts created other unanticipated problems. The morphological alterations fundamentally changed many hydraulic parameters (i.e., slope, depth, width, and channel roughness) of the natural river systems. The resulting higher velocity flows and steeper elevational gradients between shortened upstream and downstream sections accelerated erosional processes such as headcutting and downcutting (Robbins and Simon 1982). Headcutting is a progressive degradation that begins with scouring of the streambed at the head of the constructed channel and proceeds upstream. As the headcut progresses upstream, the scouring produces a downward and lateral degradation (downcut) in which the channel becomes progressively incised and results in lowering of the streambed and widening of the channel. Problems associated with headcutting include: (1) mass wasting of streambanks, resulting in widening of the channel and marked increases of in-stream large woody debris, (2) accelerated lateral channel migration, (3) increased deposition of sediment downstream as the channel seeks to return to the before-channelization gradient, and (4) lowering of groundwater levels adjacent to the headcut reach (Hupp 1992, USACE 1995, Diehl 1998, Wiens and Roberts 2003).

The Wolf River in western Tennessee has been affected by headcutting and downcutting since 1964, when channelization ended at river km 35.3 (river mile 21.9) (USACE 1995). At that time, the lower 35 km of the river in Shelby County, Tennessee, had been altered (USACE 1995). To date, a headcut proceeding upstream episodically at an average rate of 0.6 km per year has affected 17 km of the Wolf River upstream of the constructed channel. Within the initial reaches of the headcut where the channel is most severely incised, the streambed is, on average, 6 m lower and the channel is more than twice its original width (USACE 1995). As a result, flows seldom exceed channel capacity throughout most of the headcut reach and the Wolf River and its floodplain have essentially become disconnected (Wiens and Roberts 2003).

Wiens and Roberts (2003) investigated the hydrological impacts of headcutting on the adjacent BLH wetlands along a 13-km reach of the Wolf River during the winter and summer of 2000. Data, including depth to groundwater, were collected from relatively mature BLH wetlands adjacent to the channel. Shallow groundwater wells (1 m deep) were installed approximately 50 m from the riverbank at 13 sites according to standard protocols (Sprecher 1993). The results of that study showed that average groundwater levels were significantly lower along the headcut reach compared to the unaltered reach (78.6 cm and 46.4 cm below ground surface, respectively). Moreover, by late May, the groundwater along the headcut reach was more than 1 m below the ground surface, while the groundwater remained within 1 m of the ground surface along the unaltered reach throughout the collection period. According to the 1987 Wetlands Delineation Manual (Environmental Laboratory 1987), the BLH forests along the headcut reach would not have met the hydrologic criteria to be considered wetlands (i.e., saturated conditions within the top 30 cm of the soil for at least 5 percent of the growing season). If this hydrologic regime is now typical, these BLH forests have essentially become mesic terraces that would no longer qualify as wetlands.

Wiens and Roberts (2003) demonstrated that the hydrologic regime within the headcut reach had been altered; however, data were collected only during one year and the period was one of below average rainfall (U.S. Geological Survey 1999). Further, their study was based on hydrologic data from wells installed along transects parallel to, and approximately 50 m from, the river. It was unclear, therefore, how far the effects of altered hydrology extended away from the river and, subsequently, how much of the floodplain may have lost its characteristic wetland hydrology.

METHODS: The floodplain adjacent to the headcut reach was stratified into two sampling units defined as: (1) minimally incised (i.e., the area closest to the most recent headcut) and (2) deeply incised. Ninety-three temporary groundwater wells were installed (1 m deep) at 25-m intervals along twelve 200-m transects perpendicular to the channel. All transects were placed in areas were hydric soil indicators were present. Three replicate transects were located within the control area, six replicate transects were located in the minimally incised area, and three were located in the deeply incised area (Figure 2). Twelve standard wells (six upstream and six downstream of the headcut) had been previously installed by Wiens and Roberts (2003). At each of these existing wells, a temporary well was installed and a hole was excavated to compare results from the three sampling techniques. Holes were also excavated adjacent to each temporary well along all 12 transects to increase sample size for the comparison study. The depth to groundwater in the wells and holes was measured using a calibrated stick (Figure 2). Wells were monitored throughout the early part of the growing season (April and May 2002) following rain events when groundwater was likely to be within 1 m of the soil surface.

Analysis of Variance (ANOVA) was used to test for differences in mean depth-to-groundwater levels among treatments at each 25-m interval. Paired-difference t-tests were used to test for differences among methods in the comparison study. Significance was accepted at an alpha of 0.1.

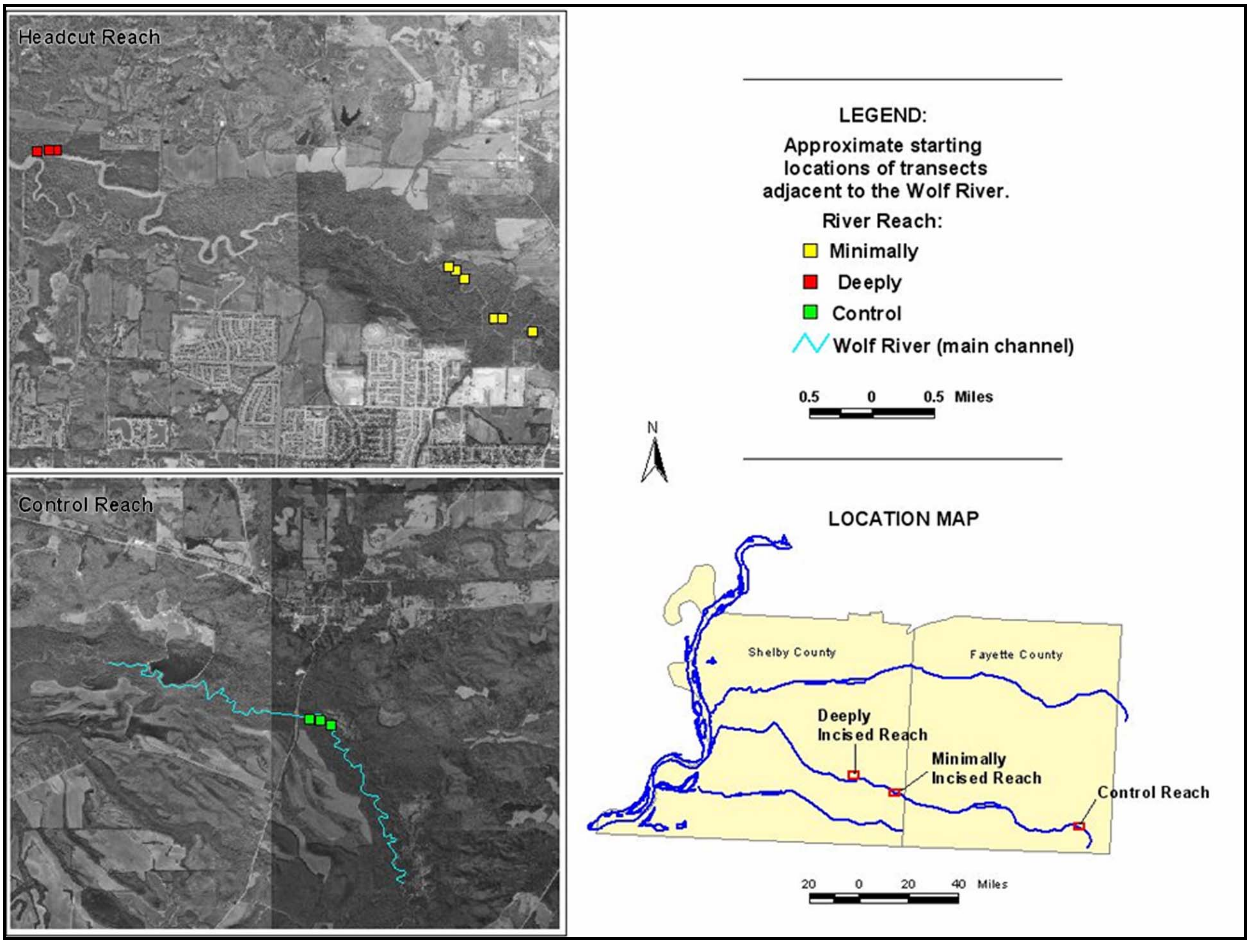

Figure 2. Approximate starting locations of transects within the Wolf River study area. Six replicate transects were located in the minimally incised area (yellow), three were located in the deeply incised area (red), and three were located within the control area (green)

RESULTS: Depth to groundwater was measured in the treatment and control reaches during April and May 2002. Prolonged flooding during the two April sampling periods resulted in portions of the study area being inaccessible and measurements could not be taken on consecutive days. In fact, in one period, there was a seven-day interval between the first and final sample. During the May sampling period, two separate measurements were obtained from all three areas (two treatments and one control) on five consecutive days. Thus, the May data are believed to be the most appropriate for comparing hydrology among the treatments and will be the focus of the remainder of this discussion. During the first sampling period (May 4–6), water inundated nearly the entire control area to a mean maximum flooding depth of approximately 16 cm following two significant rainfall events (Figure 2). Variable depth measurements (approximately -4 to +16 cm) were likely due to microtopographic variation along the transects. At both headcut areas, bankfull levels were rarely exceeded and flooding occurred for a brief period only in some portions of the minimally incised area. Mean groundwater levels at both treatments varied from approximately 11 to 67 cm below the surface (Figure 3). Significant differences in the mean depth to groundwater were observed at distances of 25 m ($p = 0.09$), 75 m ($p = 0.05$), and 100 m ($p = 0.09$) from the channel.

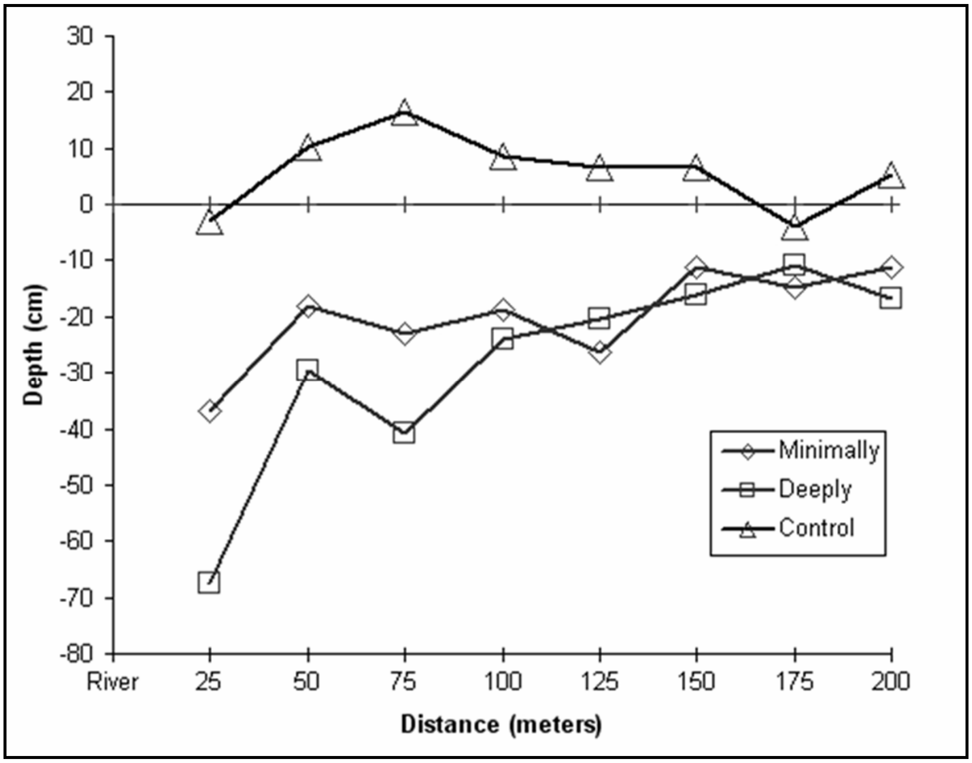

Figure 3. Average water level depths at 25-m intervals perpendicular to the Wolf River during the first sampling period (May 4–6, 2002)

During the subsequent sampling period (May 6–8), changes in both surface and groundwater had occurred in all areas. In the control reach, the floodwaters had receded and the only surface water present was that ponded in depressions and sloughs. Water levels were lowest in wells located both close to and farther from the river; measurements at intermediate distances indicated intermediate depths. In both headcut reaches, groundwater levels had also dropped substantially throughout the majority of the sample area (Figure 4). The general pattern in both headcut reaches was similar to that of the previous sample, but levels overall were lower, typically averaging between approximately 30 and 50 cm below the surface. Significant differences in the mean depth to groundwater were observed at distances of 25 and 75 m ($p = 0.10$ and $p = 0.09$, respectively).

COMPARISON OF GROUNDWATER MONITORING METHODS. Differences in groundwater measurements among the three methods (standard wells, temporary wells, and holes) ranged from 0–9.4 cm, but the majority of the measurements (84 percent) were within 5 cm of each other (Figure 5). Significant differences were detected when comparing standard well measurements with both temporary well and hole measurements, but no differences were detected between temporary wells and holes ($P=0.25$). There was no consistent pattern in measurements among the three techniques, but the greatest depth to groundwater was most often recorded in the standard wells (63 percent) and the shallowest depth most often in the temporary wells (53 percent). The average difference in measurements among the three methods ranged from 2.4 to 2.9 cm.

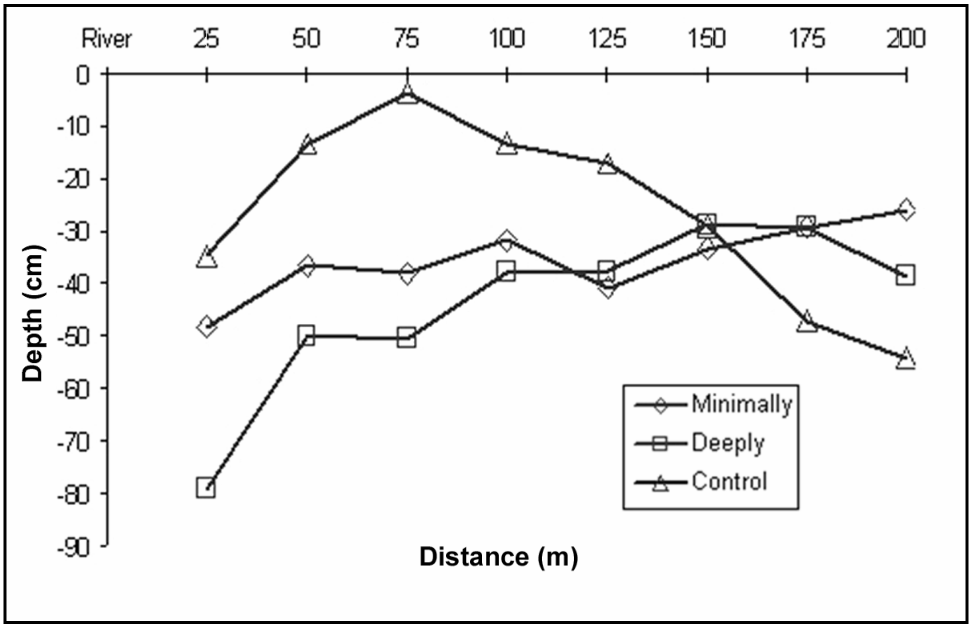

Figure 4. Average water level depths at 25-m intervals perpendicular to the Wolf River during the second sampling period (May 6–8, 2002)

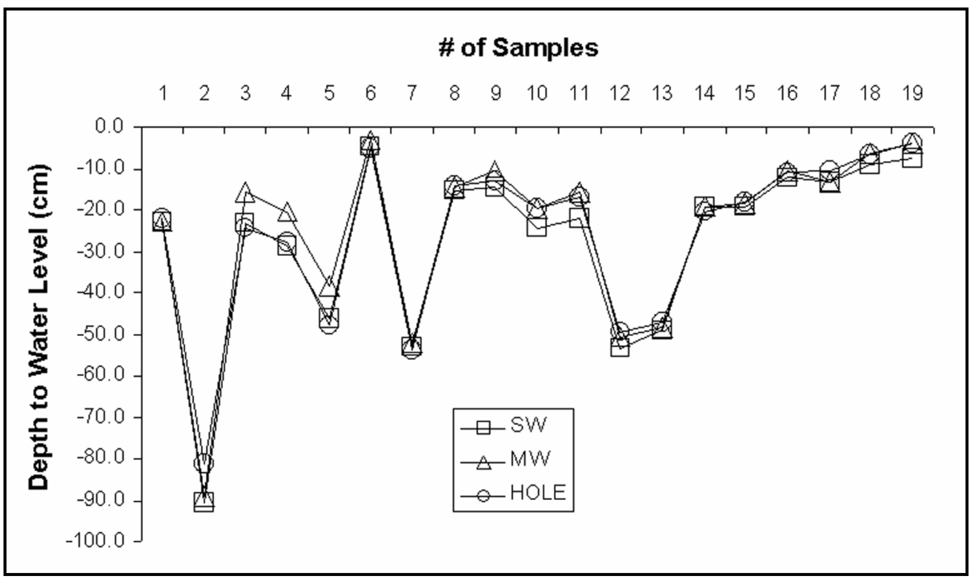

Figure 5. Comparison of groundwater measurements for three sampling techniques: (SW) standard monitoring well, (MW) modified monitoring well, and (HOLE) 1-m-deep hole

CONCLUSIONS: Approximately 17 km of the Wolf River has been affected by headcutting and downcutting as a result of channelization. Where erosion has been most severe, the steeped banks and widened channel have prevented the river from overtopping its banks, thus eliminating flooding of the adjacent wetlands. Studies have shown that drainage ditches that cut across floodplains effectively lower localized groundwater levels (Maki et al. 1980, Tucci and Hileman 1992). Headcut rivers essentially function as large drainage ditches by lowering the groundwater levels in the vicinity of the headcut reach. Wiens and Roberts (2003) documented that channelization and headcutting resulted in significantly lower groundwater levels along headcut reaches of the Wolf River. Their study, however, was conducted during a period of below-average rainfall (2000) and all measurements were taken within 50 m of the channel. The study documented herein was conducted during a typical rainfall year (USGS 1999), but nevertheless supported their conclusions. Furthermore, in almost all instances, groundwater levels in the unaltered (control) reach of the river were found to be substantially higher than in areas in which the channel has become incised. This was especially true at distances out to 125 m from the channel. In both the minimally and deeply incised areas, there was a trend of decreasing depth to groundwater with increasing distance from the channel. There was, however, considerable variability in groundwater levels, presumably due to topography, and it is not possible to predict groundwater conditions at a point within the floodplain based solely on its proximity to the channel. The trend was slightly different for the control area. Like the treatment areas, depth to groundwater decreased initially moving away from the channel but then began to increase again at a distance of 75 m. There are many potential confounding factors that may be responsible for this trend and it is not possible to pinpoint the cause (or causes). However, in the control area, the topographic variation was noticeably greater with sloughs and ridges being more numerous than in either of the incised areas. Thus, given the study design, some wells were potentially located in slightly higher spots, and others were potentially located near a slough that could have caused localized drawdowns of the groundwater, since sloughs have the same effect on groundwater levels as active channels and ditches. For example, it is likely that a large slough near the end of the control transect was responsible for the increasing depth to groundwater there.

Of special significance is the absolute level of the groundwater in the treatment areas relative to the control. In the control area, the floodplain was inundated for approximately 6 days following two significant rainfall events on May 1 and May 4 (NOAA record of climatological observations, May 2002). Groundwater then remained in the upper portion of the soil profile for several additional days. Except for the area closest to the channel (presumably the natural levee), groundwater levels were within 15 cm of the surface out to a distance of 125 m from the channel throughout the sampling period. It is not known how long this condition persisted after the sampling period, and whether or not "wetland hydrology" as defined by interpretation of the 1987 Wetland Delineation Manual (Environmental Laboratory 1987) existed as a result of this rainfall and flooding event. However, there are striking differences between the hydrologic regime of the control area relative to the portions of the floodplain in which the channel is incised.

In the study areas, the growing season is 238 days; thus 12 days of flooding or saturation to the surface are required to meet the criteria for wetland hydrology. In the control area, the possibility for the criteria to be met existed for at least 8 days (6 days of flooding and 2 days of saturated conditions) following only one flood event; while in both treatment areas, no flooding occurred and groundwater levels rarely reached the surface. Thus, the possibility of the wetland hydrology criteria being met in the headcut reaches seems unlikely. The implication is that continual downcutting of the channel has eliminated overbank flooding and that the larger channel has had the additional effect of lowering groundwater levels to the point that saturation no longer occurs in the upper portion of the soil profile. Bottomland hardwood forests adjacent to the headcut reaches that presumably once were jurisdictional wetlands no longer meet that criterion.

To be considered a jurisdictional wetland, an area must possess wetland hydrology, soils, and vegetation. Although this study focused on groundwater levels within the wetlands adjacent to the river (i.e., the hydrology), the plant community had been previously characterized by Wilder (1998) and Wiens and Roberts (2003). Wilder (1998) found that wetland species were common in both headcut and natural reaches, but that there was a general trend toward fewer wetland-tolerant species and more upland species in areas where headcutting had occurred. Similarly, Wiens and Roberts (2003) found that the communities along the headcut and natural reaches contained similar numbers of obligate, facultative wetland, and facultative plant species, but that facultative upland species were twice as common in the headcut areas. Though no vegetation data were collected for this study, the authors' conclusion that the areas adjacent to the headcut reaches no longer meet wetland criteria is supported by these previous studies.

COMPARISON OF GROUNDWATER MONITORING METHODS: While the floodplains of low-gradient rivers such as the Wolf are characterized by little topographic relief, there were minor elevation changes that could not be accounted for. This alone may have had some effect on measurements, but the authors believe that it was minimal and did not influence the overall outcome of the study. None of the wells were placed in a location that was obviously either concave or convex; however, the influence of nearby features could not be completely controlled. The more likely influences on the variable groundwater levels were differences in underlying strata that either allowed or impeded downward flows. Although the soils mapped in all areas sampled were of the same soil series and had generally similar properties, small-scale (within a few meters) variability in soil conditions can be considerable, as evidenced by the variability in measurements among the replicate wells in both the treatment and control areas. Another confounding factor previously mentioned was the presence of active and remnant channels within the floodplain itself. These internal drainages have the potential to influence local groundwater levels.

Although significant differences among the three procedures (standard wells, temporary wells, and holes) for determining shallow groundwater levels were detected, differences were minor and all three procedures yielded very similar measurements. The average difference among the three procedures was less than 3 cm and nearly all were well within the level of accuracy desired for most wetland studies. Due to various constraints, it was not possible to survey well heights to correct for differences in ground surface elevation. Although an attempt was made to eliminate this bias by placing wells and holes in close proximity to each other, slight elevational changes could account for some of the differences in measurements among the three methods. Localized variability in actual levels due to differing subsurface conditions (e.g., soil texture, depth to fragipan, root channels, differential uptake by plant roots) is another potential explanation. The U.S. Army Corps of Engineers (1993) noted that in wells whose bottoms were in an unsaturated horizon of higher permeability, water might be "wicked" away from the well, thus producing lower readings than actual water tables. Of the nine other reasons listed that shallow wells or piezometers might sometimes produce faulty results (U.S. Army Corps of Engineers 1993), only plugged screens were a potential source of error in this study.

The findings summarized herein have some important implications regarding groundwater determination and monitoring. It is a common practice to install wells to monitor groundwater for the purpose of determining whether or not areas have "wetland hydrology." Wells are especially useful in mitigation projects where there is a need to determine if specific "performance standards" are being met. In large mitigation areas, the installation of numerous wells may be required. Wells are not expensive, but the time and effort to purchase the materials, construct the wells, and install them can be significant. If the project site is a considerable distance from a road or trail, transporting sand, bentonite, and concrete can be a daunting task. This study indicated that such effort may not be required to obtain accurate groundwater measurements and that both alternatives investigated yielded results comparable to the standard wells. If soils are relatively permeable and water enters a hole and stabilizes quickly, the authors see no need to install wells in cases where only shallow groundwater is of interest. If this is not the case, installation of wells may be warranted, especially where repeated measurements at numerous locations, or continuous (automatic) recordings, are desired. This study further suggests that if wells are needed, the use of sand and bentonite as recommended by the U.S. Army Corps of Engineers (1993) may be optional. The installation of wells by simply driving them into the ground with a mallet required minimal time and equipment. Additional studies should be conducted in other areas with different soil types to determine if these results are widely applicable in other areas.

POINTS OF CONTACT: For additional information, contact Dr. Thomas H. Roberts at Tennessee Technological University (931) 372-3138 or the Manager of the Wetlands Research Program, Mr. Glenn Rhett (601)-634-3717, *Glenn.G.Rhett@erdc.usace.army.mil*. This technical note should be cited as follows:

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