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Final Report to the U.S. Fish and Wildlife Service
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December 2002, revised December 2003

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Chapter 1

Hydrology of Lisbon Bottom

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Chapter 1. Hydrology of Lisbon Bottom

Robert B. Jacobson and Brian P. Kelly

Abstract

Lisbon Bottom consists of approximately 875 ha of river bottom along the Missouri River in Howard County, Missouri, from approximately river mile (RM) 213 to RM 219 (figs. 1-1–1-3). Before regulation and structuring of the Missouri River, riverine[1] areas like Lisbon Bottom were shifting mosaics of dynamic habitat patches that were created and maintained by hydrologic and geomorphic processes. Flow regulation, navigation structures, and bank-stabilization projects isolated Lisbon Bottom from the river by decreasing the magnitude and frequency with which hydrologic and geomorphic processes could alter habitat characteristics. The flood of 1993 breached agricultural levees around Lisbon Bottom, creating numerous levee-break scours, and re-establishing a connection to the Missouri River.

Management of wetland resources requires an understanding of how water recharges wetlands, how quality of the water may vary with source, and the costs and ecological benefits associated with manipulations of water sources. Observations and monitoring of surface- and ground water at Lisbon Bottom indicate the relative contributions to wetlands of water from the main channel by overbank flooding, water from the main channel by subsurface connection, water from direct rainfall, and water discharging from valley-wall tributaries. These sources of water are distributed among the many types of wetlands that exist at Lisbon Bottom, including deep scours formed during the 1993 and 1995 floods, shallow temporary wetlands with minimal direct surface drainage area, and shallow temporary wetlands with direct surface-water connections to valley-wall tributaries.

Deep scours associated with levee breaks and crevasse splays at upstream and downstream ends of Lisbon Bottom are connected through subsurface flow to the main channel. Water levels in these scours vary with flow in the main channel, direct rainfall, and to a lesser extent, valley-wall tributaries, but because of ground-water sources, the water levels change slowly over time. Because the down-valley gradient of Lisbon Bottom is greater than the channel slope, flooding in the main channel recharges downstream scours through surface-water flow before recharging upstream scours. Wetlands along the valley wall, far from the main channel, are recharged by main-channel flow only when flow is well over bank. These wetlands are recharged more frequently by local rainfall that falls directly into surficial drainage areas and by flow from valley-wall tributaries. Hydrologic variation in wetlands that are recharged by local rainfall is of greater magnitude and much more frequent than variation in deep scours, resulting in markedly different hydrologic disturbance regimes.

[1] The term *riverine* is used to describe the area encompassing the channel and adjacent flood-plain areas; the flood plain is considered to extend to those areas that would potentially flood with an average frequency of at least once in one hundred years in the absence of bank revetments and levees.

Introduction

Lisbon Bottom is located in a valley segment[2] between the junctions of the Grand and Osage Rivers (figs. 1-1, 1-2). This segment is on the margin of the Ozark Plateaus Physiographic Province and it is cut into relatively uniform Paleozoic cherty limestone, cherty dolomite, and minor quantities of sandstone and shale. This segment is characterized by a relatively wide valley subsegment from the Grand River junction to near Glasgow, Missouri (RM 224-250) and a narrow valley subsegment from Glasgow to the Osage River junction (RM 131-224). In the wide-valley subsegment and the segment upstream of the Grand River junction, the Missouri Valley is nearly five times wider than in the narrow-valley subsegment. Downstream of the Osage River junction, the Missouri River is increasingly affected by hydrologic characteristics and the addition of coarse sediment from the Ozark Plateaus. Lisbon Bottom is within the narrow-valley subsegment where the valley is about 3.5 km wide, with few alluvial terrace remnants, and steep, bedrock bluffs. The narrow valley and bedrock walls act to confine large floods and to promote scour and secondary currents where the channel impinges on the valley walls. A more complete description of Missouri River physiography can be found in Kelmelis (1994); a description of physiography and geomorphology of Lisbon Bottom can be found in Jacobson and others (1999).

Lisbon Bottom is a typical loop bottom (fig. 1-3; Schmudde, 1963). Before stabilization, loop bottoms would migrate downstream due to lateral erosion at the upstream margins and deposition on the downstream margins. Flood flows that overtopped the upstream margin would tend to build up sandy natural levees, which might be separated by interposed crevasses where concentrated flows cut through the levees. Crevasses commonly occupied swales left from previous channel migration and so acted to guide flood flows from the channel, across the loop bottom, and toward the valley wall. Because of this, there is a tendency for loop bottoms to have wetlands along the downstream one-half of the valley wall. At Lisbon Bottom small tributary basins also provide water for these low, wet areas. Because levees and splays build up the upstream margins of loop bottoms, natural loop bottoms have higher gradients than the channel, and they tend to flood from downstream to upstream as water backs up through old overflow channels. As a result, when large floods overtopped natural levees at the upstream margin, they would typically encounter slackwater from backflooding.

The upstream margin of Lisbon Bottom has natural levees in excess of 186 m above sea level (asl); the downstream margin has elevations as low 181 m asl. Ridges and swales oriented northwest to southeast are apparent on the 1979 topographic map of the bottom but have been partly obliterated by erosion and deposition by the 1993 flood (fig. 1-4). The slope of the bottom is approximately 0.8 m/km (0.0008 m/m), compared to 0.2 m/km (0.0002 m/m) in the channel.

The soils of Howard County including the Lisbon Bottom area were mapped in the 1970s (Grogger and Landtiser, 1978) and have not been remapped since. As a result of the floods of 1993–1996, the surface materials of Lisbon Bottom have changed extensively in distribution; however, the description of soils from

[2] A valley segment is a length of a river valley between substantive tributaries and having relatively uniform physiographic and geologic characteristics. For the purposes of this report, a tributary is considered to be substantive if it adds greater than approximately 5% of the cumulative drainage area and (or) drains an area of significantly different hydrologic response, sediment yield, or water-quality contribution.

1978 is still valid. The surface soil consists of materials ranging from well-sorted sand to silty clay, and ranging from zero pedogenic[3] alteration to development of organic-rich A horizons and weak B horizons. The soils of Lisbon Bottom are classified as entisols and mollisols, indicating the predominance of weak pedogenic development and accumulation of organic matter in wetter environments. The 1978 soil maps showed a unit classified as riverwash in lateral bars along the left bank[4] and adjacent to the channel. Sarpy sand (typic udipsamment) was mapped in natural levee positions along the upstream, left bank RM 216-218, and in a long splay extending approximately one half of the long axis of Lisbon Bottom, adjacent to and east of the chute. This sand splay is indicative of historic, high-energy deposition on Lisbon Bottom similar to that which occurred in 1993, but prior to 1978. Hodge loamy fine sand (typic udipsamment) was mapped on low-relief ridges and also indicates deposition of bars or splays. Hagni silt loam (mollic udifluvent) is stratified silt loam and fine sandy loam, and was mapped on low ridges and intermediate elevations on the bottom. Leta silty clay (fluvaquentic hapludoll) is the wettest soil mapped at Lisbon Bottom, and consists of fine sediments deposited in overflow channels, swales, and low areas subjected to back flooding. Nodaway silt loam (mollic udifluvent) was mapped on alluvial fans from the tributary valleys of Buster Branch, Cooper Creek, and unnamed smaller tributary basins along the eastern valley wall. These alluvial fans were formed from re-worked loess from the uplands located to the east of Lisbon Bottom; the fans provide bench areas at somewhat higher elevations immediately adjacent to the valley wall.

Climatology, Hydrology, and Regulation History of the Grand-Osage Segment

The regional climate for Lisbon Bottom is temperate; average annual temperature is 12.2 °C (54 °F) and average annual precipitation is 990 mm (39 inches) (NOAA, 1997). Low temperatures and low precipitation tend to coincide in January, but peak precipitation tends to occur in May, two months ahead of the peak temperature.

The closest long-term, discharge-rated stream gage is located at Boonville, Missouri (fig. 1-1). The U.S. Geological Survey has operated this stream gage continuously since 1925. Between Lisbon Bottom and Boonville, the Missouri River gains very little discharge; the drainage area increases by only approximately 0.5%. Therefore, the Boonville stream gage can be used to evaluate hydrologic characteristics at Lisbon Bottom. However, because the valley and channel cross section and hydraulic roughness are different between Lisbon Bottom and Boonville, the relative stages and areas inundated are not expected to match, especially at flows above bankfull. The U.S. Geological Survey also operates a gage approximately 12 km upstream of Lisbon Bottom at Glasgow, Missouri. This gage has a short and non-continuous record of discharge, but it provides a long record of stage for comparison with Lisbon Bottom.

[3] Pedogenesis refers to the integrated chemical, physical, and biological processes that form and differentiate soil horizons.
[4] Left and right bank refer to banks as seen while facing downstream.

Background and Objectives

River-corridor wetlands can be recharged through multiple pathways, or some combination of pathways (Kelly, 2001). The most direct source of recharge is direct rainfall, or rainfall that contributes runoff from local drainage areas around wetlands. Many river bottoms along the Missouri River also receive local runoff from valley-wall tributaries that collect runoff from drainage basins in the uplands adjacent to the Missouri River valley. Historically, the tributaries flowed onto the valley bottom and recharged wetlands along their banks and in overflow basins. Although many of these tributaries flowed naturally along the valley wall until hitting the mainstem of the river, landowners and drainage districts often stabilized this alignment with levees to protect the agricultural bottomland. Bottomland wetlands are also recharged from overflow of the main channel; when the flow is from the upstream margin of the bottom the flooding is called *topflooding* and when it is from the downstream margin it is referred to as *backflooding*. Finally, bottomland wetlands can be recharged or maintained through ground-water reservoirs, which can in turn be recharged from the main channel, valley-wall tributaries, or direct rainfall. Because ground water is not directly observable, the least is known in general about the relative influence of ground water. Studies completed in areas similar to Lisbon Bottom indicate that the ground-water reservoir can fluctuate with river level, but usually with a lagged and lower-magnitude response (Kelly, 2001). Hence the ground-water reservoir acts as a buffer that evens out wetland recharge events and ground-water observations indicate a longer-term, averaged hydrologic influence on wetlands compared to surface-water events.

Recharge pathways may also be quite dynamic on a multi-year to decadal time frame. Alterations of the land surface by erosion, sedimentation, engineering, and biota have the potential to change how surface and ground water are distributed. Deepening of side-channel chutes, for example, may contribute to drawdown of the water table and dewatering of wetlands. Beavers (*Castor canadensis*) are capable of excavating new channels and damming up old channels, thereby substantially changing the distribution of surface water and sediment. Continuing alteration of the land surface by geomorphic and biologic processes diminishes the ability to extrapolate recent hydrologic conditions over multi-year time frames.

Informed and cost-effective management of river-bottom wetlands requires an understanding of how water travels to wetlands, and how recharge pathways influence hydroperiod, water quality, and disturbance regime. A general question confronting land managers is whether the management objectives can be achieved without altering natural wetland recharge processes, or whether instead it is cost effective to manage recharge sources actively. The objective of this study was to develop a general understanding of hydrologic controls on wetland recharge, using Lisbon Bottom as a representative Missouri River bottom. Stage-discharge relations for Lisbon Bottom and short-term monitoring of hydrologic responses were intended to develop a preliminary understanding of recharge pathways and possible ecological consequences.

Methods

Separate, but related, ground-water and surface-water datasets were assembled for this study. The surface-water part of the study focused on characterizing pathway, magnitude, and frequency of recharge at selected wetlands. The ground-water part of the study was developed from widely spaced monitoring wells that characterize ground water broadly over Lisbon Bottom.

Four wetlands were chosen among the many present at Lisbon Bottom, to represent distinct hydrologic environments (fig. 1-3). Each of these wetlands can receive water from multiple sources, depending on different combinations of main-channel flow, valley-wall tributary flow, local precipitation events and the disposition of the ground-water table. Nonetheless, the four wetlands were chosen to illustrate the best end members of surface-water hydrologic environments.

Wetland 4 is a deep levee-break scour approximately 170 m from the main channel. It was chosen to represent wetlands that would be flooded from upstream (topflooding). The area between Wetland 4 and the channel is characterized by sandy soils and gently hummocky topography associated with a natural levee and small crevass splays. Wetland 4 is not connected to a valley-wall tributary most of the time, but can receive overflow when local rainfall contributes to high runoff in the Buster Branch drainage basin.

Wetland 26 was chosen to represent wetlands subject to flooding mostly from downstream (backflooding). This is also a deep, levee-break scour. It is approximately 500 m from the main channel and, although separated by a levee, approximately 150 m from a small tributary which is connected directly to the main channel (Buster Branch). Wetland 26 also can receive flow upstream from Buster Branch during large local runoff events.

Wetland 11 was chosen to represent a wetland that owes much of its recharge to valley-wall tributary flow during much of the year. It is fed by the upper reaches of Buster Branch and by Lay Creek, which was routed along the valley wall and separated from the bottom by a levee prior to USFWS ownership of Lisbon Bottom; flow to Wetland 11 was restored in 1994 when Refuge managers breached the valley-wall levee. Wetland 11 is extensively vegetated with grasses, and other emergent vegetation. Wetland 11 is topographically wide and shallow and probably typical of many wetlands that existed in this part of the Missouri River valley bottom prior to agricultural land uses.

Wetland 10 was chosen to represent a temporary wetland without direct connection to a valley-wall tributary. Only during very wet conditions does Wetland 10 receive discharge through the upper reaches of Buster Branch. Wetland 10 is a broad, shallow basin that is extensively vegetated with cottonwood and willow trees that germinated after the flood of 1993, which is in marked contrast to Wetland 11 that has extensive aquatic macrophytes and few trees.

Elevation benchmarks were installed upstream and downstream of Lisbon Bottom along the main channel, in order to relate discharge in the main channel to river stage. In addition, elevation benchmarks were installed upstream and downstream in the side-channel in order to develop stage-discharge relations in the chute (fig. 1-3). Stages measured from these benchmarks were related to discharges at Boonville. In addition, high-water marks from the flood of June 2001 were surveyed and used to extend the stage-discharge relations to a relatively infrequent flood. Pressure transducers and data loggers were installed in four wetlands and operated during spring–summer 2001. Stages at the pressure transducers were converted to water-surface elevations by surveying true elevations into the gage sites. A rain gage and one stream stage gage (Lay Creek) were installed to characterize hydrologic inputs from local rainfall and runoff from valley-wall tributaries.

Six ground-water monitoring well locations and two staff gages were established to investigate ground-water flow relations to wetland recharge (fig. 1-3). Monitoring wells were constructed of 2-inch diameter schedule 40 PVC. Each deep well is 30 to 40 feet deep with a 10 foot screened interval at the bottom of the well and a one-foot sump at the base of the well. Staff gages were constructed of steel plates with 0.01 foot graduated marks. Ground-water levels, river stage, and chute stage were measured in June, August, October, November of 1999; January and February of 2000; and January, February, March, April, May, June, July, September, and October of 2001. Hourly river stages at RM 218.5 (calculated from the Boonville USGS gage) and dates of ground-water measurements are shown on figure 1-5.

Depth to ground water ranged from -1.08 to 18.82 feet (-0.33 to 5.74 m) for all manual ground-water measurements. Measured water-table altitudes ranged from 588.45 feet to 606.54 feet (179.36 to 184.87 m) above sea level. Measured Missouri River stage altitudes at mile 218.5 ranged from 585.37 to 611.75 feet (178.42 to 186.46 m) above sea level. Measured chute stage altitudes on the south end of the chute ranged from 584.70 to 598.63 feet (178.22 to 182.46 m) above sea level. Wetland stage measured at Wetland 5 ranged from 601.76 to 604.14 feet (183.42 to 184.14 m) above sea level.

Hourly measurements of ground-water level and rainfall were made using an automatic water level recorder and rain gage at Well 2 from November 29, 2000 until April 28, 2001. Ground-water altitudes ranged from 588.20 o 598.25 feet (179.28 to 182.35 m) above sea level. Between November 29, 2000 and April 28, 2001, maximum rainfall was 2.34 inches on April 12, 2001 and total rainfall was 17.63 inches.

Wetland water-surface elevation data and ground-water monitoring results do not completely overlap with the time period of biological and limnological sampling described in other sections of this report. Nevertheless, the hydrologic data show general characteristics of wetlands at Lisbon Bottom that help put biological and limnological data in hydrologic context. The stage-discharge data developed for the main channel lead to basic understanding of frequency of flooding from the main channel, and how frequency varies among different parts of Lisbon Bottom.

Results and Discussion

Stage-discharge and Overflow of Lisbon Bottom

Stage-discharge relations at RM 218 (the upstream margin of Lisbon Bottom) and at RM 213.4 (the downstream margin of Lisbon Bottom) have convex-upward shapes indicative of flows that spread out of the channel and over un-leveed flood plains (fig. 1-6). The relations are modeled well by relating stage to the logarithm of discharge.

The stage-discharge relation can be compared with flow frequency at the Boonville gage to calculate stage frequency at Lisbon Bottom. Stage frequencies are plotted in figure 1-7 for each day of the water year (October–September), as calculated from the post-regulation Boonville record 1967–1999. Reference lines are provided to indicate the stage at which general flooding occurs upstream and downstream. These reference elevations are based on general elevations of the land surface adjacent to the channel, ignoring human-made levees. As shown in the figures, flooding from upstream or downstream is most likely during April–May. Downstream flooding is significantly more likely than upstream flooding due to the general slope of the bottom surface, with some periods having frequencies as high as 1 in 10. On an annual basis, flooding from upstream occurs only 3 days per year on average whereas flooding from downstream occurs 11 days per year on average.

Surface-water Relations and Wetlands

Wetlands at the upstream and downstream margins of Lisbon Bottom hold water more persistently than interior wetlands. Stage gages at Wetland 4 at the upstream end of Lisbon Bottom maintained a high water-surface elevation even when flow in the main channel was substantially lower than the wetland water surface (fig.1-8A). Wetland 4 is a relatively deep scour at a levee break. Local rainfall events—shown as Lay Creek stages in fig. 1-8B for reference—also recharged Wetland 4; the April 10, 2001 storm is a good example. The period 6/4–6/12/2001 included a flood with daily mean discharge of 365,000 cfs at Boonville, a flood of approximately 10-year recurrence (U.S. Army Corps of Engineers, written communication, 1997). Although local rainfall also helped recharge Wetland 4 during this flood, at stages of about 185.5 m asl, most of the wetland area at the upstream end receives direct flow from the Missouri River.[5] Once recharged by the June 2001 flood, Wetland 4 remained at a high stage for at least another month, even when flow in the main channel was as much as 3 m lower than the wetland in mid- July. This observation indicates that although it is relatively deep and within the part of the bottom that should be dominated by sandy natural levee deposits, Wetland 4 is not strongly connected by ground water to the river.

Wetland 26 at the downstream end of Lisbon Bottom is another deep, levee-break generated scour. Unlike Wetland 4, however, Wetland 26 shows less persistence of water surfaces after recharge events, indicating that water is flowing away from Wetland 26, probably through ground-water flow (fig. 1-8C). Topography indicates that Wetland 26 should recharge from backflooding of the Missouri River when stage at RM 213.4 reaches approximately 183.6 m asl. Wetland 10 flooded from local rainfall and runoff during the 4/10/2001 event and was then relatively unaffected by main channel flows until 5/8/2001. During 5/7–5/10/2001 there was no local precipitation and a small rise in river level to about 182.8 m asl was associated with about 0.5 m of rise in Wetland 26. As the river stage was considerably less than the 183.6 m asl that should allow surface-water connection between the wetland and the scour, this is interpreted as evidence of a ground-water or other connection between the wetland and the main channel. Possibly, beaver excavations or a mis-operating flap gate on a culvert under the levee allowed water to enter Wetland 26 at stages well below the general land surface. Subsequent rises in wetland stage are difficult to separate from local rainfall effects, but concurrent rises at RM 213.3 and in Wetland 26 indicate general backflooding when stage at RM 213.6 is about 183.6 m asl (with water levels at Wetland 26 about 184.2 m asl due to slope of the water surface between Wetland 26 and the stage measurement at RM 213.3).

[5] The minimum stage at RM 218 sufficient for surface recharge to Wetland 4 may be as low as 184 m asl through small crevasses; however these crevasses apparently plug frequently with large woody debris and sediment, so they should probably not be considered a reliable source of recharge.

Wetlands 10 and 11 contrast substantially with Wetlands 4 and 26 (fig. 1-8D). Both wetlands are broad, shallow basins. Wetland 10 has only infrequent connection to valley-wall tributaries, and due to the shallow depths, little opportunity for ground-water inflows. Wetland 10 was dry during most of this study, with exceptions that resulted from intense local rainfall and total flooding of the bottom. Wetland 10 water level increased as a result of 2.4 inches of rain received in the 4/10/2001 storm and remained dry through several subsequent storms of as much as 1.0 inch of rainfall. Wetland 10 recharged again from 2.05 inches of rainfall from two storms 6/3–6/6/2001, just before and overlapping with the large flood 6/5–6/11/2001. Wetland 10 flooded again 6/22–7/1/2001 when flow in the main channel at RM 218 again surpassed 185.5 m asl.

In contrast to Wetland 10, Wetland 11 was frequently flooded by local rainfall events as well as by infrequent but large floods from the main channel (fig. 1-8D). Local rainfall of as little as 0.42 inch (for example, 4/14–4/15/2001) resulted in water-surface elevation changes of several centimeters. Rainfall of 0.69 inch during 5/11/2001 resulted in 30 cm of rise in water surface in the wetland. Due to the broad, shallow morphology of the basin, small changes in water-surface elevation can affect large areas of wetland. Direct connection of Wetland 10 to Lay Creek results in frequent, small-magnitude recharge events in addition to any recharge from bottom-covering floods.

Ground-water Relations and Wetlands

Intersection of the water-table surface with land-surface topography indicates the extent of wetlands that would exist if wetlands were connected to ground water through highly transmissive sediments and if ground water were the only source of recharge to the wetlands. On the short term—days to weeks—actual water-surface elevations and spatial extents of wetlands will be different from the ground-water prediction because of local rainfall, runoff from valley-wall tributaries, or overflow from the main channel. The potentiometric surface (distance of the water surface above or below the land surface) and the calculated locations of wetlands at Lisbon Bottom are shown for each ground-water measurement event in figure 1-9. The potentiometric surface is the surface that represents the static head of water in an aquifer; it is defined by the levels to which water will rise in tightly cased wells from a given point in an aquifer. In the Missouri River alluvial aquifer, the potentiometric surface defines the water table. The distance of the water surface above or below the land surface was calculated by subtracting the potentiometric surface from the land surface using high-resolution digital elevation data of Lisbon Bottom. The calculation includes topography of the chute and the channel. However, the topography of the navigation channel depicted in these figures is very approximate and hydraulic control exerted by a notched structure at the upstream end of the chute is not taken into account; therefore, results in the navigation channel and chute should be interpreted with caution.

Several important features of the hydrology of Lisbon Bottom are illustrated in this figure. High ground-water levels measured during times when river stage is high as shown in figure 1-9 for August 11, 1999 and April 4, 2001–July 26, 2001, indicate the general close connection between the river and ground water at Lisbon Bottom. Low ground-water levels occur when river stage is low as shown in figure 1-9, October 7, 1999–February 21, 2001 and September 6–October 3, 2001. A persistent area of higher ground-water levels occurs near the eastern valley wall. This area is somewhat topographically lower that the rest of Lisbon Bottom. These two characteristics result in a predicted close interaction between ground-water levels and wetland stages for the deeper wetlands located along the eastern valley wall. These include Wetlands 4, 5, 7, 8, 20, 21, 22, 25, 26, and 28. Slow recession of water surfaces after overflow during the June 2001 flood (figs. 1-8A, C) indicates that the connection between ground water and wetlands can be slow, perhaps because of fine, impermeable sediment that has been deposited in the wetlands.

Other shallower wetlands in this general area also can be affected by ground water when ground-water levels rise above the land surface (fig. 1-9, June 26, 2001). Conversely, Wetlands 13 through 19, located along the old cross levee on the southern part of Lisbon Bottom are largely unaffected by ground water. Even when measured ground-water levels were highest on June 26, 2001 (fig. 1-9) these wetlands are predicted to be unaffected by ground water. Any water present in these wetlands during this time most likely came from direct rainfall or surface runoff.

Ground-water levels were continuously measured in Well 2 from November 29, 2000 until April 28, 2001. Ground-water levels in Well 2 and Missouri River stage at mile 216.5 are shown in figure 1-10. Ground-water levels at Well 2 respond to changes in river stage within a few days and follow the general river stage trend. For example, the river peaked at 182.67 m on March 24, 2001 and ground-water level in Well 2 peaked 6 days later at 181.77 m on March 30, 2001. Ground-water levels in areas located closer to the river respond more quickly to river stage changes than in areas located farther from the river. This has important implications for wetlands located along the eastern valley wall. Although ground-water levels may respond more slowly to river stage changes in the area along the eastern valley wall, once ground-water levels rise they will not decrease quickly. Therefore, a seasonal cycle of high river stage in spring and early summer will result in wetland stage increases caused by increases in ground-water levels. Lower river stages in fall and winter will result in drainage of the wetlands as ground-water levels decrease.

Conclusions

The results of this study illustrate the diversity of wetland types and recharge pathways on the Missouri River valley bottom. As indicated in the following chapters, the hydrologic variations seen in Lisbon Bottom wetlands translate to distinct limnological and biological characteristics. Recognition of the hydrologic basis for differentiation of Missouri River wetlands should be useful to achieve the most cost-effective land management.

Schmudde (1963) recognized and articulated the fundamental truth that bottom lands naturally flood from downstream to upstream, that downstream areas flood more frequently than upstream areas, and that the effect is more pronounced on loop bottoms with flood-plain slopes that are substantially greater than the slope of the main channel. This study adds to these observations by quantifying the difference in flood frequency: the downstream margin of Lisbon Bottom is subject to flooding on average 11 times per year whereas the upstream margin floods on average only 3 times per year. In addition, upstream marginal wetlands like Wetland 4 are subject to rapid sedimentation as a result of overbank flows with high sediment concentrations (see Chapter 2). High sedimentation rates would contribute to short lives or high maintenance costs for wetlands developed on the upstream margin of river bottoms like Lisbon.

Wetlands 4 and 26 on the upstream and downstream margins of Lisbon Bottom owe their existence to intense scouring associated with failures of man-made levees, and are therefore not examples of natural wetlands that would occur in non-engineered river systems. Natural wetlands at upstream margins would more likely be associated with crevasses interspersed with sandy natural levees. Although also formed by scours associated with breaching of topographic barriers, natural crevasses would likely be shallower and more elongate than Wetland 4. Natural wetlands in downstream margins are more likely to be associated with valley-wall streams, and therefore be shallower and more extensive than Wetland 26. Although altered by the levee along Buster Branch, the land adjacent to the confluence of Buster Branch with the main channel would be an example of such a natural, downstream-margin wetland (fig. 1-4). Because natural wetlands would likely be shallow and broad, they would not have the persistence of water levels observed in Wetlands 4 and 26 at Lisbon Bottom. Nevertheless, scour wetlands are now common along the Missouri River as a result of levee breaks from the 1995, 1993 and previous floods (Galat and others, 1997).

In addition to recharge from the main channel, upstream and downstream marginal wetlands showed the effects of local rainfall and of ground-water connections to the main channel. In general, main-channel floods had greater and more persistent effects on water levels in these wetlands, but local rainfall events contributed substantially to recharge. Persistence of water levels after large events may be due to the ability of big floods to recharge the entire valley-bottom water-table aquifer.

Interior wetlands like Wetlands 10 and 11 are also subject to recharge from surface water when the main channel floods overbank. However, these wetlands differ markedly in having highly variable water-surface levels that are strongly determined by connections to valley-wall tributaries. Wetland 10, in particular, displayed high frequency variation in water-surface elevations as a result of tributary flows from Lay Creek. High-frequency variations in this shallow wetland basin may result in highly variable soil moisture conditions and therefore a distinct hydrologic disturbance regime.

Ground-water level results indicate the broad, time-averaged relations between ground-water and wetland recharge. Three prominent patterns are evident in the potentiometric contours presented in figure 1-9. During dry periods, when flow in the chute is relatively low, potentiometric contours embay in the upstream direction, indicating that ground water is discharging from the alluvial aquifer to the chute. Most of the measurement dates show this pattern; only August 11, 1999, October 7, 1999, May 14, 2001, July 26, 2001, and October 3, 2001 deviate from the pattern. The deviating dates show a second prominent pattern, with potentiometric contours embaying in the downstream direction, indicating recharge of the alluvial aquifer from the chute. August 11, 1999 (fig. 1-9) is a strong example of this pattern; this measurement was made during or shortly after a small rise on the main channel. Similarly, the October 3, 2001 measurement shows the same pattern was made shortly after a small rise (fig. 1-9). These two patterns indicate one of the prominent functions of side-channel chutes on the Missouri River. They contribute to both recharge and discharge of the alluvial aquifer, and presumably increase variability of water levels in wetlands adjacent to the chute.

The third prominent pattern in the potentiometric contours is the increased ground-water levels adjacent to the valley wall on the east side of Lisbon Bottom. This may be caused in part by lowering of the ground-water table toward the chute, and in part by recharge by valley-wall tributaries. Coupled with lower ground-surface elevations along the valley wall, this relation creates persistently high water-surface elevations and wetland recharge along the valley-wall margin. The management implication of this observation is that, although these wetlands are located at greater distances from the main channel, they are naturally wetter for longer times during the year.

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