Implications for Adaptive Habitat Management of the Overton Bottoms North Unit, Big Muddy National Fish and Wildlife Refuge, Missouri

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Abstract

Integrated, landscape-scale investigations of ecological responses to hydrologic reconnection of the flood plain at Overton Bottoms, Missouri, demonstrate the value of multidisciplinary approaches to adaptive management of flood-plain restoration. Surficial geologic mapping at Overton Bottoms North Unit documented the foundation of materials and topography that influence the spatial distribution of water on the flood plain. Surface and subsurface hydrologic investigations documented the temporal variability of hydrologic events affecting the flood plain, and how surficial geology and excavation of a side-channel chute influenced the spatial distribution of water. Decade-scale monitoring of vegetation community responses in flood-plain areas reconnected to the flood plain documented trends of increasing cottonwood/willow patch area at the expense of weeds/forbs/grasses area. Comparison of trends in cottonwood/willow expansion with surficial geologic and hydrologic characteristics suggests patterns of colonization are systematically controlled by hydrology, and mediated by surficial geology and topography. A season-long experiment quantifying cottonwood growth rates adjacent to the chute demonstrated annual-scale sensitivity of vegetation communities to hydrologic alterations of the valley bottom. During a season of relatively high flow, cottonwood growth rates adjacent to the chute were frequently as much as two times faster than those located several hundred meters from the chute, presumably because ground-water recharge from the chute prevented soil moisture from being a growth-limiting factor. The integrated, landscape-scale understanding gained from these studies should provide useful information to guide design and management of similar rehabilitation projects in flood plains for large rivers.

Introduction

The Overton Bottoms area, Missouri, presented an opportunity to evaluate ecosystem responses of flood-plain rehabilitation in a field-scale experiment. The flood-plain area was opened to the Missouri River when levees broke in 1993, and subsequent excavation of a side-channel chute increased the hydrologic connection between the flood plain and main-stem channel. This report presented an integrated analysis of interactions among geologic, hydrologic, and vegetation characteristics at the site. As a case study, the project provided some new insights into functions of flood-plain ecosystems; these insights will hopefully be tested, replicated, and refined at other sites. In addition, the studies provided specific information that should be useful for performance evaluation of the Overton Bottoms restoration project. In general, the study illustrated the value of scientific information in design and management of flood-plain rehabilitation projects.

Surficial Geologic Framework

Underlying sediments and topography determine much about how the river interacts with its flood plain, including how often it is flooded and how efficiently it retains water. Chapter 2 in this report documented the surficial flood-plain stratigraphy of the Overton Bottoms North Unit, evaluated geologic effects on physical and biotic processes, and suggested some implications for bottomland management. The results show that surficial geology of Missouri River valley bottoms presents a three-dimensional mosaic of sharply contrasting material properties that would be expected to have a strong effect on hydrologic characteristics, ecosystem processes, and habitat potential.

Detailed mapping and cross sections at Overton Bottoms North also provided understanding to inform models of how the Missouri River has changed during the late Holocene. Models of historical river changes can help define reference conditions to guide restoration activities. They also provide a conceptual framework for extending geologic mapping to other areas. Unlike wide valley segments upstream, the bedrock-bounded reach of the Missouri River in the Overton Bottoms area records only deposits from a relatively young, low-sinuosity, island-braided system. This recent geologic view of the river adds three-dimensional understanding of the reference condition to sparse historical information.

The distribution of contrasting channel-fill and point-bar units identified at Overton Bottoms North has a potentially strong influence on interaction of surface and ground water. Generally, channel fills (channel-fill allounits) will be better at retaining surface water than point-bar allounits because they are relatively impermeable and occur in topographic depressions. Fine-grained, low-permeability strata in channel fills, however, can also diminish infiltration of surface water and recharge of the alluvial aquifer. Because of their topographic position and low permeability, channel-fill allounits have high potential for natural wetlands and would provide good opportunities for construction of engineered wetlands.

Where overlying top strata are thin, point-bar allounits can be areas of enhanced recharge to the alluvial aquifer. These units also are more prone to rapid infiltration and drainage, and will tend toward comparatively xeric species. Point-bar units do not have high potential for engineered wetlands, and they may present risks of increased contamination of the aquifer in the event of chemical spills.

Hydrologic Framework and Responses to Reconnection of the Flood Plain

Hydrologic assessment at Overton Bottoms North Unit (Chapter 3) quantified the effects of reconnection of the flood plain to the mainstem Missouri River. The Overton Bottoms reach provided a unique opportunity to evaluate hydrologic functions in the flood plain before and after side-channel chute construction, and after subsequent adaptive re-excavation of the chute. The objectives of the study were to quantify relations among river stage, chute stage, ground-water levels, and rainfall; and to quantify how hydrologic reconnection due to chute construction altered the hydrology at Overton Bottoms.

Monitoring of ground-water altitudes after the initial reconnection in 1993 demonstrated that ground water varied closely with river altitude at Overton Bottoms North. This is probably an inherent feature of Missouri River bottomlands resulting from the high permeability of sandy deposits, and would tend to occur even in bottomlands surrounded by levees. Breaching of levees and chute construction, however, served to enhance the coupling of surface and ground water. Because of a conservative initial design, water flow in the first-generation chute occurred less frequently than in the second-generation chute. Hence, effect of the first-generation chute on ground water was measurable, yet modest. The wider and deeper second-generation chute increased the interaction between surface water and ground water because its geometry allowed water to flow through it most of the year and because the bottom of the chute was excavated into permeable sand units below the water table. Depth to ground water and variability of depth to ground water generally increased from the pre-chute condition, to the first-generation-chute conditions, and was greatest for second-generation-chute conditions at most monitoring wells. Between pre-chute and second-generation-chute conditions, the median water level at several observation wells decreased 0.5–0.9 m.

When water flows in the river were relatively high, the chute construction allowed the Missouri River to inundate Overton Bottoms more frequently and at a lower stage compared to the pre-chute condition. Prior to breaching of the levee, water flowed onto the flood plain about once every 10 years. After the levee was breached, water flowed onto the flood plain about three days per year on average. And, since construction of the second-generation chute, flow is present through the chute about 345 days per year. Increased hydrologic connection increased inundation of low-lying areas, recharge to wetlands, and variability of the ground-water table. During low-water conditions, however, the chute served to drain adjacent wetlands. Therefore, chute construction at Overton Bottoms North had the net effect of making wetlands drier during dry periods and wetter during and immediately after flood periods.

Land Cover Responses to Hydrologic Reconnection

Breaching of levees at Overton Bottoms during the 1993 flood and eventual conversion of much of the agricultural land to conservation purposes during 1993–2002 provided an opportunity to evaluate how valley-bottom vegetation communities would adjust to hydrologic reconnection under minimal management intervention (chapter 4). Landsat Thematic Mapper (TM) multispectral satellite image data were used to map generalized classes of vegetation and land cover on five different dates between September 1994 and September 2002. Ten mapped data sets documented how the vegetation communities changed over time: 5 classified images showed the land-cover classes for each year, 4 images showed the change in those classes from one date to the next, and 1 image documented the overall changes in the classes between 1994 and 2002. Each classified image also was analyzed for spatial characteristics of the vegetation classes to characterize patch dynamics.

The dominant change observed at Overton Bottoms 1994–2002 was expansion of willows and cottonwoods at the expense of former agricultural land that had grown into weeds/forbs/grasses. While the area of cottonwoods and willows increased by a factor of 10 (72 ha to 702 ha) during this period, the increase was not uniform. Growth was most pronounced in low-lying areas adjacent to the river where depth to ground water was shallow and soils were relatively moist. In these low-lying flood-plain areas surficial geologic units seemed to have little control on the size and shape of cottonwoods/willows expansion areas.

On higher alluvial surfaces, growth of the cottonwoods/willows class was more strongly controlled by surficial geology. Cottonwoods/willows growth was concentrated in channel-fill allounits as identified and mapped in chapter 2.

The channel fills presumably have greater retention of soil moisture than surrounding point-bar areas, and therefore provide somewhat more amenable conditions for germination and growth of cottonwoods/willows seedlings. In contrast, the permeability and structure of adjacent point-bar allounits in this area limits water availability.

The documented temporal trends suggest that the cottonwoods/willows class will continue to increase in area, although at a decreasing rate. Trends of patch characteristics also suggest that mean core area and total edge will continue to increase. As discussed in chapter 4, these patch characteristics may affect habitat quality for wildlife. The correspondence between cottonwoods/willows patches and channel-fill geologic units suggests that the surficial geology template will lead to persistent, arcuate patches of cottonwoods/willows if natural colonization processes are not interrupted.

Cottonwood Growth Responses to Hydrologic Alteration

The study in Chapter 5 assessed the direct effect of the second-generation side-channel chute on cottonwood growth at the Overton Bottoms North Unit. Growth rates were assessed using dendrobands that were placed on 75 trees across three transects oriented perpendicular to the chute. Growth was measured each week June–September, 2004, during a period characterized by somewhat wetter-than-usual conditions. The experimental design was intended to explore the question of whether the chute's evident effect on ground-water altitude (as documented in chapter 3) serves to enhance or diminish cottonwood growth.

Cottonwood growth was found to be higher in plots closer to the river or side-channel chute. Moreover, growth appeared to fluctuate with hydrologic condition: periods of increased water flow were associated with periods of increased cottonwood growth. During the latter part of the growing season, cottonwood growth followed the decline of river and the ground-water table. Although the period of monitoring was relatively short, these results support the hypothesis that during periods of high river flow, the side-channel chute recharges ground water and enhances cottonwood growth. Variation in cottonwood growth could not be attributed to differences in other factors like air temperature, solar radiation, or competition for light.

The side-channel chute was designed to provide more shallow-water habitat in the Missouri River corridor, mainly to promote recovery of native and endangered aquatic species. While the alteration of ground-water flow has the potential to adversely affect riparian wetland communities during dry periods, this study indicated that during wet periods the opposite can happen. Hence, the results suggest that there is not necessarily an acute trade-off between management of aquatic and riparian species in which enhancement of habitat for one necessarily diminishes habitat for the other. Monitoring over a longer period would be necessary to establish long-term effects of the chute on growth rates and woody community structure.

Scientific Investigations and Adaptive Management of the Missouri River Flood Plain

Our scientific investigations at Overton Bottoms opportunistically used a flood-plain rehabilitation project as a field-scale quasi-experiment. The experiment yielded new insights into landscape-scale ecological responses and generated hypotheses for additional testing. The experiment, in turn, also provided new understanding that should be highly applicable to adaptive management of rehabilitation projects in the Missouri River flood plain. In particular, the experiment demonstrated how surficial geology and hydrology create the fundamental mosaic of habitat potential on a typical bottomland. Documentation of how hydrology, vegetation patterns, and cottonwood growth rates have been altered and continue to change as a result of rehabilitation indicates how the project has performed and whether it is likely to meet long-term project objectives. We believe that this integrated understanding also will be useful to inform land acquisition decisions, and design and management of similar projects.

Surficial alluvium and its topographic expression mediate the distribution of water (and therefore energy and nutrients) in the Overton Bottoms flood plain. It follows that understanding of the geologic, topographic, and hydrologic framework of a bottomland site provides substantial information on the characteristics of habitat that can be supported on the site. For example, surficial alluvium maps depict the spatial distribution of sediments with a wide range of potential for inundation, and for transmitting and retaining water. Recognition of the characteristics and spatial patterns of these sediment units could be useful in design of wetlands and alignments of side-channel chutes. In the case of wetlands, design of wetland cells along water-retaining channel-fill allounits would result in arcuate wetland areas that would mimic those of the natural flood plain and would be inherently more efficient at retaining water than cells arcuated across permeable units. In the case of side-channel chute alignments, recognition of locations, sediment characteristics, and thickness of channel-fill allounits should provide useful information for alignments and channel dimensions. In particular, understanding of sediment distributions would be important for designing whether water in the chute is purposefully isolated from adjacent valley-bottom alluvium, or whether excavations extend into permeable sediments to enhance transmission of water into the alluvial aquifer. Understanding of the distribution of sediment properties would also be useful in predicting costs of chute construction and whether a side-channel chute is likely to migrate rapidly or slowly. For example, if the design objective for a chute is to promote dynamic aquatic habitats by encouraging rapid lateral erosion and migration, the alignment should avoid channel-fill allounits that would have sediment with higher resistance to erosion compared to point-bar allounits.

Hydrologic responses to reconnection of Overton Bottoms North with the Missouri River demonstrate some of the trade-offs inherent in side-channel chute constructions. In the pre-chute condition, Overton Bottoms North was connected to the river through breached levees during overbank flooding events. Without a chute to enhance ground-water and surface-water drainage, ground-water altitudes remained high and water drained slowly from the flood plain whenever overbank floods occurred. The first-generation chute increased aquatic habitat availability in the chute itself and increased the number of flow events that connected with the flood plain. At the same time, the first-generation chute also decreased ground-water altitudes during low-flow conditions, resulting in enhanced drainage of wetlands. This affect was increased for the deeper, wider second-generation chute. This result indicates that land managers should be aware of the potential trade-off between gains to aquatic habitats and losses of wetlands.

Integrated effects of hydrologic reconnection and the surficial alluvium framework were observed in the retrospective analysis of vegetation community classes. The remotely sensed observations from 1994–2002 captured mainly effects of relatively passive vegetation management wherein natural processes of succession and expansion were allowed to occur. This passive approach would presumably minimize cost to land managers, but may not achieve specific management goals such as habitat enhancement for particular species or elimination of invasive species. The results document that the cottonwoods/willows class increased in extent, core area, and total edge, especially in low-lying areas adjacent to the river channel, whereas in higher parts of the valley bottom, the cottonwoods/willows class expanded preferentially into areas mapped as channel-fill allounits. Under passive management, arcuate patches of cottonwoods/willows will probably continue to expand along ancient channel fills in the higher-elevation parts of the Overton Bottoms North, increasing total area of this vegetation class and total edge habitat. The cottonwoods/willows class has been slower to expand in point-bar allounits between the channel fills, presumably because of lower soil moisture in these landscape positions. This observation indicates that managers could target point-bar units preferentially to establish more xeric grass or tree species, while retaining channel fills for wetlands and mesic species.

The single-season study of cottonwood growth rates was a more specific assessment of the trade-off between aquatic habitat enhancement and potential degradation of terrestrial habitat: did the hydrologic gradients created by the side-channel chute have a measurable effect on growth rates of trees adjacent to the chute? Although it was hypothesized that the increased ground-water drainage adjacent to the chute would decrease growth rates, the opposite effect was documented as cottonwoods grew faster adjacent to the chute during the wet, early part of the growing season. Other potential factors–such as surficial geology and stand-density dependent growth–were discounted as insignificant. Although growth rates were actually increased as a result of the chute during this relatively wet season, declines in growth rates adjacent to the chute later in the season when river flows decreased also indicated that growth rates could be sensitive to low flow conditions as well. These results confirm that woody vegetation growth can be affected by side-channel chutes, although the effect is not always negative. The implication for adaptive management of bottomland resources is that side-channel chutes can be expected to alter hydrologic gradients in ways that can be significant to adjacent vegetation communities. Chute alignments that minimize depth and excavation in highly transmissive sediment would minimize this effect.

The studies presented here may also be useful in setting a baseline for continued monitoring and evaluation of responses to rehabilitation. Long-term evaluations of rehabilitation projects are rare (Bernhardt and others, 2005; Downs and Kondolf, 2002) and the existing level of documentation at Overton Bottoms may be unprecedented. The hydrologic drivers at Overton Bottoms North can be expected to change over time as the morphology of the second-generation side-channel chute adjusts to the discharge and characteristics of its bed and banks. The second-generation chute is relatively young (created in 2003) and geomorphic monitoring indicates that it is actively eroding and widening (Jacobson and others, 2004; Robert Jacobson, oral commun., 2005). Adjustments to the chute morphology will alter its effects on ground-water and surface-water connections and wetland distributions, as well as directly affecting flood-plain habitats by eroding and depositing new sediments. Changes to morphology also can be expected to change the hydrologic gradients adjacent to the chute, with consequent effects on vegetative growth rates and community structure. In addition, as shown in chapter 4, vegetation community classes are continuing to change total extent and shape, and these successional and colonization trends can be expected to continue.

Whether these changes will be consistent with long-term management goals of the Overton Bottoms area is difficult to predict. However, these studies documented that the Overton Bottoms North ecosystem (as measured by physical habitat and vegetation variables) is continuing its dynamic trend of change that began in 1993. Continued monitoring of selected characteristics of this site would provide managers with additional information on what to expect as similar rehabilitation sites adjust to hydrologic reconnection. Such information may prove useful in aligning management goals with the inherent habitat potential of the landscape.

One important piece of information that would come from such monitoring are the typical rates of ecological change and consequently how long monitoring should be maintained. Design of effective long-term monitoring needs to balance information content and cost (Palmer and others, 2005). We recommend continued monitoring of fundamental drivers (hydrology) and first-order effects (geomorphic changes to the chute) complemented with monitoring of selected biological indicators. Biological indicators should have clear importance to management goals or ecosystem processes, and they should be chosen to minimize errors associated with sampling variability. Remotely sensed mapping of vegetation community changes is a relatively cost-effective means to monitor broad scale changes, although at modest spatial (30-m) and temporal (annual) resolution.

The USGS Lower Missouri River Central Region Integrated Science Program (CRISP) project was carried out to contribute integrated scientific assessments to adaptive management in the Missouri River corridor. The project has documented: (1) the fundamental role of surficial geology in determining habitat potential of the valley-bottom landscape, (2) connections among surface water, ground water, and wetlands, (3) influence of surficial geology and topography on vegetation community colonization patterns in passively managed bottomlands, and (4) enhancement of cottonwood growth rates adjacent to the constructed side-channel chute. This information is directly applicable to pressing management and policy decisions, including strategies for acquisition of conservation land and design of habitat restoration projects.

The project was designed to incorporate geologic, hydrologic, geographic, and biologic disciplinary expertise to develop a comprehensive assessment of how management actions have affected habitats of a part of the Big Muddy National Fish and Wildlife Refuge, and how results of that assessment can be incorporated back into management and design decisions. The results have demonstrated the synergy of integrated science by uncovering landscape-scale relations affecting patterns and dynamics of flood-plain habitats that would not be apparent as a result of single-discipline approaches. We believe that the results of this study will contribute to the continued involvement of science in adaptive management, and should prove beneficial to the design of similar rehabilitation projects on the Lower Missouri River.

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