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Relations Among River Stage, Rainfall, Ground-Water Levels, and Stage at Two Missouri River Flood-Plain Wetlands

Water-Resources Investigations Report 01-4123

Prepared in cooperation with the
U.S. Environmental Protection Agency

U.S. Department of the Interior
U.S. Geological Survey

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By Brian P. Kelly

ABSTRACT

The source of water is important to the ecological function of Missouri River flood-plain wetlands. There are four potential sources of water to flood-plain wetlands: direct flow from the river channel during high river stage, ground-water movement into the wetlands in response to river-stage changes and aquifer recharge, direct precipitation, and runoff from surrounding uplands. Concurrent measurements of river stage, rainfall, ground-water level, and wetland stage were compared for two Missouri River flood-plain wetlands located near Rocheport, Missouri, to characterize the spatial and temporal relations between river stage, rainfall, ground-water levels and wetland stage, determine the source of water to each wetland, and compare measured and estimated stage and ground-water levels at each site. The two sites chosen for this study were wetland NC-5, a non-connected, 50 feet deep scour constantly filled with water, formed during the flood of 1993, and wetland TC-1, a shallow, temporary wetland intermittently filled with water. Because these two wetlands bracket a range of wetland types of the Missouri River flood plain, the responses of other Missouri River wetlands to changes in river stage, rainfall, and runoff should be similar to the responses exhibited by wetlands NC-5 and TC-1.

For wetlands deep enough to intersect the ground-water table in the alluvial aquifer, such as wetland NC-5, the ground-water response factor can estimate flood-plain wetland stage changes in response to known river-stage changes. Measured maximum stage and ground-water-level changes at NC-5 fall within the range of estimated changes using the ground-water response factor. Measured maximum ground-water-level changes at TC-1 are similar to, but consistently greater than the estimated values, and are most likely the result of alluvial deposits with higher than average hydraulic conductivity located between wetland TC-1 and the Missouri River.

Similarity between ground-water level and stage hydrography at wetland NC-5 indicate that ground-water-level fluctuations caused by river-stage changes control the stage of wetland NC-5. A 2-day lag time exists between river-stage changes and ground water and stage changes at wetland NC-5. The lack of a measurable response of wetland NC-5 stage to rainfall indicate that rainfall is not a large source of water to wetland NC-5. Stage in wetland TC-1 only increased at high river stage in June and July 1999, and from runoff caused by local rainfall during the winter. The 2-day lag time between peak stages at wetland TC-1 and peak Missouri River stages compared to the 1-day lag time between Missouri River stage and ground-water peaks at wetland TC-1 indicates ground-water flow does not directly affect wetland stage at TC-1, but surface-water flow does affect wetland stage at TC-1 during high river stage. Comparing wetland TC-1 stage to potential water sources indicates the most likely explanation for the rise in stage at wetland TC-1 is surface runoff

supplied via seepage through the levees and upward flow of ground water through alluvial deposits of higher hydraulic conductivity during high river stage. The rate of decrease in wetland TC-1 stage was limited by the rate at which ground-water level decreased. Stage response to rainfall at wetland TC-1 during the winter months and no response to greater rainfall amounts during spring and summer months indicate that evapotranspiration may limit the affect of rainfall on stage at wetland TC-1 during the growing season.

INTRODUCTION

Historically, the lower Missouri River flood plain was a braided series of oxbow lakes, seasonally flooded wetlands, and wooded sloughs. These wetlands were created and destroyed by the unregulated meandering and flooding of the Missouri River. Channelization and flood-control projects, initiated in the 1800's and accelerated in the 1940's, have straightened and narrowed the river, making the creation of wetlands less likely, and thereby reducing flood-plain habitat for fish and wildlife (Funk and Robinson, 1974). Upstream, a series of flood-control dams and reservoirs have altered the historic flooding patterns and sedimentation loads that impact the flood plain.

Three wetland types remained in the Missouri River flood plain before the 1993 flood: remnant wetlands such as oxbows and wooded sloughs, temporary or seasonally flooded wetlands, and managed waterfowl areas. Oxbow lakes are large remnants of the Missouri River channel, while wooded sloughs are relatively small forested habitats associated with an altered drainage ditch, a remnant stream channel, or a cutoff main river slough. Temporary wetlands are intermittently inundated and often farmed during dry conditions. Waterfowl areas are diked and hydrologically controlled wetland pools intensively managed for concentrating food and habitat for migrating waterfowl.

Missouri River flood discharges overtopped and breached more than 500 levees between Kansas City and St. Louis, Missouri, during the flood of 1993. These levee breaches accounted for 90 percent of erosion and deposition features of the 1993 flood (Scientific Assessment and Strategy Team, 1994). Breached or overtopped levees often left deep, steep-sided scours near the levee break with erosional and depositional zones occurring downstream from the scour (blew hole, blue hole, or blowouts) (Schalk and Jacobson, 1997; Galat and others, 1995). About 81,500 acres of lower Missouri River flood plain were impacted by scouring (Soil Conservation Service, 1993). Two categories of scour type were identified: those that are continually attached to the river, and those that are non-connected. These were identified by the Missouri River Post-flood Evaluation Project, a biological project of the Missouri Department of Conservation, the Natural Resources Conservation Service, and several universities, which begun after the flood of 1993. Although these types of scour holes are not natural flood-plain habitats, they may function as analogs to flood-plain wetlands of unregulated rivers.

The source of water is important to the ecological function of these flood-plain wetlands. There are four potential sources of water: direct precipitation, runoff from the surrounding uplands, direct flow from the river channel during high river stage, and movement of ground water into the wetlands in response to river-stage changes and aquifer recharge. Changes in wetland stage from direct precipitation are limited by the amount of rainfall. Runoff from the surrounding uplands can provide water to wetlands on the flood plain and is most important for wetlands near the base of the river-valley walls, where upland streams enter the flood plain, or for wetlands located in or near drainage channels. Direct flow from the river channel during high stages can impact all wetland types in the flood plain, but is most frequent in areas of the flood plain unprotected by levees. Fluctuations in river stage cause changes in ground-water levels in the Missouri River alluvium. The movement of ground water into wetlands in response to changes in river stage has the greatest effect on wetlands that are deep enough to intersect the water table present in the flood plain.

Questions arise concerning how to most effectively manage flood-plain wetlands. The source of water and the magnitude and timing of water-level fluctuations in these wetlands impact water quality, ecological function, and human use. Intensively-managed wetland complexes provide abundant habitat for a great variety of species. Passive management for flood-plain wetlands may provide ideal short-term results; however, wetland water levels dependent on the natural hydrology of the flood plain may not consistently provide the desired habitats. Therefore, a need exists to better understand relations among water-level changes in wetlands and changes in rainfall, runoff, ground-water levels, and river stage.

A study was conducted by the U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (USEPA) to evaluate these relations for two wetlands located on the Missouri River flood plain. The objectives of the study were to measure river stage, rainfall, ground-water levels, and stage at two Missouri River flood-plain wetland sites, and characterize the spatial and temporal relations between river stage, rainfall, ground-water levels, and wetland stage to infer sources of water to each wetland. Data were collected between June 1999 and July 2000. The purpose of this report is to present the results of the study.

Study Area

The flood plain of the Missouri River is underlain by alluvial deposits consisting of clays, silts, sands, gravels, cobbles, and boulders. In general, the finer clays, silts, and sands are located near the surface of the alluvium and the coarser sands, gravels, cobbles, and boulders are located near the base of the alluvium. Numerous investigations have presented lithologic cross sections showing a 20- to 30-ft (feet) thick silt-clay cap that overlies the sands and gravels of the alluvium in most parts of the lower Missouri River flood plain (Kelly and Blevins, 1995; Emmett and Jeffery, 1968, 1969a, 1969b, 1970). This cap exists in the study area and may limit water flow between the land surface and the alluvial aquifer. The humid continental climate of the study area is characterized by large variations and sudden changes in temperature and precipitation. The study area receives about 37 inches of rainfall per year (Gann and others, 1971).

The study area is a part of the Missouri River flood plain near Rocheport, Missouri. Two wetlands (a deep, non-connected scour and a shallow, temporary basin) were selected based on minimal or intermittent hydrologic interactions with surface water. This minimized changes in wetland stage caused by direct surface-water flow, which allowed more precise measurement of the effect of ground-water-level changes on wetland stage. The two sites were wetland NC-5, a deep, non-connected scour formed during the flood of 1993, located at Diana Bend Conservation Area (Missouri Department of Conservation) in Howard County, and wetland TC-1, a shallow, temporary wetland located in Overton Bottoms in Cooper County (fig. 1). The “non-connected” and “temporary” designations are from the Missouri River Post-flood Evaluation Project. Wetland NC-5 is a scour hole with a maximum depth of 50 ft, contains water all year, and is located approximately 2,200 ft [670 m (meters)] from the Missouri River. Wetland TC-1 intermittently contains water and is located approximately 1,540 ft (470 m) from the Missouri River. It is relatively shallow when water is present, less than 5 ft. In addition to the two sites chosen for instrumentation, wetland NC-3, a large scour, is located approximately 7,550 ft southeast of wetland TC-1, and may have a surface connection to wetland TC-1 at high stage. Both wetlands NC-5 and TC-1 were protected from direct flooding by the Missouri River during this study by levees. Because these two wetlands approximately bracket a range of wetland types that currently exist in the Missouri River flood plain, the responses of many other Missouri River wetlands to changes in river stage, rainfall, and runoff should be similar to the responses exhibited by wetlands NC-5 and TC-1.

Methods

One monitoring well and one cluster of four wells of various depths were installed at each site. The monitoring well was about 40 ft deep at wetland NC-5 and about 44 ft deep at wetland TC-1. Ground-water-level data collected from the wells provided the information used to determine the relation between ground water and wetland stage at the site. The monitoring well was located as close to the wetland as possible considering site conditions, and the well cluster was located within 50 ft of the monitoring well. Each site had a data logger with satellite transmission to record hourly water levels in the monitoring wells, stage in the wetland, and rainfall. All electronically recorded data were automatically downloaded to the USGS national database every 4 hours. Monthly visits to each site were made to manually measure water levels and to service and calibrate electronic equipment.

River stage near each site was estimated using linear regression from river stages measured to the nearest 0.01 ft concurrently at the USGS streamflow gaging station at Boonville, Missouri (river mile 196.6) and at a reference point located at the bridge over Moniteau Creek near Rocheport, Missouri (fig. 1). River stage at river miles 190 and 187.5 were estimated using the regression by interpolation along the river between the gage at Boonville, Missouri, and the reference point at Moniteau Creek. A total of 12 measurements at Moniteau Creek were compared to

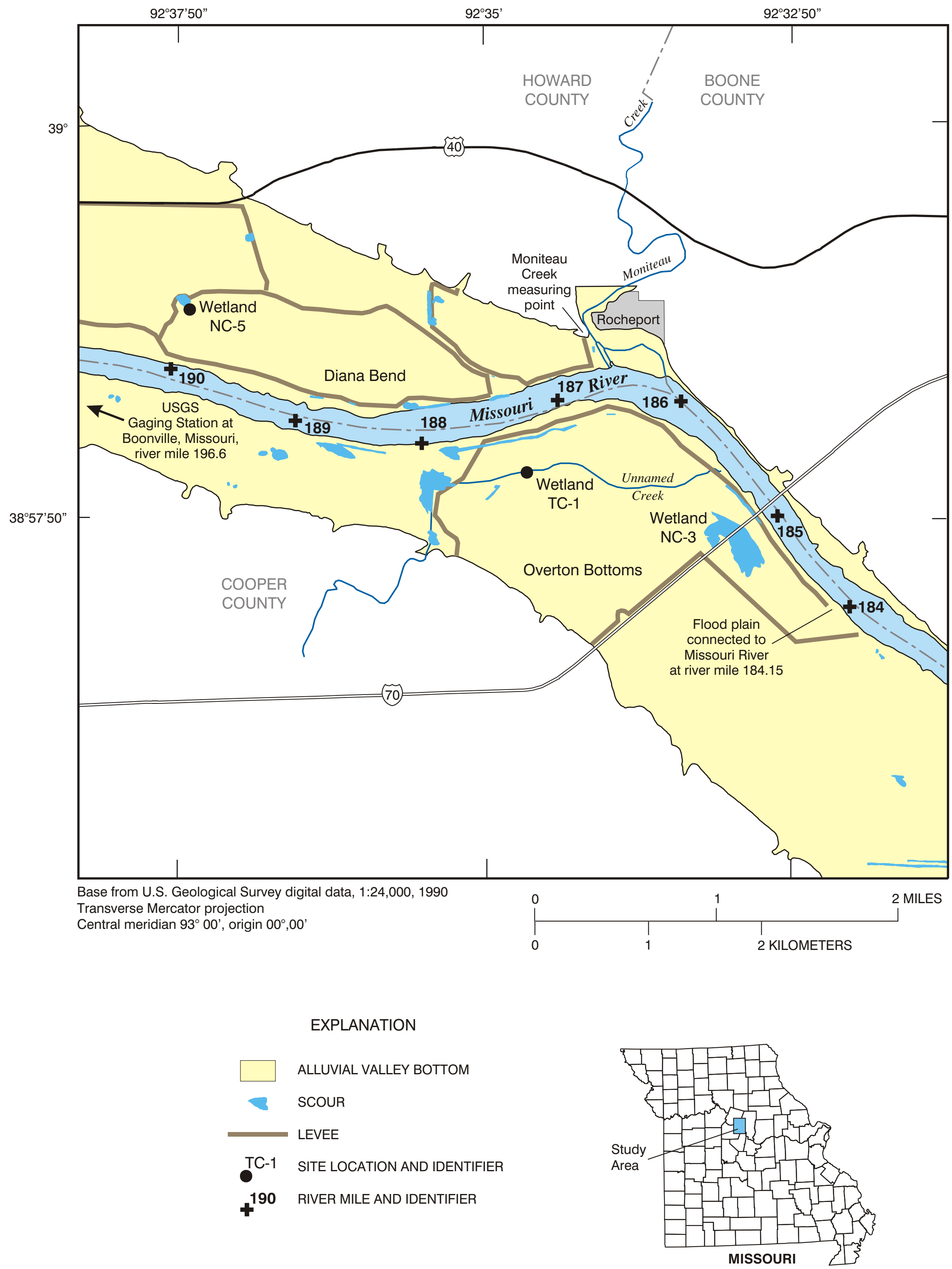

Figure 1. Location of study area.

corresponding measurements at Boonville. The coefficient of determination (r^2) of the linear regression is 0.979. The 95 percent confidence interval for the estimated water levels is plus or minus 0.1 ft.

Water levels within wells were measured automatically using a shaft encoder, float, and counter weight assembly to 0.01-ft accuracy, or a vented pressure transducer to 0.01-ft accuracy. Time and water levels were recorded hourly by a data logger. Hourly water-level recordings were checked with monthly manual measurements made using an electric water-level measuring tape divided into increments of 0.01 ft. All reference points of wells were surveyed from a nearby benchmark to 0.01-ft accuracy with respect to sea level. Water levels were converted to altitude above sea level and reported to 0.01-ft accuracy.

The stage in each wetland was recorded using a staff gage surveyed to 0.01-ft accuracy with respect to sea level. Water levels were converted to altitude above sea level and reported to 0.01-ft accuracy. Water levels within the wetland were automatically measured to 0.007-ft accuracy using a vented pressure transducer. Time and water levels were recorded hourly by a data logger. Pressure readings were calibrated to the staff gage readings and converted to altitude above sea level.

Rainfall was measured in increments of 0.01 inch with a tipping bucket rain gage. A description of instrumentation at each wetland and the time during which measurements were made are listed in table 1.

Missing data for ground-water levels were estimated, when necessary, by comparing concurrent measurements of ground water in adjacent wells, and

Table 1. Instrumentation, depths, and dates of measurement at wetlands NC-5 and TC-1

[Approx., approximately; ft, feet; na, not applicable]

Name	Instrument description	Depth of well or wetland	Dates of measurement
Wetland NC-5 gage	Pressure transducer	Approx. 50 ft	June 15, 1999 to July 6, 2000
Well NC-5	Pressure transducer	39.73 ft	July 6, 1999 to July 6, 2000
Well NC-5A	Float and counter weight	5.17 ft	June 15, 1999 to July 7, 1999 (dry after July 7, 1999)
Well NC-5B	Float and counter weight	5.96 ft	July 6, 1999 to July 23, 1999 (dry after July 23, 1999)
Well NC-5C	Float and counter weight	8.16 ft	June 15, 1999 to August 20, 1999 (dry after August 20, 1999)
Well NC-5D	Float and counter weight	22.04 ft	June 15, 1999 to July 6, 2000
Rain gage NC-5	Tipping bucket rain gage	na	June 15, 1999 to July 6, 2000
Wetland TC-1 gage	Pressure transducer	Variable	June 23, 1999 to July 6, 2000
Well TC-1	Pressure transducer	44.43 ft	July 7, 1999 to July 6, 2000
Well TC-1A	Float and counter weight	8.5 ft	Dry for all measurements
Well TC-1B	Float and counter weight	23.86 ft	July 7, 1999 to July 6, 2000
Well TC-1C	Float and counter weight	14.57 ft	June 16, 1999 to August 30, 1999 (dry after August 30, 1999)
Well TC-1D	Float and counter weight	10.88 ft	June 15, 1999 to August 1, 1999 (dry after August 1, 1999)
Rain gage TC-1	Tipping bucket rain gage	na	June 23, 1999 to July 6, 2000

calculating the missing ground-water data based on the average difference between available concurrent measurements. Missing water-level data for wetland NC-5 were estimated, when necessary, by comparison to water levels in well NC-5. Missing water levels in wetland TC-1 were not estimated. Rainfall data were recorded without interruption for the study period.

Concurrent measurements of river stage, ground-water level, rainfall, and wetland stage were compared for each wetland. Comparison of measured river stage, ground-water level, rainfall, and wetland stage was used to characterize the relative contribution of each of these to changes in wetland stage; the lag time between changes in river stage, ground-water level, and rainfall to wetland stage; and the relative importance of river stage, ground-water level, and rainfall on wetland stage.

CONDITIONS AT WETLAND NC-5

The range of river stage, wetland stage, and water levels in wells recorded at NC-5 are listed in table 2. Highest and lowest water levels recorded may not correspond to the actual highest and lowest water levels that occurred between June 15, 1999, and July 6, 2000, because of intermittent gaps in data collection.

Water levels at wetland NC-5 from June 15, 1999, to July 6, 2000, are shown in figure 2. The hydrograph for the Missouri River shows a typical change in stage over the course of the year. In spring and summer, stages are relatively high because of increased releases of water from upstream dams and increased rainfall. In fall and winter, river stage is down because of decreased releases of water from upstream dams and reduced rainfall. Water levels in wetland NC-5, well NC-5, and wells NC-5A through NC-5D closely follow the trend of river stage, although variation was substantially muted. Wells NC-5A, NC-5B, and NC-5C became dry during July and August of 1999, as the ground-water level decreased below their maximum depths, and remained dry for the rest of the study.

Aligning river-stage peaks near wetland NC-5, and water-level peaks at wetland NC-5, well NC-5, and wells NC-5A through NC-5D by shifting the time scale for the water levels illustrates a lag time of approximately 2 days between river-stage changes and changes

Table 2. Highest and lowest water-level altitudes and dates of occurrence for wetland NC-5

[Datum is sea level; ft, feet; na, not applicable; <, less than; >, greater than]

Location	Altitude of wetland bottom or well bottom (ft)	Highest water-level altitude (ft)	Date of highest water level	Lowest water-level altitude (ft)	Date of lowest water level or when well went dry	Water-level range (ft)
Missouri River at river mile 190	na	587.0	July 1, 1999	565.7	February 4, 2000	21.3
Wetland NC-5	525 (approx.)	578.84	July 3, 1999	567.74	February 19, 2000	11.10
Well NC-5	543.24	579.06	July 6, 1999	567.73	February 18, 2000	11.30
Well NC-5A	577.49	579.74	July 3, 1999	<577.83	June 23, 1999 (well dry)	>1.91
Well NC-5B	576.70	578.86	July 6, 1999	<576.70	July 23, 1999 (well dry)	>2.23
Well NC-5C	574.50	579.28	July 3, 1999	<574.62	August 17, 1999 (well dry)	>4.66
Well NC-5D	560.62	579.36	July 3, 1999	567.76	February 18, 2000	11.60

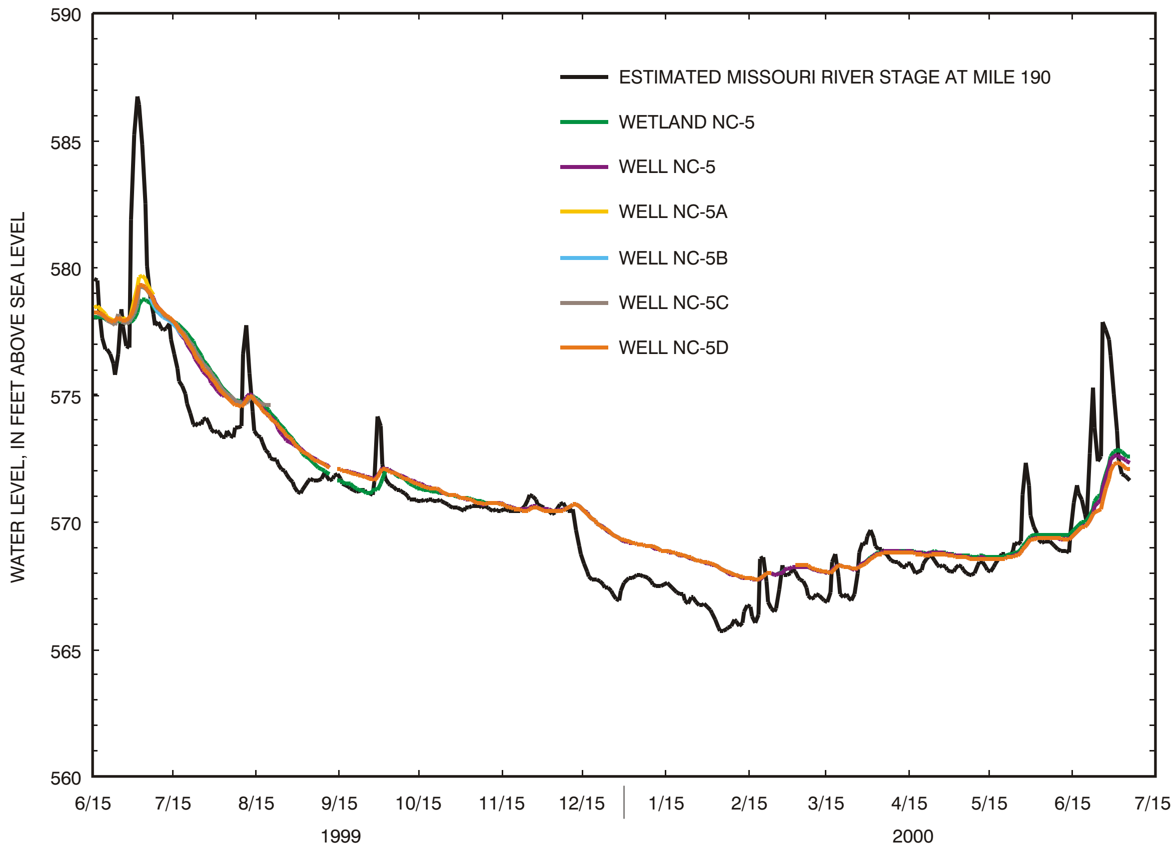

Figure 2. Water levels at wetland NC-5, well NC-5, and wells NC-5A through NC-5D from June 15, 1999, to July 6, 2000.

in wetland stage and ground water at wetland NC-5 (fig. 3). Daily rainfall, river stage, and wetland NC-5 stage are shown in figure 4 for the period of this study.

CONDITIONS AT WETLAND TC-1

The range of river stage, wetland stage, and water levels in wells recorded at wetland TC-1 are listed in table 3. Highest water levels recorded may not correspond to the actual highest water levels that occurred between June 15, 1999, and July 6, 2000, because recorders were inundated in July 1999.

Water levels at wetland TC-1 from June 15, 1999, to July 6, 2000, are shown in figure 5. Water was present about 25 percent of the time in wetland TC-1 during the period of record. The only time wetland TC-1 stage responded to a change in river stage was in June and July 1999, during high river stage. Well TC-1 and wells TC-1B, TC-1C, and TC-1D follow the trend of river stage for the period of record. Well TC-1A remained dry for the entire study and wells TC-1C and TC-1D became dry in August 1999 as the ground-water level decreased below their maximum depths and remained dry for the rest of the study. Well TC-1B became dry in January 2000 as the ground-water level decreased below its maximum depth and remained dry until March 2000, when the ground-water level increased above its maximum depth.

The rapid increase in stage at wetland TC-1 and in ground-water level in well TC-1D in late June and early July 1999 is shown in figure 5. Peak water levels in wells were not recorded during the peak and recession of this event because flood waters inundated the instrumentation. Water levels in wetland TC-1 and wells TC-1C and TC-1D did not exhibit the relatively rapid decrease that river stage did following this time. Instead, wetland stage and ground-water levels in wells TC-1C and TC-1D decreased more slowly and were nearly identical from July 7, 1999, to August 2, 1999. Water level in well TC-1C did not respond to the river stage rise from August 9, 1999, to August 14, 1999, but water levels in well TC-1B and well TC-1 increased and decreased with river stage (fig. 5).

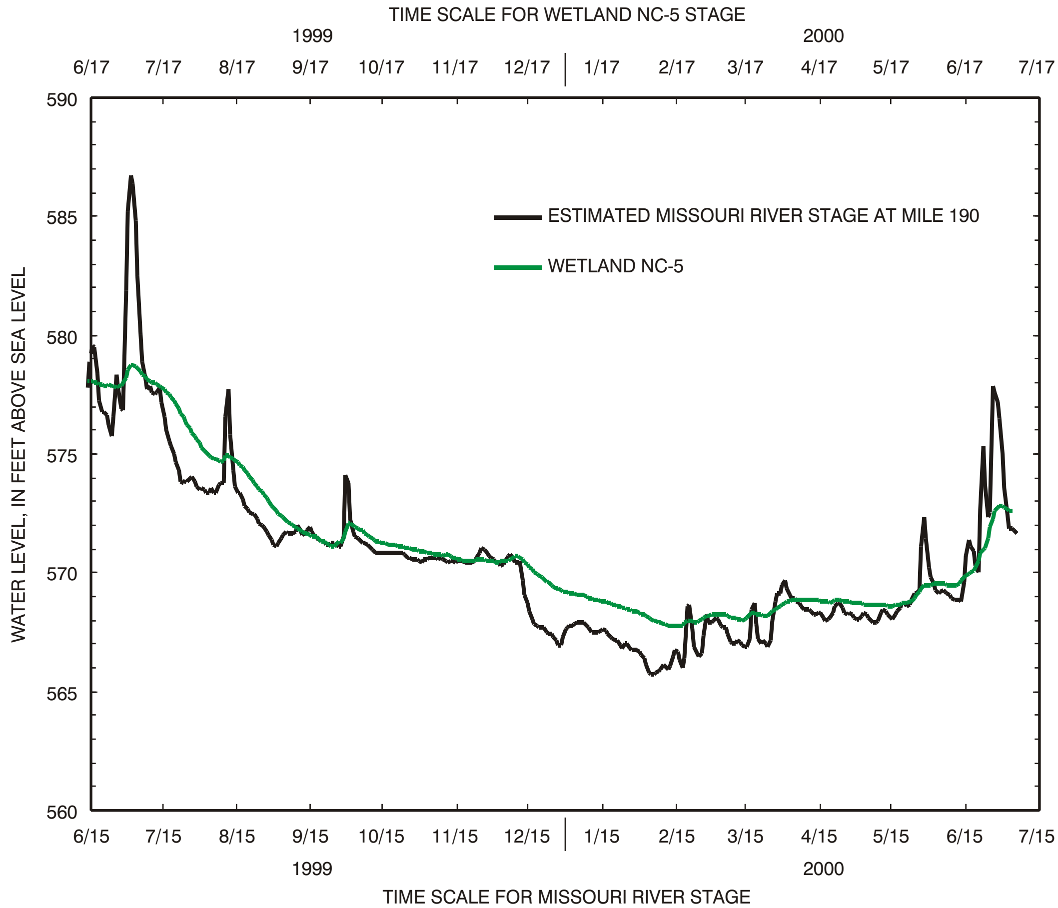

Figure 3. Two-day lag time between river stage and stage at wetland NC-5.

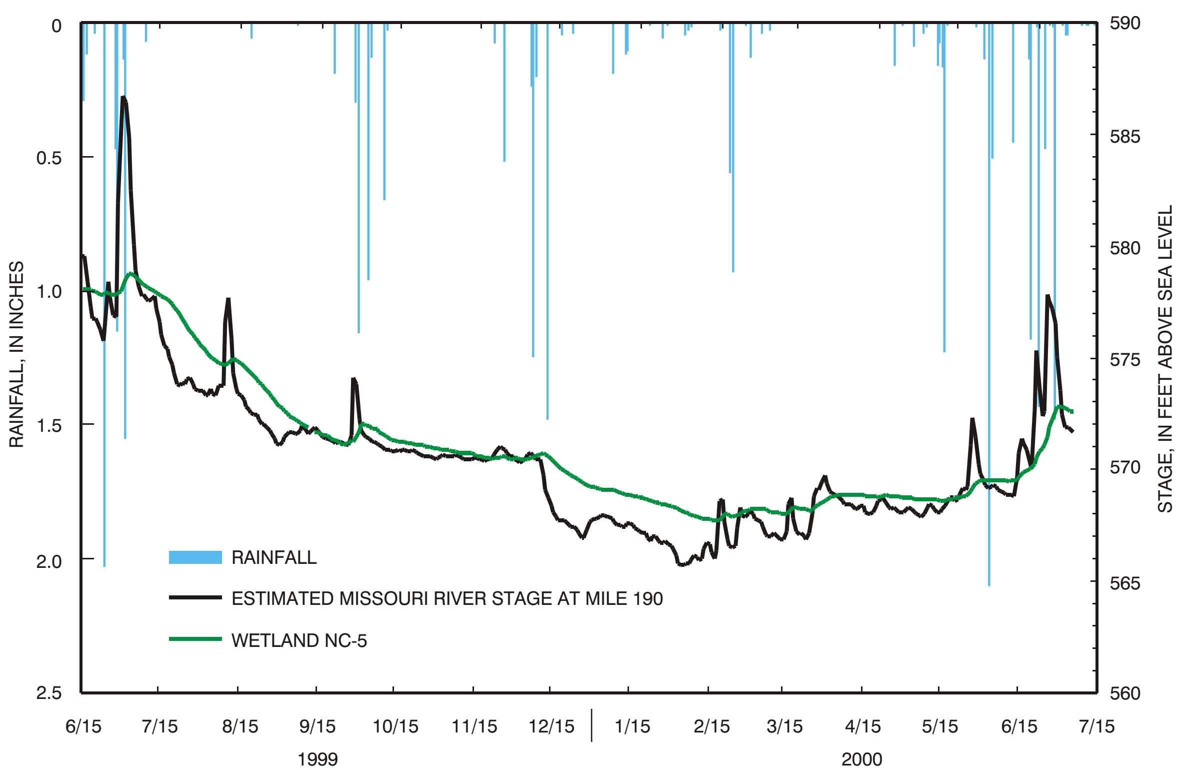

Figure 4. Daily rainfall, river stage, and wetland NC-5 stage.

Table 3. Highest and lowest water-level altitudes and dates of occurrence for wetland TC-1

[Datum is sea level; ft, feet; na, not applicable; <, less than; >, greater than]

Location	Altitude of bottom of wetland or well (ft)	Highest water-level altitude (ft)	Date of highest water level	Lowest water-level altitude (ft)	Date of lowest water level or when well went dry	Water-level range (ft)
Missouri River at river mile 187.5	na	584.9	July 1, 1999	563.6	February 4, 2000	21.3
Wetland TC-1	577.60	583.33	July 3, 1999	577.60	August 14, 1999	5.73
Well TC-1	546.32	580.72	July 7, 1999	566.54	February 17, 2000	14.18
Well TC-1A	580.08	dry	na	dry	na	na
Well TC-1B	564.72	580.72	July 7, 1999	<567.87	January 19, 2000 (well dry)	>12.85
Well TC-1C	574.01	581.55	July 7, 1999	<574.65	August 30, 1999 (well dry)	>6.9
Well TC-1D	577.70	582.12	July 2, 1999	<577.88	August 1, 1999 (well dry)	>4.24

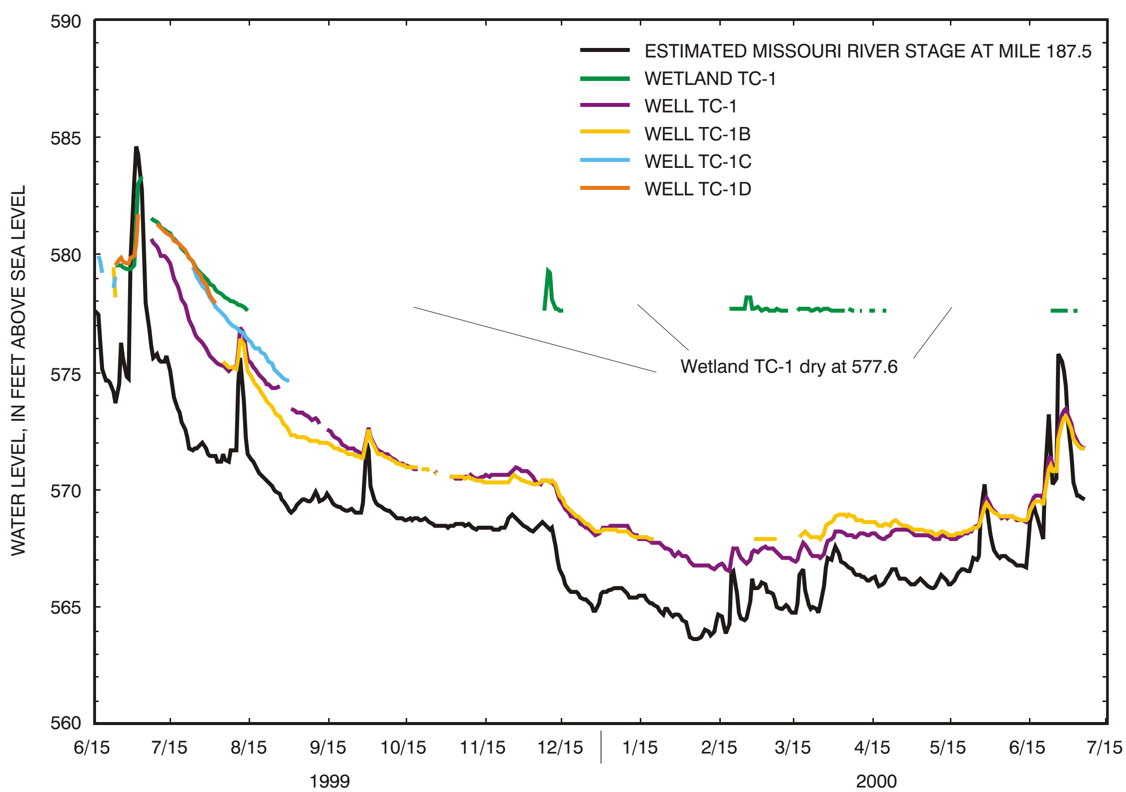

Figure 5. Water levels at wetland TC-1 and wells TC-1B through TC1-D from June 15, 1999, to July 6, 2000.

Aligning river-stage peaks near TC-1 and wetland TC-1 stage peaks by shifting the time scale for the water levels (fig. 6) indicate a lag time of approximately 2 days between the peak river stage and the peak wetland stage during June and July 1999. Aligning river-stage peaks near TC-1 and ground-water level peaks at wetland TC-1 by shifting the time scale for the ground-water levels (fig. 7) indicate a lag time of approximately 1 day or less between peak river stage and peak ground-water levels for the period of record. With the exception of two periods, December 9, 1999, to December 15, 1999, and February 18, 2000, to April 20, 2000, wetland TC-1 remained dry from August 15, 1999, to the end of data collection on July 6, 2000 (fig. 5). Daily rainfall, river stage, and stage for wetland TC-1 are shown in figure 8.

ESTIMATED GROUND-WATER LEVELS AT UNMEASURED SITES

Missouri River stage is measured continuously at numerous gages along the river. A previous study of the lower Missouri River alluvial aquifer in the Kansas City metropolitan area (Kelly, 2000) used ground-water flow simulations to develop a relation called the ground-water response factor (GWRF) that can be used to estimate the response of ground water to river-stage changes in the lower Missouri River alluvial aquifer. The use of the GWRF assumes that lithology and hydraulic properties are similar in the lower Missouri River alluvial aquifer. For scours or wetlands deep enough to intersect the ground-water table in the alluvial aquifer, such as wetland NC-5, this method can be used to estimate flood-plain wetland stage changes in response to known river-stage changes, and may provide flood-plain managers with additional knowledge of the hydroperiod, the cyclic fluctuation of water, of these types of wetlands. The GWRF is defined as the change in ground-water level at a known distance from the river, divided by the magnitude of the flood pulse at a specified time after the beginning of a flood pulse. The GWRF is a function of flood-pulse magnitude, distance from the river, and time after the beginning of a flood pulse, and is unique for each combination of these three values. By multiplying FP (the magnitude of the flood pulse or change in river stage) by the GWRF determined for that distance and time, the GWLC (ground-water-level change) is estimated for any magnitude change in river stage. To facilitate the comparison of flood-pulse magnitudes and distances from the river between data in Kelly (2000) and this report, both standard and metric units are used in this section. For example, to estimate the change in stage of a wetland 500 m from the river, 3 days after a 0.5-m-magnitude, 1-day-duration flood pulse, use the approximate GWRF (from Kelly, 2000; table 15) of 0.056, as follows:

$$GWLC = FP \times GWRF$$
$$= 0.5 \times 0.056$$
$$= 0.028 \text{ m}$$

The GWRF and corresponding standard deviation were determined for each day after the beginning of a flood pulse (GWRF day) at 100-m distance intervals from the Missouri River (Kelly, 2000). A comparison of measured water-level changes, estimated water-level changes using the GWRF, and the estimated water-level changes within one standard deviation predicted using the GWRF are listed in table 4 for NC-5, and table 5 for TC-1. The GWRFs calculated for 600- and 700-m distances were used for the comparison with water levels at NC-5, located approximately 2,200 ft (670 m) from the Missouri River, and GWRFs calculated for 400- and 500-m distances were used for the comparison with water levels at TC-1, located approximately 1,540 ft (470 m) from the Missouri River. Because wetland TC-1 was dry during most of the study period it did not respond directly to ground-water-level changes and water levels from the wetland are not included in the comparison.

Measured maximum water-level changes at wetland NC-5 were compared to estimated water-level changes using the GWRF and fall within the range of predicted changes. Measured maximum water-level changes in wells at wetland TC-1 were compared to estimated water-level changes using the GWRF and are close, but consistently greater than the estimated values and are most likely the result of alluvial deposits with higher than average hydraulic conductivity located between wetland TC-1 and the Missouri River.

RELATIONS AMONG RIVER STAGE, GROUND-WATER LEVELS, AND WETLAND STAGE

The close similarity between the hydrograph of wetland NC-5 and the hydrographs of well NC-5 and wells NC-5A through NC-5D indicate that fluctuations in ground-water level caused by river stage changes control the stage of wetland NC-5. As river stage rises, water flows from the river into the alluvium, and

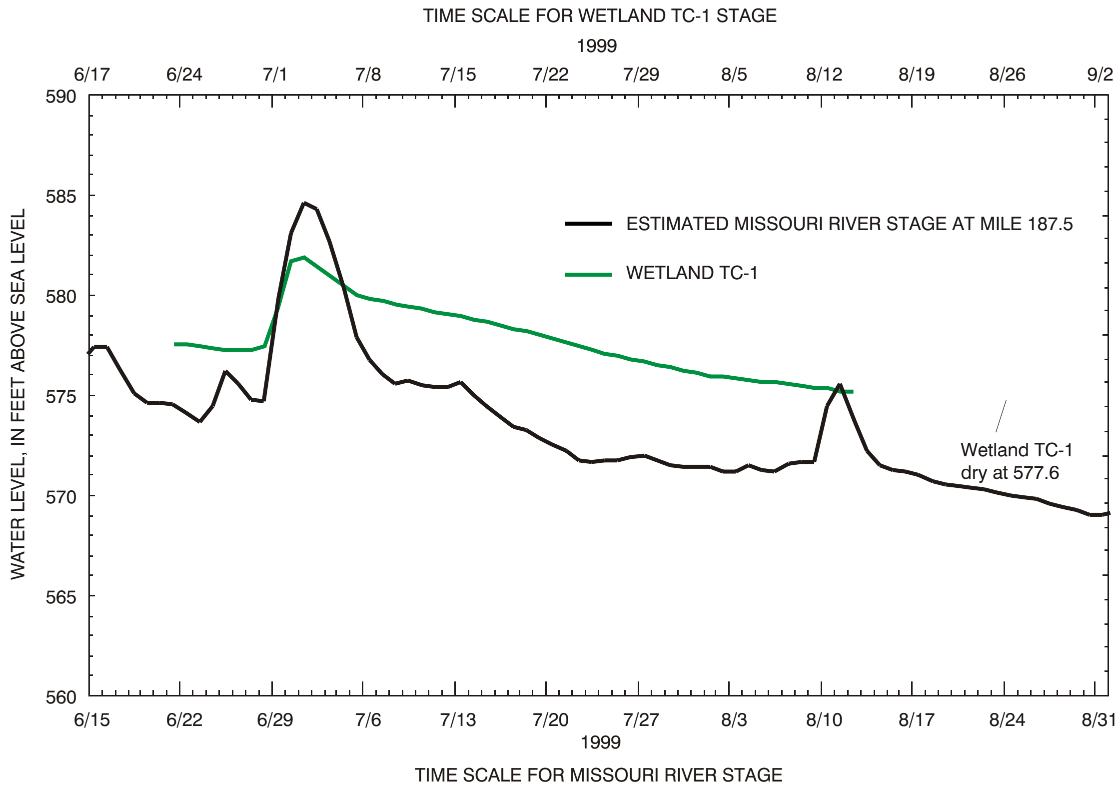

Figure 6. Two-day lag time between river stage and wetland TC-1 stage, June to August of 1999.

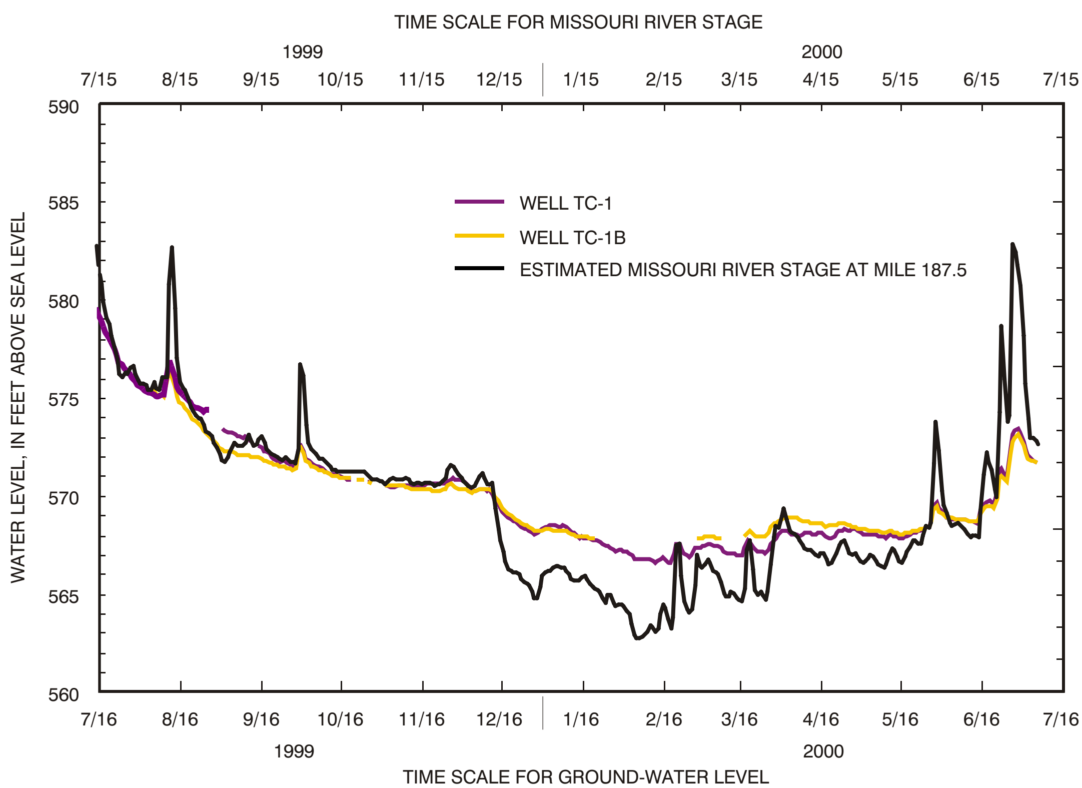

Figure 7. One-day lag time between river stage and ground water at wetland TC-1.

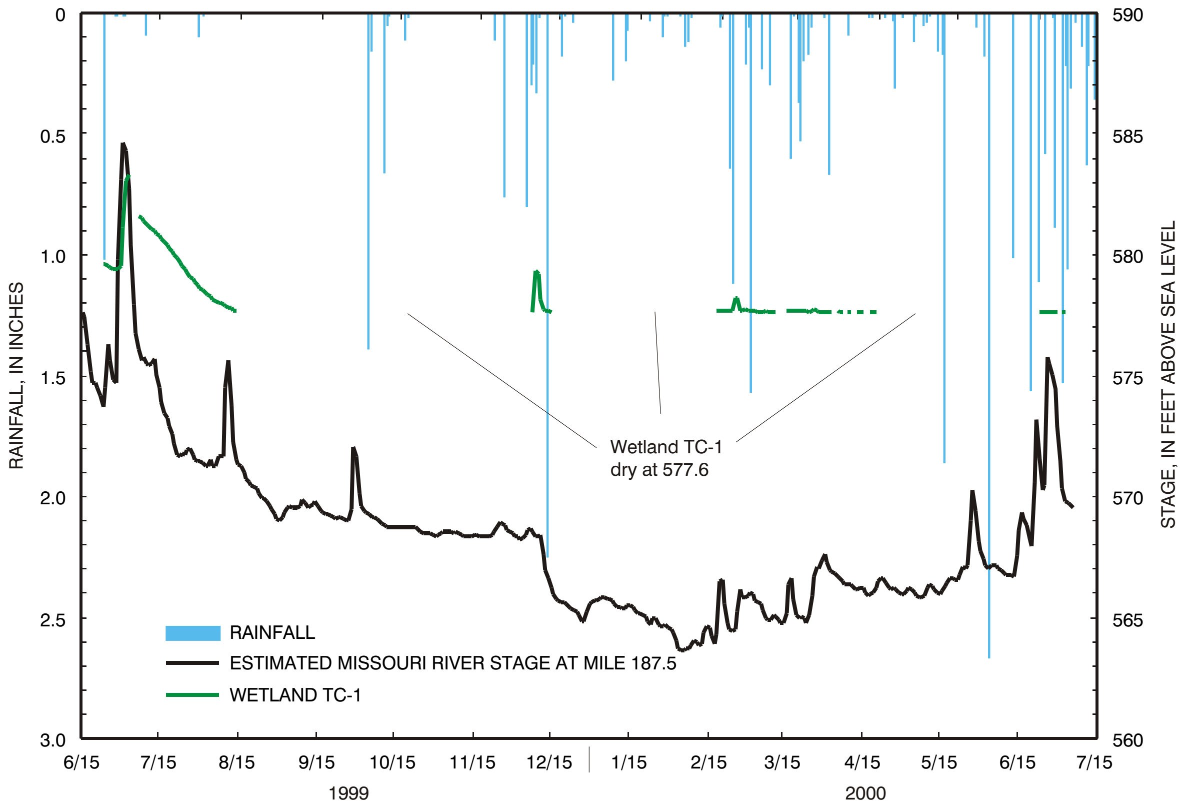

Figure 8. Rainfall, river stage, and wetland TC-1 stage.

ground-water level rises. With continued high-river stage, the rise in ground-water level propagates into the alluvium. When river stage decreases, ground-water levels nearest the river decrease first, and the decrease of ground-water levels also propagates away from the river and into the alluvium. The result of these processes is that the response of ground-water levels to changes in river stage lag behind the river stage changes. Because river-stage fluctuations occur more rapidly than the rate at which ground-water levels can respond, the magnitude of the change in ground-water level at a particular distance from the river usually is less than the magnitude of the change in river stage. Water levels in flood-plain wetlands deep enough to intersect the water table, like wetland NC-5, respond to changes in river stage in the same way as ground-water levels respond to changes in river stage. The hydrographs shown in figure 2 illustrate the response of ground water and stage at wetland NC-5 to river-stage fluctuations as described above. The hydrographs of river stage and wetland NC-5 stage shifted by time (fig. 3) indicate a 2-day lag time between river-stage changes and changes in ground water and stage at wetland NC-5.

The effect of rainfall on stage at wetland NC-5 is difficult to determine for several reasons. In contrast to the uplands on either side of the river valley, the relatively flat flood plain limits local runoff during rainfall events. Relatively flat topography also limits the predictability of runoff paths if runoff does occur. Rainfall events occurred during or about the same time as a rise in river stage in June, September, November, and December of 1999, and in May and June of 2000 (fig. 4). Rainfall did not occur without an associated river-stage rise during the study period. In addition, any stage increase from direct rainfall onto the water surface is difficult to measure because the bottom of wetland NC-5 intersects the highly permeable sands of the alluvial aquifer. A rainfall event of sufficient intensity to overcome the rate at which water is transmitted from wetland NC-5 to the aquifer did not occur during the study period. With these limitations in mind, the lack of measurable response of wetland NC-5 stage to rainfall events indicates that direct rainfall and runoff have an undetectable affect on stage, and are not a major source of water to NC-5. However, other scours similar to NC-5 could provide large amounts of focused recharge to the underlying alluvial aquifer if they received significant runoff from the uplands.

Table 4. Comparison of measured and estimated water-level changes at wetland NC-5

[Max., maximum; ft, feet; GWRF, ground-water response factor; m, meter; STD, standard deviation; High, using GWRF+STD for 1,969-ft distance; Low, using GWRF-STD for 2,297-ft distance]

Well or scour	Max. water-level change (ft)	Day of max. water-level change	Water-level change/river-stage change	GWRF day	Simulated GWRF value: 1,969 ft (600 m) distance	Simulated GWRF value: STD	Simulated GWRF value: 2,297 ft (700 m) distance	Simulated GWRF value: STD	Estimated maximum water-level change (ft): High	Estimated maximum water-level change (ft): 1,969 ft (600 m) distance	Estimated maximum water-level change (ft): 2,297 ft (700 m) distance	Estimated maximum water-level change (ft): Low
Event beginning on 6-28-99 and ending on 7-15-99. Maximum river stage change was 9.87 ft (3.01 m) on 7-1-99 (event day 4). GWRF from 8-day, 3-m simulation results												
Wetland NC-5	0.92	7-3-99	0.093	6	0.181	0.118	0.135	0.101	2.95	1.79	1.33	0.34
Well NC-5A	1.75	7-3-99	.177	6	.181	.118	.135	.101	2.95	1.79	1.33	.34
Well NC-5C	1.41	7-3-99	.143	6	.181	.118	.135	.101	2.95	1.79	1.33	.34
Well NC-5D	1.30	7-3-99	.132	6	.181	.118	.135	.101	2.95	1.79	1.33	.34
Event beginning on 8-9-99 and ending on 8-16-99. Maximum river stage change was 3.95 ft (1.2 m) on 8-11-99 (event day 3). GWRF from 8-day, 1-m simulation results.												
Wetland NC-5	0.28	8-13-99	0.071	5	0.115	0.088	0.079	0.070	0.802	0.454	0.312	0.036
Well NC-5	.39	8-12-99	.099	4	.091	.077	.060	.059	.664	.36	.237	.004
Well NC-5C	.30	8-13-99	.076	5	.115	.088	.079	.070	.802	.454	.312	.036
Well NC-5D	.41	8-12-99	.104	4	.091	.077	.060	.059	.664	.36	.237	.004
Event beginning on 9-27-99 and ending on 10-17-99. Maximum river stage change was 3.04 ft (0.93 m) on 9-29-99 (event day 3). GWRF from 8-day, 1-m simulation results.												
Wetland NC-5	0.8	10-3-99	0.263	7	0.162	0.107	0.117	0.089	0.818	0.492	0.356	0.085
Well NC-5	.45	10-1-99	.148	5	.115	.088	.079	.070	.617	.349	.240	.027
Well NC-5D	.44	10-1-99	.144	5	.115	.088	.079	.070	.617	.349	.240	.027

The hydrologic response of wetland TC-1 to river stage, ground water, rainfall, and runoff was very different than the response exhibited by wetland NC-5. The hydrographs of water levels shown in figure 5 illustrate the response of ground water and stage at wetland TC-1 to river-stage fluctuations. For the period of record, stage in wetland TC-1 only increased during high river stage and from runoff caused by local rainfall. Before July 1999, the ground-water level in well TC-1D was higher than wetland TC-1 stage, indicating upward ground-water flow into wetland TC-1. River stage never became higher than the surrounding levees upstream from wetland TC-1 during the study period. Water levels in wetland TC-1 were, however, higher or nearly the same as ground-water levels near wetland TC-1. Between July 1, 1999 and August 15, 1999, rainfall was not sufficient to explain the increase in wetland TC-1 stage above ground-water level (fig. 5). In addition, the 2-day lag time between peak stage at wetland TC-1 and peak stage on the Missouri River, compared to the 1-day lag time between the river and ground-water levels at TC-1, indicate a less direct hydraulic connection between the river and the wetland. High resolution elevation data provided by the USACE (Kim Penner, U.S. Army Corps of Engineers, written commun., 2000) indicate that at stages above 579.5 ft, wet-

Table 5. Comparison of measured and estimated water-level changes at wetland TC-1

[ft, feet; GWRF, ground-water response factor; m, meter; STD, standard deviation; High, using GWRF+STD for 1,312-ft distance; Low, using GWRF-STD for 1,640-ft distance]

Well	Maximum water-level change (ft)	Day of maximum water-level change	Water-level change/ river-stage change	GWRF day	Simulated GWRF value: 1,312 ft (400 m) distance	STD	1,640 ft (500 m) distance	STD	Estimated maximum water-level change (ft): High	1,312 ft (400 m) distance	1,640 ft (500 m) distance	Low
Event beginning on 8-9-99 and ending on 8-16-99. Maximum river stage change was 3.95 ft (1.2 m) on 8-11-99 (event day 3). GWRF from 8-day, 1-m simulation results.												
Well TC-1	1.72	8-11-99	0.435	3	0.192	0.129	0.120	0.096	1.26	0.758	0.474	0.948
Well TC-1B	1.32	8-11-99	.334	3	.192	.129	.120	.096	1.26	.758	.474	.948
Event beginning on 9-27-99 and ending on 10-17-99. Maximum river stage change was 3.04 ft (0.93 m) on 9-29-99 (event day 3). GWRF from 8-day, 1-m simulation results.												
Well TC-1	1.19	9-30-99	0.39	4	0.233	0.142	0.153	0.109	1.14	0.708	0.465	0.134
Well TC-1B	1.18	9-30-99	.388	4	.233	.142	.153	.109	1.14	.708	.465	.134

land TC-1 has a surface connection to wetland NC-3, the large scour near I-70 located approximately 765 ft (233 m) from the Missouri River and approximately 7,550 ft (2,300 m) southeast of wetland TC-1 (fig. 1). In addition, wetland NC-3 is connected to the Missouri River for river stages above 580.6 ft at river mile 184.15, downstream from wetland NC-3.

The potential effect on wetland TC-1 stage by a change in wetland NC-3 stage can be evaluated by estimating the maximum water level change for wetland NC-3 during July 1999 using the GWRF (table 6) and comparing stages between wetlands TC-1 and NC-3. This method can estimate stage changes in wetland NC-3 caused only by ground-water-level changes in response to river stage changes, and not a change in wetland NC-3 stage caused by a surface connection to the river.

The measured responses of ground-water level to river-stage changes at wetland TC-1 were consistently greater than water-level changes estimated using the GWRF. For this reason, the high estimate listed in table 6 for the maximum stage change at wetland NC-3 was chosen for the comparison to wetland TC-1 stage. The maximum estimated stage at wetland NC-3 was 580.38 ft; the maximum measured stage at wetland TC-1 during this same event was 583.31 ft. The higher stage at wetland TC-1 indicates that wetland NC-3 stage changes in response to river-stage changes did not back water into wetland TC-1 at the peak. However, the estimate for maximum stage at wetland NC-3 was greater than 579.5 ft, the altitude at which TC-1 and NC-3 have a surface connection, indicating that wetland NC-3 stage changes can, at times, affect stage at wetland TC-1. As previously stated, wetland NC-3 connects to the river at stages above 580.6 near river mile 184.15. During the study period, this connection to the river only occurred between June 30, 1999, and July 3, 1999, when river stage exceeded 580.6 at river mile 184.15. Wetland TC-1 stage minus stage for river mile 184.15 between June 30, 1999, and July 3, 1999, is shown in figure 9. Wetland TC-1 stage is less than river stage on June 30, 1999, and July 1, 1999, and then rises above river stage on July 2, 1999, and July 3, 1999. The maximum difference between wetland TC-1 stage and river stage on June 30, 1999, and July 1, 1999, was -0.78 ft (altitude 580.3 at river mile 184.15). Because wetland TC-1 stage increased to at least 583.3 ft on July 3, 1999, (3.41 ft higher than the river at mile 184.15) a source of water other than the direct connection to the river at mile 184.15 was the cause of the stage increase.

There was little or no precipitation on the 9 days before the increase in stage beginning on June 30, 1999, at wetland TC-1; wetland TC-1 was protected from upstream flooding by levees during this study. A levee located about 2,200 ft west of wetland TC-1 lies between the wetland and the unprotected part of the flood plain upstream from wetland TC-1 at river mile 188. River stage, estimated using the regression and

Table 6. Estimated water-level changes at wetland NC-3

[GWRF, ground-water response factor; ft, feet; m, meter; STD, standard deviation; High, using GWRF+STD at 656-ft distance; Low, using GWRF-STD at 984-ft distance]

		Simulated GWRF value				Estimated maximum water-level change (ft)				Estimated maximum stage (ft)			
Well or scour	GWRF day	656 ft (200 m)	STD	984 ft (300 m)	STD	High	656 ft (200 m) distance	984 ft (300 m) distance	Low	High	656 ft (200 m) distance	984 ft (300 m) distance	Low
Event beginning on 6-28-1999 and ending on 7-15-1999. Maximum river stage change was 9.87 ft (3.01 m) on 7-1-99 (event day 4). GWRF from 8-day, 3-m simulation results													
Wetland NC-3	4	0.562	0.224	0.378	0.189	7.75	5.55	3.73	1.86	580.38	578.18	576.36	574.49

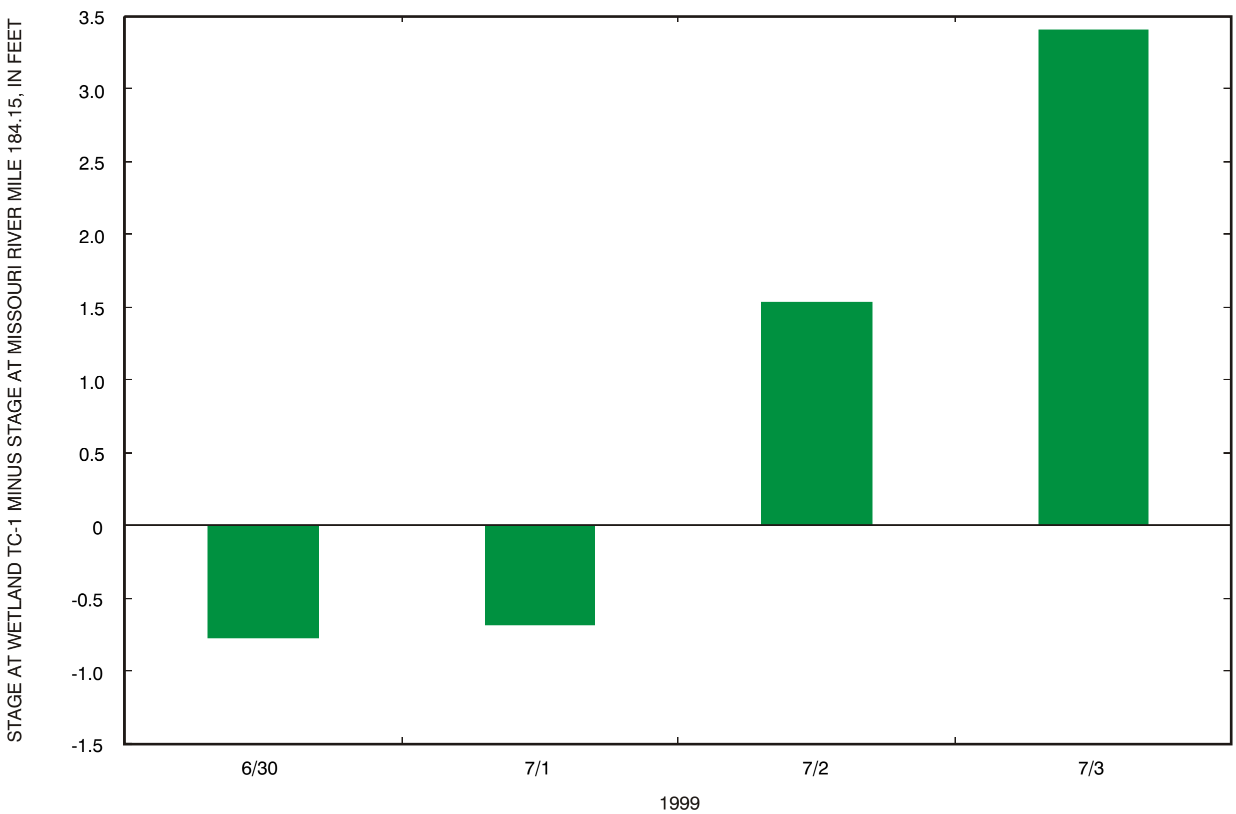

Figure 9. Wetland TC-1 stage minus river mile 184.15 stage, June 30, 1999, to July 3, 1999.

interpolation methods previously discussed, at river mile 188 peaked at 585.3 on July 1, 1999, at 6:00 p.m. River stage at river mile 187.5 peaked at 584.9 on July 1, 1999, at 6:00 p.m. At this stage, water was within about 5 ft of the levee top. The most likely explanation for the rise in stage at wetland TC-1 during this time is surface water supplied to the flood plain via seepage through the levees, and upward flow of ground water through alluvial deposits of relatively high hydraulic conductivity driven by the hydraulic gradient between the river and the flood-plain surface during high-river stage.

During the recession of water levels at wetland TC-1 after July 1, 1999, stage remained above or nearly equal to shallow ground-water levels, indicating infiltration of water from TC-1 into the alluvial aquifer. This pattern indicates that TC-1 stage and shallow ground-water levels are closely related, that the rate of decrease in wetland stage was limited by the rate at which ground-water level decreased, and that the wetland was a source of recharge to the alluvial aquifer during this time.

TC-1 remained dry after August 15, 1999, except for two periods, once in December 1999 and again from February to April 2000. The presence of water in wetland TC-1 from December 9, 1999, to December 15, 1999, was caused by 4.78 inches of rainfall between November 11, 1999, and December 9, 1999. The 2.53 inches of rainfall between November 11, 1999, and December 8, 1999, most probably saturated the soil column enough to allow runoff to develop within the small basin that drains into wetland TC-1 from the 2.25 inches of rainfall on December 9, 1999. This scenario is supported by the 2.88-ft (34.56-inch) rise in wetland TC-1 stage on December 9, 1999 (fig. 7). Between December 15, 1999, and February 16, 2000, 1.29 inches of rain fell in several small events without reappearance of water in wetland TC-1. On February 17, 1999, 0.64 inch of rain followed by 1.12 inches of rain on February 18, 1999, resulted in a 0.11-ft (1.27-inch) rise in wetland TC-1 stage. On February 25, 2000, 1.57 inches of rain caused wetland TC-1 stage to rise 0.49 ft (5.85 inches) by February 26, 2000. Between February 27, 2000, and April 20, 2000, 3.65 inches of rain fell in several small events, and wetland TC-1 water depths remained at or below 0.1 ft. From April 21, 2000, to the end of data collection on July 6, 2000, a total of 15.03 inches of rain fell. The largest event, 2.67 inches, occurred on May 26, 2000. During this time wetland TC-1 remained dry.

The average rates of decrease of wetland TC-1 stage after the stage increases of December 9, 1999, and February 25, 2000, were 0.55 and 0.7 inches per hour, respectively. Because wetland TC-1 has no outlet for surface-water flow at stages below about 1.9 ft, and because evapotranspiration was negligible at that time of year, these decreases in stage represent water flow from wetland TC-1 into ground water and indicate the infiltration rate of the bottom material in the wetland. Wetland TC-1 stage response to rainfall during the winter months and the lack of response to greater rainfall amounts during spring and summer months indicate that evapotranspiration may limit the effect of rainfall on wetland stage at TC-1 during the growing season.

Wetlands NC-5 and TC-1 may approximately represent two morphologic end members of wetland types found in the Missouri River flood plain. Deep scours like wetland NC-5 contain water throughout the year. The bottoms of these scours may intersect the highly conductive sand of the underlying alluvial aquifer allowing a relatively rapid exchange of water between the scour and ground water. Ground-water fluctuations caused by river-stage changes have a large effect on water levels in these deep, non-connected scours. Temporary wetlands like TC-1 usually are shallow depressional features that have bottom material with low permeability. These wetlands have significantly less interaction with ground water because of their lack of depth and low-permeability bottom material. As a result, water levels respond to local rainfall and runoff to a greater degree than the larger scours. Because these two wetlands may approximately represent morphological end members of a continuum of wetlands in the Missouri River flood plain, the responses of many other wetlands to changes in river stage, rainfall, and runoff should fall within the range of the responses exhibited by wetlands NC-5 and TC-1.

SUMMARY

The source of water is important to the ecological function of flood-plain wetlands. There are four potential sources of water to flood-plain wetlands: direct flow from the river channel during high river stage, movement of ground water into the wetlands in response to river-stage changes, direct precipitation, and runoff from the surrounding uplands. The source of water and the magnitude and timing of water-level fluctuations in these water bodies may affect water quality, ecological function, and use. This report presents con-

currently measured river stage, rainfall, ground-water levels, and wetland stage at two wetlands located on the Missouri River flood plain near Rocheport, Missouri. Wetland NC-5 is a permanent scour hole up to 50 feet deep and is under water all year. Wetland TC-1 is a temporary wetland where water is not present all year. Because these two wetlands may approximately represent two morphological end members of wetland types found in the Missouri River flood plain, the responses of other wetlands to changes in river stage, rainfall, ground-water-level changes, and runoff should fall within the range of the responses exhibited by wetlands NC-5 and TC-1.

One monitoring well and one cluster of four wells of various depths were installed at each site to collect ground-water-level data. A linear regression from river stages concurrently measured at the U.S. Geological Survey streamflow gaging station at Boonville, Missouri, and at a reference point located at the bridge over Moniteau Creek near Rocheport, Missouri, was developed and river stage near wetlands NC-5 and TC-1 were estimated by interpolation along the river between the two points. Rainfall was measured with a tipping bucket rain gage. Time and water levels were recorded by a data logger at hourly intervals.

Concurrent measurements of river stage, rainfall, ground-water level, and wetland stage were compared for each wetland to characterize the relative contribution and importance of potential sources of water on wetland stage. For scours such as wetland NC-5 or wetlands deep enough to substantially intersect the ground-water table in the alluvial aquifer, the ground-water response factor (GWRF) can be used to estimate water-level changes in response to known river-stage changes, and may provide flood-plain managers with additional knowledge of the hydroperiod of these types of wetlands. Measured maximum water-level changes at wetland NC-5 estimated using the GWRF fell within the range of predicted changes. Measured maximum ground-water-level changes at wetland TC-1 are similar to but consistently greater than the estimated values, and are most likely the result of alluvial deposits with higher than average hydraulic conductivity located between wetland TC-1 and the Missouri River.

The close similarity between stage at wetland NC-5 and the ground-water levels in wells at wetland NC-5 indicate that fluctuations in ground-water level caused by changes in river stage control the stage of wetland NC-5. The hydrographs of river stage and wetland NC-5 stage shifted by time indicate a 2-day lag time between river stage changes and changes in ground water and stage at wetland NC-5. The lack of a measurable response of wetland NC-5 stage to rainfall, and the isolation of wetland NC-5 from runoff and flooding by levees, indicate that direct rainfall and runoff are minimal sources of water to wetland NC-5.

The most likely explanation for the rise in stage at wetland TC-1 is surface runoff supplied to the flood plain via seepage through the levees, and upward flow of ground water through alluvial deposits of higher hydraulic conductivity during high river stage. The rate of decrease in wetland TC-1 stage was limited by the rate at which ground-water level decreased. Wetland TC-1 stage response to rainfall during the winter months and no response to greater rainfall amounts during spring and summer months indicate that evapotranspiration may limit the affect of rainfall on stage at wetland TC-1 during the growing season.

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