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Effects of Headcutting on the Bottomland Hardwood Wetlands Adjacent to 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 (Figure 1). Due to wider and deeper channel dimensions in this reach, the river no longer inundates the floodplain. This technical note describes a study to determine how this hydrologic change has affected the bottomland hardwood (BLH) wetlands adjacent to the Wolf River. Specific objectives were to compare shallow groundwater levels, herbaceous community composition, and growth patterns of *Quercus phellos* L. in wetlands adjacent to headcut and reference portions of the channel. This study also will provide quantitative baseline data for further research and for monitoring the progress or success of any future restoration programs.

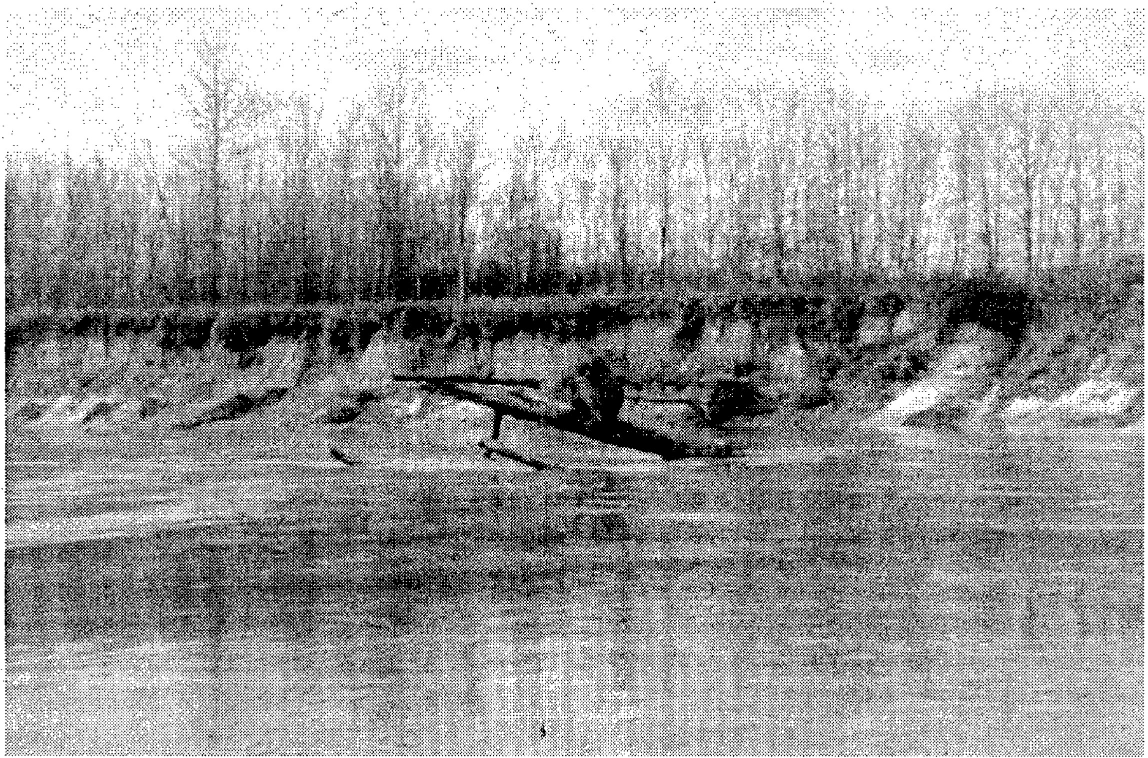

Figure 1. Headcutting on the Wolf River, Tennessee

BACKGROUND: Riparian BLH forests and southern deepwater swamps constitute the most extensive classes of wetlands in the United States (Mitsch and Gosselink 1993). The largest concentration of these wetlands is located along the Lower Mississippi Valley (LMV) from southern Illinois to the Gulf of Mexico (Newling 1998). BLH wetlands are currently threatened by human expansion in nearly every location that they occur (Shankman 1999). More than 75 percent of the historic BLH wetlands in the LMV have been lost (Dahl 1990).

These wetlands perform many functions, including storing and slowing surface water flows, providing nutrients to the floodplain through deposition of particulates and organic matter, exporting minerals and nutrients to in-stream and downstream systems, and providing habitat for many plant and animal species (Mitsch and Gosselink 1993; Wilder and Roberts 2002). These processes are driven hydrologically by seasonal flooding that occurs in pulses during winter and spring (Mitsch and Gosselink 1993).

During the 1920s and 1930s, the natural meandering channels of the Wolf River and many of its tributaries began to be replaced by straightened channels (U.S. Army Engineer District, Memphis, 1995). In 1964, channelization ended at river km 35.3 (river mile 21.9) at the mouth of Gray's Creek (U.S. Army Engineer District, Memphis, 1995). While large floods occurred less frequently in the upper reaches of the system, the convergence of flows downstream proved too large for the receiving river channel to accommodate. This resulted in more frequent flooding of greater depth and duration downstream, and a concurrent increase in property damages in Memphis (Poff et al. 1997; U.S. Army Engineer District, Memphis, 1995).

Because the upstream end was not "armored" to prevent scouring and erosional processes (U.S. Army Engineer District, Memphis, 1995; Diehl 1998), both headcutting and downcutting have ensued since 1964 (Brush and Wolman 1960; Diehl 1998). Although episodic in nature, the Wolf River headcut has been proceeding upstream at 0.6 km per year on average, and to date has affected 17 km of river upstream of the constructed channel. Currently, the headcut is in the vicinity of the Collierville-Arlington Road (CAR) bridge. In the most downstream reaches of the headcut, the bed level has dropped an average of 6 m, and the channel is more than twice the original width (U.S. Army Engineer District, Memphis, 1995).

Although the typical annual flood regime still exists in the BLHs upstream (U.S. Army Engineer District, Memphis, 1995), flows in the headcut reach seldom exceed channel capacity, and inundation of the floodplain has essentially ceased. The last major flood that occurred in the impacted reach of the study area was in April 1973, with a gage height of 7 m and a peak flow of 512.6 m^3/s (Germantown Gage, *http://ncdc.noaa.gov/servlets/ACS*) (U.S. Army Engineer District, Memphis, 1995)); thus, the Wolf River and its floodplain have essentially become disconnected. The effects of this change on groundwater levels and on the forest community are unknown.

EFFECTS OF CHANNELIZATION AND HEADCUTTING ON RIPARIAN ECOSYSTEMS: Channelization and headcutting cause a disruption of the flood regime that can change critical river-floodplain interactions, thereby degrading adjacent floodplain ecosystems (Shankman 1999). Deepened channels and drainage ditches that are cut across floodplains effectively lower the elevation of localized shallow groundwater (Kuenzler et al. 1977; Maki et al. 1980; Bedinger 1981;Tucci and Hileman 1992). Native plant communities in bottomland systems are affected by lower water tables and reduced hydroperiods (Bragg and Tatschi 1977; Fredrickson 1979; Maki et al. 1980; Bedinger 1979; Reiley and Johnson 1982; Hupp 1992). Shankman (1999) found that the disruption of free-flowing streams sometimes altered conditions of these habitats such that they no longer were capable of supporting wetland species. The drier conditions that commonly follow channelization (Rosgen 1996; Tucci and Hileman 1992) can allow mesic species to compete with those adapted to hydric conditions (Fredrickson 1979; Maki et al. 1980; Shankman 1996).

Because of the longevity of canopy tree species, changes in community composition would first become apparent in the herbaceous layer (Shugart 1987). Shankman (1996) noted that changes in canopy species dominance are evident only after many years following dramatic environmental changes. Maki et al. (1980) found that in channelized systems, a mesic understory develops under a more hydric overstory. There are, however, many variables that affect community dynamics. For example, successful colonization for some species may be episodic because they require a series of dry years to become well established (Shankman 1999).

STUDY AREA: The Wolf River is located in the northeastern corner of the LMV, and is 138 km long with a watershed area of 2,121 km^2. From its headwaters in Tippah County, Mississippi, the river flows to the northwest through western Tennessee to meet the Mississippi River near Memphis (Figure 2). In spite of the extensive alteration of the BLH wetlands, 12,829 ha of wetlands remain within the Wolf River Basin. The upper reaches in Tennessee contain some of the few remaining unchannelized sections of higher order river in the LMV. Because of their scarcity, unaltered ecosystems of this type have been designated as nationally significant (U.S. Army Engineer District, Memphis, 1995). The major factors affecting the Wolf River and its associated BLH ecosystem include (1) channelization of the headwaters in Mississippi and of the lower 35 km in Shelby County, TN; (2) urban development throughout much of the lower reach; and (3) extensive conversion of BLH wetlands to agriculture, especially in the headcut reach (U.S. Army Engineer District, Memphis, 1995).

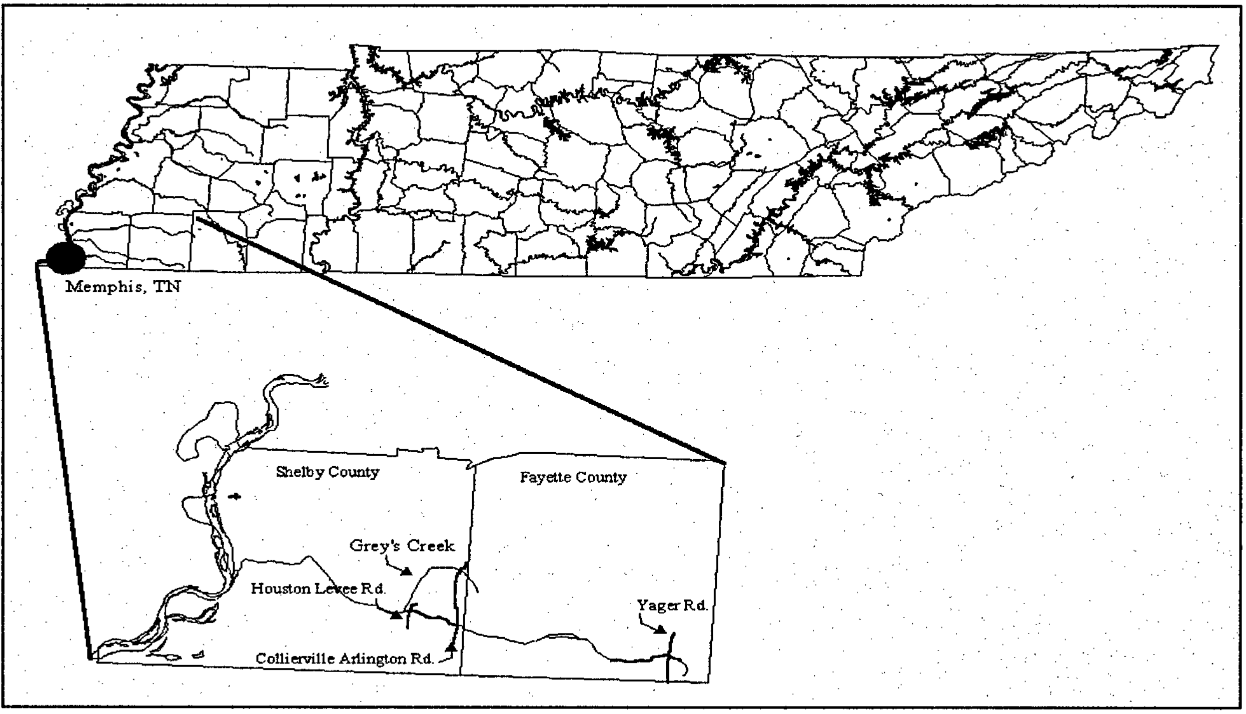

Figure 2. Location of study sites adjacent to the Wolf River in southwestern Tennessee

Wilder and Roberts (2002) subdivide the BLHs adjacent to the channel of the Wolf River into three easily identifiable zones: flats, depressions, and ridges. The focus of this study was the flats, commonly referred to as back swamps, which make up the majority of the floodplain. The term "flats" as used in this context differs from the "flats" subclass in the hydrogeomorphic (HGM) wetland classification (Brinson 1993), which consists of wetlands driven primarily by precipitation, not overbank flooding. Because in this study area, flats in unaltered systems are alternately dry or inundated depending on recent rainfall and overbank flow events, it was believed that the effects of headcutting and downcutting would be more strongly expressed there than in either of the other two zones.

The natural plant community of BLH flats in the Wolf River Basin is characterized by the presence of green ash (*Fraxinus pennsylvanica* Marsh.), willow oak (*Quercus phellos* L.), water oak (*Q. nigra* L.), cherrybark oak (*Q. pagodifolia* Ell.), and swamp chestnut oak (*Q. michauxii* Nutt.). Common understory species include ironwood (*Carpinus caroliniana* Walter), slippery elm (*Ulmus rubra* Muhl.), and deciduous holly (*Ilex decidua* Walter). Common ground-level species include trumpet creeper (*Campsis radicans* L.), poison ivy (*Rhus radicans* L.), false nettle (*Boehmeria cylindrica* (l.) Schwartz), and various sedges (*Carex* spp.) (Wilder 1998).

Thirteen sites that were representative of the HGM low-gradient riverine flats subclass in Tennessee (Wilder and Roberts 2002) were selected from permitted access areas during a reconnaissance of the Wolf River floodplain in spring 1999. Eight reference sites were in Fayette County within the Wolf River Wildlife Management Area near La Grange in an unaffected region of the river between Yager Road and the "Ghost section" of the Wolf River (Figure 2). Considerations for site selection included the presence of a relatively undisturbed, mature (i.e., average overstory trees >30 cm diameter breast height (dbh)) BLH community and landowner permission to access the sites. The five headcut study sites were in Shelby County, within the upper 13.5 km of the headcut reach, between the Houston Levee Road at river km 39.9 (river mile 24.3) and the Collierville-Arlington Road (CAR) at river km 52.7 (river mile 32.7) (Figure 2). The headcut sites were located on private lands and lands acquired by the Wolf River Conservancy for use as a greenway. These five sites approximately coincided with locations chosen by the U.S. Army Corps of Engineers as potential restoration sites (Davis 1998). Because of the progressive nature of the headcutting process, there is some variation between sites adjacent to the headcut river channel.

METHODS:

Subsurface Hydrology. Shallow groundwater wells (1 m deep) were installed approximately 50 m from the riverbank at each of the 13 study sites according to protocols in Sprecher (1993). Groundwater measurements were conducted at each well on a twice-monthly basis between January and June 2000. Because the gradient of the Wolf River floodplain was very low (0.04 percent) and plots were located near the river in the flats, headcut and reference study areas were assumed to be hydrologically comparable. A Split Plot, Repeated Measures Analysis of Variance (ANOVA) (Zar 1996) was used to determine whether differences existed in the mean groundwater levels between the two treatments. Differences in this and all other analyses were considered significant if $p \leq 0.05$.

Dendrological Analysis. Eighteen willow oak trees (*Q. phellos* L.) were selected from relatively mature BLH stands in the flats zone adjacent to both the headcut and reference sections of the river (for a total of 36 trees) during June 2000. Stands were relatively homogenous in species composition and structure. Trees cored were canopy-level individuals that appeared healthy and showed no signs of heart rot. It was presumed that historically, trees in both impacted and non-impacted areas had similar hydroperiods.

Two increment cores were taken per tree from opposing directions using a 40-cm-long, 5.15-mm-diameter increment borer. Cores were transported to the lab in labeled plastic straws and prepared according to procedures outlined in Stokes and Smiley (1968). Skeleton plotting and cross-dating were conducted according to protocols found in Stokes and Smiley (1968) to determine accurate dates for each ring. Ring widths were measured to the nearest 0.001 mm and converted into basal area increments (cm^2) to remove age-related growth differentials. Cross-dating accuracy was confirmed using the computer program COFECHA (Holmes 1983). Average growth rates were compared using a Split Plot, Repeated Measures ANOVA (Zar 1996) to determine if differences existed between treatments. Within treatments, growth rates between two time intervals (1964-1989 and 1990-1999) also were compared using the same analysis.

Herbaceous Plant Community Assessment. Plant surveys were conducted during May 2000. Each of the 13 groundwater wells was used as the midpoint of a 100-m transect oriented parallel to the stream channel in an east to west direction. At 10-m intervals on the south side of the transect, ground level vegetation was sampled inside 1-m^2 quadrats. The number of individuals and the percent cover by species were recorded. Density and coverage measurements from the two treatments were compared using a *t*-test. The Bray-Curtis version of Sorenson's Similarity Index (SSI) (Spatz et al. 1970; Mueller-Dombois and Ellenberg 1974; Chambers 1983) was used to compare communities in the two treatments. Relative density, relative frequency, and relative coverage were calculated for each species encountered. These results were combined to render an importance value (IV) for each species. The IVs for all species found in each treatment are mathematically combined to provide the SSI. The plant communities were considered different if the SSI value was less than 0.5 (Barbour et al. 1999).

Prevalence indices (PIs), which reflect the degree of association between plants and their tolerance for wetness, were calculated for the plant communities in both treatments according to protocols outlined by the Federal Interagency Committee for Wetland Delineation (FICWD) (1989). This relationship is described in the *National List of Plant Species that Occur in Wetlands* (Reed 1988). The PI is calculated as follows: obligate plants are assigned a score of 1, and each group following with lower tolerance for hydric conditions is represented by the next consecutive number up to 5. After the plant species are identified, the number of occurrences of each species (with a known indicator status) is multiplied by the respective index score; for example the number of obligate species is multiplied by one. This process is repeated for each class of species (Facultative Wetland through Upland plants) and the numbers for each group are summed. This number then is divided by the total occurrence for all status classes to derive a score for the overall community (FICWD 1989). This score is interpreted as a measure of the relative "wetness" of the community. For example, a PI of 2.52 would indicate that the community is composed of species with a tolerance to wetness between Facultative and Facultative Wet.

RESULTS AND DISCUSSION:

Subsurface Hydrology. Between the months of January and June 2000, groundwater fluctuated, but was present within the top 1 m of the soil surface in both treatments (Figure 3). Levels were significantly lower ($p = 0.006$) in the headcut reach (78.6 ± 31.8 cm) than in the reference reach (46.4 ± 25.4 cm) Even in the headcut reach, groundwater levels generally remained within 60-70 cm of the surface through much of the spring, but by late May, the groundwater had dropped to nearly 1 m and several of the wells were dry. Wells in the reference reach continued to have water in them throughout the data collection period.

According to the 1987 *Wetland Delineation Manual* (Environmental Laboratory 1987), soils must be flooded, ponded, or saturated within the top 30 cm (approximately 12 in.) of the soil surface for a minimum of 5 percent of the growing season (12 days in this study area) (U.S. Department of Agriculture Soil Conservation Service 1989) in order to meet the criteria for wetland hydrology. Measurements taken between January and June 2000 documented that this criterion was met at plots in the reference reach, but not at those in the headcut reach. Although it is probable that the increased slope of the water table extends the length of the headcut, there currently are no data to indicate how far these effects extend away from the river. The wells in this study were relatively close to the channel (only 50 m away in a floodplain hundreds of meters wide); so while the water table slope has increased there, it may still be close to the surface further from the river.

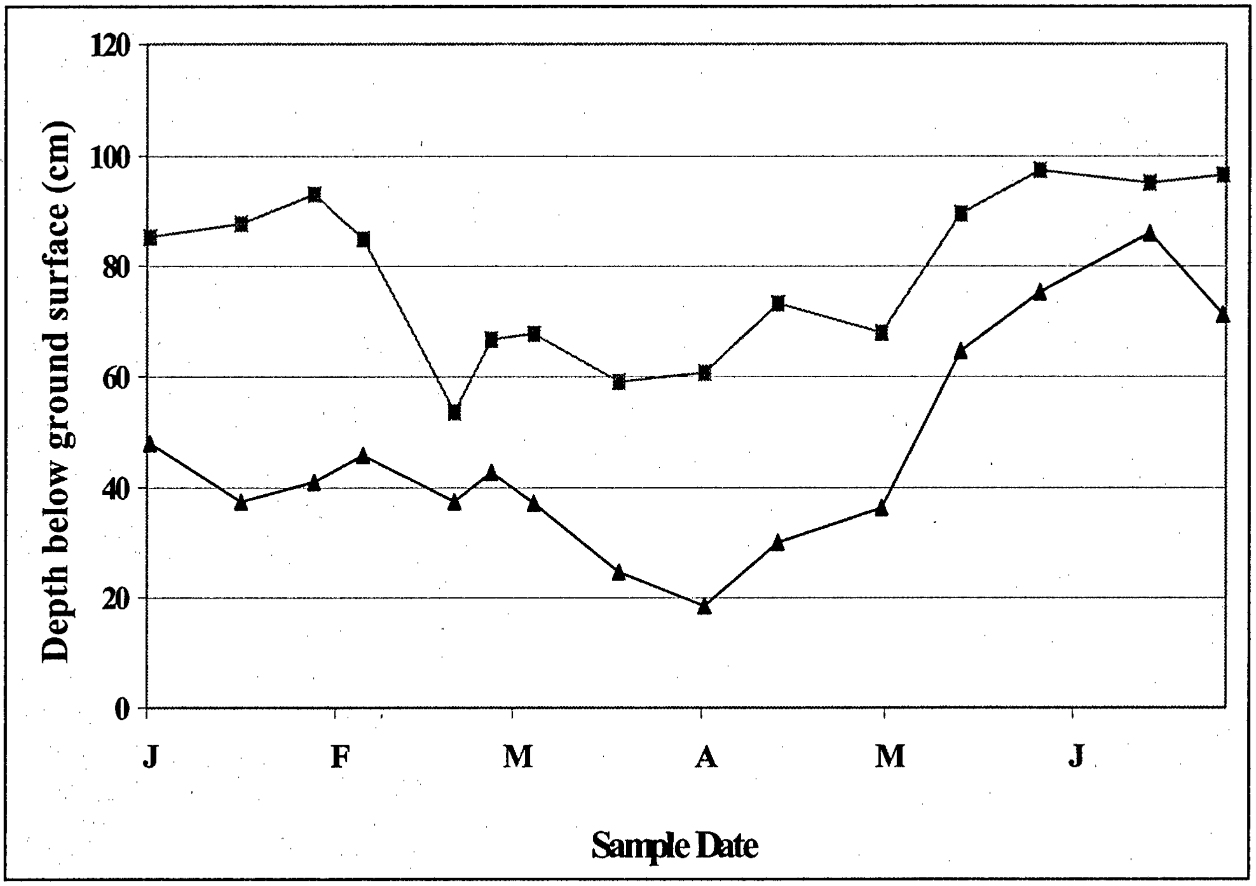

Figure 3. Mean depth (cm) to shallow groundwater in bottomland hardwoods adjacent to the Wolf River

Dendrological Analysis. Trees cored were similar in age (Table 1); thus, it is believed that they provide a valid means of comparing growth between the two areas. Growth rates (as reflected by basal area increments) from 1934 to 1999 did not differ between reference and headcut study sites (mean 42.62 ± 1.64 cm^2; mean 39.92 ± 2.14 cm^2, respectively). There was however, a pattern of slightly accelerated growth in the reference reach over that of the trees in the headcut reach that persisted for decades until the late 1980s. After that time, the growth rate of trees in the headcut reach began to exceed that of the trees in the reference reach (Figure 4).

Table 1
Descriptive Statistics of *Quercus phellos* L. in Bottomland Hardwoods Adjacent to Headcut and Reference Reaches of the Wolf River

Measurement	Headcut	Reference
Mean dbh (cm)	55.47	63.62
Mean Age (years)	45	57
Mean Ring Width (mm)	5.40	5.55
Standard Deviation	2.24	1.75
Mean Growth in Basal Area Increments (cm^2)	39.92	42.62
Standard Deviation	2.14	1.64

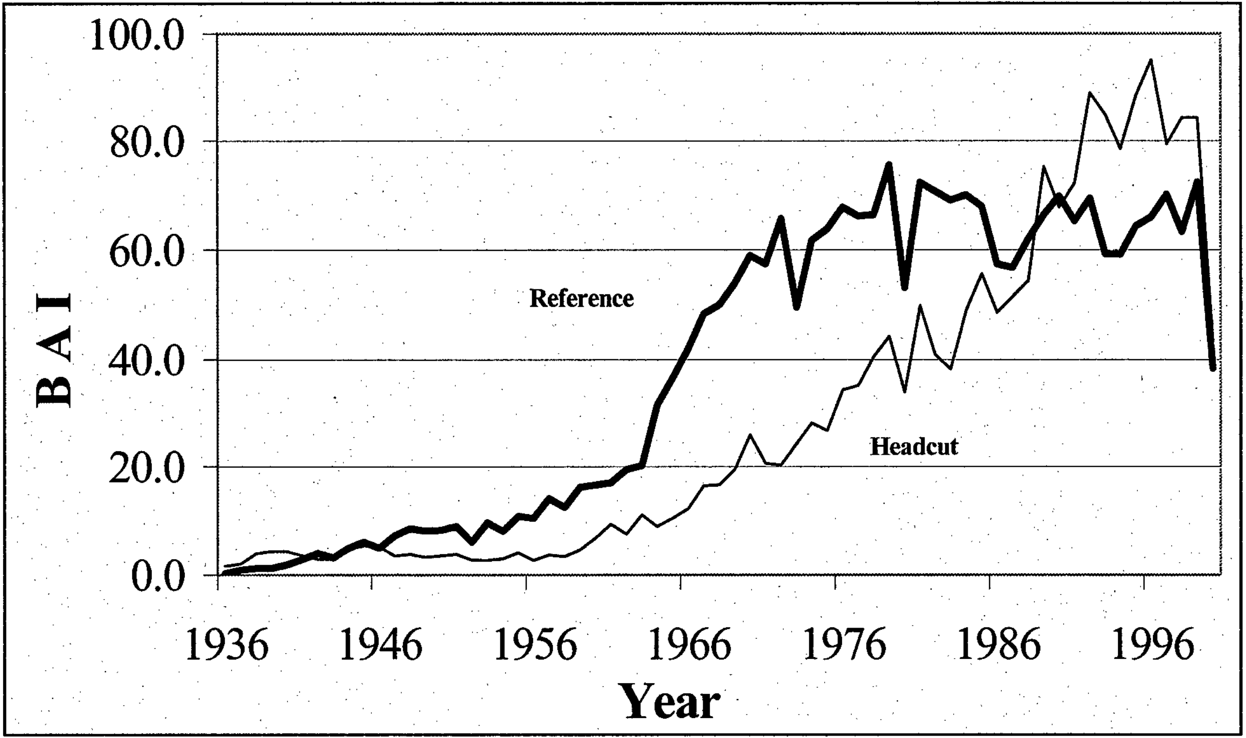

Figure 4. Average annual growth rates of *Quercus phellos* L. in basal area increments (BAI) (cm^2) by year in BLHs adjacent to the Wolf River

When growth in the reference reach from 1960 (near the end of the channelization project and when growth rates began to diverge) to 1989 was compared to that during 1990 to 1999 (53.83 ± 17.54 cm^2 and 65.41 ± 4.37 cm^2, respectively), there was no difference (p = 0.07). The growth rate in the headcut reach, however, was higher ($p = 0.0001$) during the 1990-1999 period (81.88 ± 9.15 cm^2) than during the previous period (30.56 ± 17.70 cm^2). Because trees in both treatments were selected from stands that generally were similar in structure, composition, and (as was discovered) age, forest management (and factors that it might affect such as competition) probably was not the cause of the increased growth rates in the headcut area. We believe the more likely factor was the significant alteration in hydology due to headcutting. Changes to channel morphology have led to a reduction in overbank flooding (complete elimination at the most downstream sites) and lowered groundwater levels throughout the headcut reach. This drying presumably has been sufficient to reduce the stress to the trees brought about by prolonged anoxic soil conditions during the growing season, but has not been so severe that moisture has become limiting. Mitsch and Gosselink (2000) reviewed the effects of hydroperiod on tree primary productivity and concluded that "the highest productivity occurs in systems that are neither very wet nor too dry, but have either average hydrologic conditions or seasonal hydrologic pulsing." Apparently the study sites in the headcut reach are receiving sufficient hydrology from direct precipitation and upland runoff to sustain higher-than-normal growth rates. It is uncertain whether this trend will continue into the future.

Herbaceous Plant Community Assessment. A total of 75 species were identified in the two treatment areas. Thirty-eight species were common to both the reference and headcut reaches (Table 2); however, the composition of the herbaceous community in the two reaches differed substantially (SSI = 0.35).

Table 2
Taxonomic Characteristics of the Herbaceous Plant Community in Bottomland Hardwoods Adjacent to Headcut and Reference Reaches of the Wolf River

Taxonomic Level	Cumulative Total	Number in Common	Number Unique to Reference Reach	Number Unique to Headcut Reach
Families	41	21	14	6
Genera	60	31	19	10
Species	75	38	25	12

Even given the differences in composition, mean PI scores were identical (PI = 2.4) and generally similar numbers of obligate, facultative wetland, and facultative species were present in both communities (Table 3). Facultative upland species, however, were twice as common in the headcut reach as in the reference reach. Facultative upland plants generally lack the physiological and structural adaptations to tolerate saturated soils (Mitsch and Gosselink 1993; Barbour et al. 1999) and their increased presence in the headcut area indicates drier conditions. As with the tree growth, we believe that direct precipitation and upland runoff have been sufficient to maintain the overall integrity of the original community in the headcut reach, but the increasing presence of facultative upland species suggests that changes are occurring.

Density and percent cover of vegetation were significantly lower in the headcut reach than in the reference area (Table 4). Changes in hydrology may be responsible in part for this, but the more probable cause is the increased shading from the thicker shrub layer (<10 cm dbh, >1 m high) present. Although data on the shrub layer were not collected, common privet (*Ligustrum vulgare* L.) was present in several plots within the headcut reach.

Table 3
Indicator Status and Prevalence Indices of the Herbaceous Plant Species in Bottomland Hardwoods Adjacent to Headcut and Reference Reaches of the Wolf River

Indicator Status	Definition	Headcut	Reference
Obligate wetland species	Occur in wetlands >99% of the time	5	8
Facultative wetland species	Occur in wetlands 67%-99% of the time	29	21
Facultative species	Occur in wetlands 34%-66% of the time	17	26
Facultative upland species	Occur in wetlands 1%-33% of the time	6	3
Upland species	Occur in wetlands <1% of the time	0	0
Prevalence Index	Association between a plant community and its tolerance for wetness (1 – obligate, 5 – upland)	2.4	2.4

Table 4
Characteristics of the Herbaceous Community of Bottomland Hardwoods Adjacent to Headcut and Reference Reaches of the Wolf River

Characteristic	Headcut	Reference
Number of Species (cumulative total)	49	62
Density #/m^2 (mean, ± SD)	49 ± 101^A	84.5 ± 62^B
Percent Cover #/m^2 (mean, ± SD)	20 ± 17^A	30 ± 25^B
Note: Values followed by the same letter are similar		

CONCLUSIONS: All aspects of this study suggest that the BLHs adjacent to portions of the Wolf River affected by headcutting have become much drier. This is a pattern similar to that seen in wetlands adjacent to intentionally channelized rivers and streams. Headcutting and downcutting in portions of the Wolf River have mimicked the channelization process by creating a channel that is deep enough and wide enough to contain most flows and essentially have eliminated overbank flooding. This study documented that these processes also have resulted in groundwater dropping to levels significantly lower than in non-headcut areas. This study was, however, conducted during a period of below-average rainfall, but additional groundwater data from a normal rainfall year (Moscow, TN, weather data at *ncdc.noaa.gov/servlets/ACS*) documented the same pattern. Although the water tables were nearer the surface during spring 2002 in the wells in the headcut reach, they were still mostly below 30 cm. If the hydrologic regime documented in this study is now typical, the BLH forests immediately adjacent to the headcut reach *no longer meet either the flooding or saturation criteria necessary to be considered wetlands.*

An examination of the growth rates of *Q. phellos* L. suggests that the elimination of flooding and lowering of the groundwater table also have begun to affect the BLH community. It is likely that changes in hydrology were the primary factors responsible for the increased growth rates documented in the headcut reach. It should be noted that the increase in growth should be viewed negatively as it represents a deviation from "normal" growth in BLH systems. More subtle changes also were documented in the herbaceous plant community composition and in the structure of both the shrub and herbaceous layers. Although the community is still dominated by wetland plants (PI = 2.4), there was an increase in the number of less flood tolerant species in the headcut reach. If this shift in composition continues, the nature of the BLH community has the potential to change dramatically during the next several decades.

POINT OF CONTACT: For additional information, contact Deborah J. Shafer ((601) 634-3650, *Deborah.J.Shafer@erdc.usace.army.mil*), or the Manager of the Wetlands Research Program, Mr. Glenn G. Rhett ((601) 634-3717, *Glenn.G.Rhett@erdc.usace.army.mil*). This report should be cited as follows:

> Weins, K., and Roberts, T. (2003). "Effects of headcutting on the bottomland hardwood wetlands adjacent to the Wolf River, Tennessee," *WRP Technical Notes Collection* (ERDC TN-WRP-HS-CP-2.1), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/wrtc/wrp/tnotes/tnotes.html*

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