Hydrologic Interactions Among Rainfall, Side-Channel Chutes, the Missouri River, and Ground Water at Overton Bottoms North, Missouri, 1998-2004

By Brian P. Kelly

Chapter 3 of

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Contents

Figures

Tables

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Chapter 3
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Abstract

In 2000, the U.S. Army Corps of Engineers (USACE) constructed a side-channel chute at Overton Bottoms North, near Overton, Missouri, to provide shallow water habitat in the Missouri River for native fish. The U.S. Geological Survey collected hydrologic data between 1998 and 2000 before chute construction; between 2001 and 2002 after construction of the first-generation chute; and between 2003 and 2004 after construction of a wider and deeper second-generation chute.

Rainfall during the study had little effect on ground water altitudes. Water flow in the first-generation chute occurred less frequently than in the second-generation chute. Depth to ground water was least for pre-chute conditions, greater for first-generation-chute conditions, and greatest for second-generation-chute conditions at most wells. Ground-water response depended on topography and distance from the chute or river. The median difference between ground-water and river altitude from pre-chute to second-generation-chute conditions at a low-lying wetland area near the chute increased 0.09 m (meter), but decreased -0.61 m, -0.89 m, and -0.49 m at three areas of higher land-surface altitudes, indicating lowering of the ground-water altitude relative to the river.

Chute construction breached the levee at the chute inlet and outlet, allowed more frequent inundation of the area at a lower river stage, allowed more frequent surface recharge to the aquifer from flood inundation in low-lying areas, added another river channel in the study area more inland from the main river channel, decreased the difference between ground-water and river altitude from pre-chute to second-generation-chute conditions, increased the effect of river altitude changes on ground-water altitude, and increased ground-water altitude variability. During low river stages, lack of inundation and a lower ground-water altitude will decrease water available to wetlands. During high river stages more frequent flooding and recharge of the aquifer through the chute banks will increase water available to wetlands. Therefore, chute construction at Overton Bottoms North will make wetlands drier during low river stage and wetter during high river stage.

Introduction

Historically, the Lower Missouri River flood plain contained oxbow lakes, seasonally flooded wetlands, and wooded sloughs. These wetlands were continually created and destroyed by the unregulated meandering and flooding of the Missouri River. Channelization and flood-control projects have stabilized and narrowed the river, making the creation of new wetlands rare, thereby reducing flood-plain habitat for fish and wildlife (Funk and Robinson, 1974). In addition, levees and a series of upstream flood-control reservoirs have altered the historic flooding and sedimentation patterns that affect the flood plain.

Recent efforts to mitigate the effects of management of the Lower Missouri River have centered on techniques for reconnecting wetland habitats to the main channel. The techniques include purchasing and converting farmland into more-natural ecosystems by a range of engineered and passive approaches. Catastrophic damage resulting from the large magnitude Missouri River flooding of 1993 prompted an acceleration of mitigation activities as more land became available for purchase by conservation agencies. One of these tracts of land acquired is Overton Bottoms North in central Missouri (fig. 1).

The availability and distribution of surface water and ground water are important factors controlling the composition and spatial distribution of restored flora and fauna in the Missouri River flood plain. The frequency, duration, and timing of flooding; amount and timing of precipitation; amount of runoff from local tributaries; amount of ground water lost or gained; evapotranspiration rates; ice thickness; and wetland water depth, exert strong controls on flood-plain and wetland ecosystem functions. These functions include sediment trapping, nutrient removal, flood-water storage, wildlife habitat, vegetative types, ecosystem stability, and water turbidity (Blevins, 2004). The availability of various flood-plain habitats and wetland types affects the use, distribution, and habitat for fish and wildlife. The size, habitat diversity, and proximity to other habitat types affect migratory and resident wildlife use locally and regionally.

Geology

The Missouri River flood plain is underlain by alluvial deposits of Quaternary age consisting of clay, silt, sand, gravel, cobbles, and boulders (Holbrook and others, this volume, chapter 2; Kelly and Blevins, 1995). These unconsolidated deposits overlie shale, limestone, and sandstone bedrock and form the alluvial aquifer. The nature and extent of the alluvial deposits have been greatly affected by numerous changes in discharge, sediment load, and river course during the Quaternary. The present course of the Missouri River in Missouri approximates the southernmost limit of continental glaciation.

Numerous investigations have presented lithologic cross sections showing a 6- to 9-m silt/clay cap that overlies the thick sand and gravel units in the middle of the alluvium in most parts of the Lower Missouri River flood plain (Emmett and Jeffery, 1968, 1969a, 1969b, 1970; Kelly and Blevins, 1995). The cap of fine sediment (top stratum) in the study area is mostly about 2.5 m thick, although channel fills of 7–8 m thickness have also been documented (this volume, chapter 2). The top stratum may limit water flow between the land surface and the alluvial aquifer. Typically, a thin layer of sandy gravel, gravel, and boulders is at the base of the Missouri River alluvial aquifer.

Hydrology

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 0.94 m of rainfall per year (Gann and others, 1971). The source of water is important to the ecological function of flood plains and flood-plain wetlands; the four potential sources of water are: direct precipitation, runoff from the surrounding uplands, flooding from the river channel, and ground water. Changes in wetland stage from direct precipitation are typically minimal and are limited by rainfall (Jacobson and Kelly, 2004). Runoff from the surrounding uplands can provide water to wetlands near the base of the river-valley walls where upland streams enter the flood plain or in wetlands located in or near drainage channels. Flooding from the river channel can affect the entire flood plain during infrequent large floods, but is most frequent in flood-plain areas unprotected by levees and nearest the river channel. Fluctuations in river stage cause changes in groundwater levels in the Missouri River alluvium (Kelly, 2001). The movement of ground water into wetlands in response to rising river stage has the greatest effect on wetlands that are deep enough to intersect the water table.

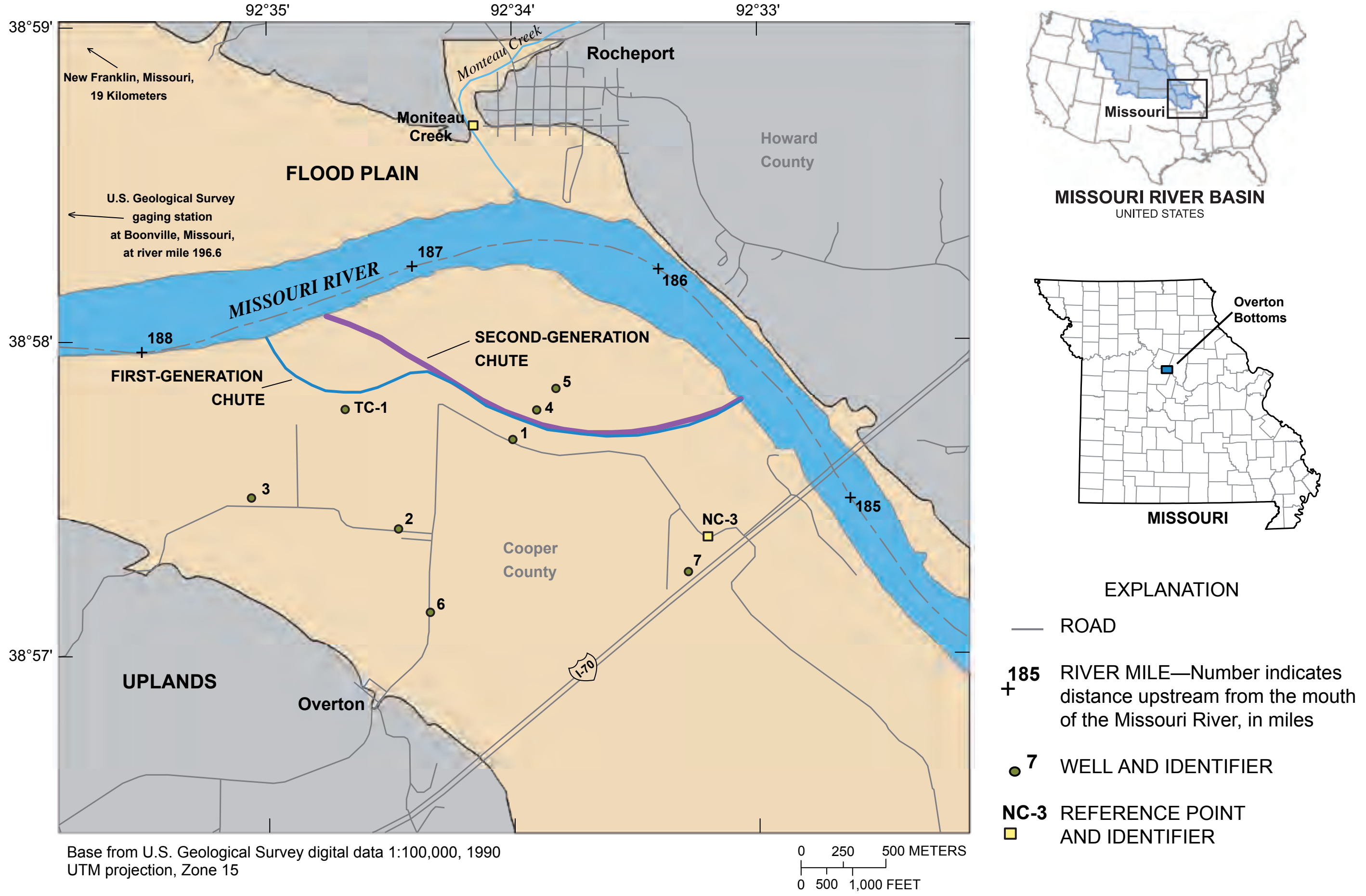


Figure 1. Study area, chute orientations, and well locations at Overton Bottoms North, Missouri.

Study Area

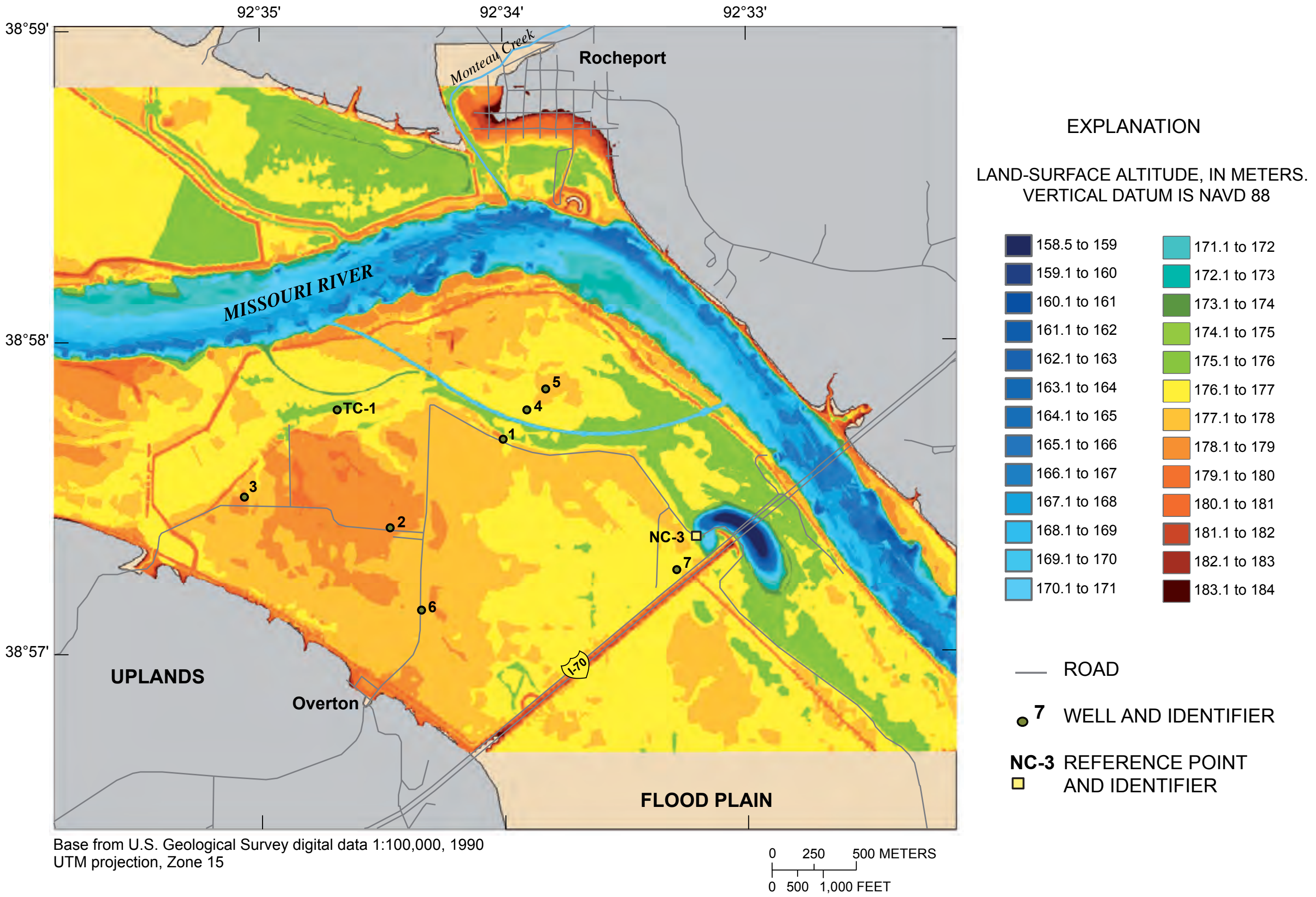
Overton Bottoms is approximately 2,143 ha (hectares) of river bottom along the south bank of the Missouri River in Cooper and Moniteau Counties, Missouri, between river mile 188 and 177. The study area is the upstream portion of Overton Bottoms (Overton Bottoms North) between river mile 188 and 185 (fig. 1). The Overton Bottoms North Unit was purchased as part of the interagency Missouri River Fish and Wildlife Mitigation Project and is administered by the Big Muddy National Fish and Wildlife Refuge, U.S. Fish and Wildlife Service (USFWS; Jacobson, this volume, chapter 1).

The Missouri River alluvial valley has generally subdued topography in the study area (fig. 2); however, highway embankments along Interstate 70 and pre-existing levees are 3–5 m above the surface of the alluvial valley in some areas. Total relief within the study area is approximately 10 m with the highest altitude between 182 and 183 m above North American Vertical Datum of 1988 (NAVD 88) near Interstate 70 and along remaining tops of levees. The lowest altitude on the flood plain (about 173 m above NAVD 88) is along the south bank of the Missouri River. Low-lying areas collect surface runoff during wet periods causing standing water to remain for some time where soils are poorly drained.

Hydrologic Investigations at Overton Bottoms North

Hydrologic data have been collected at numerous locations along the Missouri River from the Missouri-Iowa border to St. Louis, Missouri, during recent studies. Previous studies of the hydrology at Overton Bottoms North before and after construction of the side-channel chute (hereafter referred to as the chute) have provided information about the interaction of river stage, wetland stage, ground-water levels, and rainfall at the site (Kelly, 2001).

The USACE began designing a pilot chute at Overton Bottoms North in 1998. The primary design objective was to provide shallow water habitat accessible to native Missouri River fishes (fig. 1). The U.S. Geological Survey (USGS), in cooperation with the USACE, installed three monitoring wells (wells 1, 2, and 3; fig. 1) to provide ground-water level data, and a staff gage in a deep scour hole (NC-3; fig. 1) to provide stage data in support of the design and construction of the first-generation chute. In addition, a reference point located near Rocheport, Missouri, on a bridge over Moniteau Creek near the mouth was used to record Missouri River stage (from backwater on Moniteau Creek) to determine the slope of the Missouri River surface between the Boonville streamflow gage



Base from U.S. Geological Survey digital data 1:100,000, 1990
UTM projection, Zone 15

Figure 2. Land-surface altitudes for Overton Bottoms North, Missouri.

(USGS stream-gaging station number 06909000) and Overton Bottoms North (fig. 1). River stage, ground-water levels, and wetland stage data were collected monthly between June 1998 and May 1999 to provide potentiometric surface maps for the area where the new chute was constructed. In 1999, a study by the USGS, in cooperation with the U.S. Environmental Protection Agency (USEPA), evaluated the hydrology of two wetlands (Kelly, 2001). One of the wetlands, TC-1, is located at Overton Bottoms North (fig. 1). River stage, ground-water levels, wetland stage, and rainfall were measured hourly at both wetland sites between June 1999 and July 2000 to characterize the spatial and temporal relations among river stage, ground-water levels, wetland stage, and rainfall. Well TC-1 was installed at Overton Bottoms North for this study. Study results indicated shallow wetlands were most affected by rainfall and flood inundation, whereas deeper wetlands and scours were most affected by ground-water fluctuations caused by river-stage changes below flood stage.

The USACE completed construction of the pilot chute in Spring 2001. This small first-generation chute was approximately 3,000-m long, 12-m wide, and 2-m deep. The inlet design elevation was 174 m, and the outlet design elevation was 172.8 m. Geomorphic evolution of the first-generation chute is documented in Jacobson and others (2004) and this volume, chapter 1. Water-level recorders were installed in wells TC-1, 1, 2, and 3, and stage recorders were installed in wetland TC-1 and NC-3 by the USGS, in cooperation with the USFWS to continue hydrologic monitoring at Overton Bottoms North between June 2001 and June 2002 after the first-generation chute was constructed.

In 2003, the USACE modified the first-generation chute by shortening its length and increasing its depth and width to increase the duration of flow in the chute and prevent the accumulation of large woody debris that had blocked the original first-generation chute by 2002 (fig. 1). This second-generation chute is approximately 2,500-m long, 21-m wide, and 6-m deep. The inlet elevation is 170.4 m and the outlet elevation is 170.8 m. The potential change in hydrology of Overton Bottoms North caused by the large change in chute dimensions provided the impetus to continue assessment of the hydrologic interactions among water levels in the Missouri River, the chute, ground water, and adjacent wetlands.

Purpose and Scope

The hydrologic assessment at Overton Bottoms North is part of a multidisciplinary USGS effort to link hydrology, geology, and vegetative communities (this volume, chapter 1). The Overton Bottoms North Unit provided an opportunity to evaluate hydrologic effects of this rehabilitation design by comparing hydrologic functions in the flood plain before and after chute construction.

The objectives of the study were to measure and determine the characteristics of and relations among river stage, chute stage, ground-water levels, and rainfall; and to determine whether or not chute construction altered the hydrology at Overton Bottoms North. The purpose of this report is to present the results of this study including river-stage and chute-stage data, well hydrographs, potentiometric surface maps, depth to ground-water maps, and hydrologic cross sections for pre-chute, first-generation-chute, and second-generation-chute conditions. The data used were collected from 1998 to 2004.

Methods of Hydrologic Data Collection and Analysis

Rainfall, chute and river altitude, and ground-water altitude were measured at Overton Bottoms North from June 1998 to May 1999, June 2001 to June 2002, and June 2003 to October 2004. These three periods correspond to pre-chute, first-generation-chute, and second-generation-chute conditions.

Daily rainfall data for the study period were obtained from the National Weather Service site at New Franklin, Missouri, approximately 19 km (kilometers) upstream from Rocheport, Missouri (fig. 1) (National Oceanic and Atmospheric Administration, 1998, 1999, 2000, 2001, 2002, 2003, 2004). Hourly river stage at Overton Bottoms North was estimated using linear regression between river stages measured to the nearest 0.003 m at the USGS streamflow-gaging station at Boonville, Missouri (river mile 196.6) and monthly measurements of Missouri River stage at the Overton Bottoms North reference point on Moniteau Creek (Kelly, 2001; fig. 1). Twelve measurements at the reference point were compared to 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 altitude is plus or minus 0.003 m. River stage at other locations in the vicinity of Overton Bottoms North was estimated using the regression equation and linear interpolation along the river between the river gage at Boonville, Missouri and the reference point at Moniteau Creek. Chute stage was estimated by linear interpolation of Missouri River stage between the upstream and downstream ends of the chute.

Wells TC-1, 1, 2, and 3 were installed during previous studies. Wells 4 and 5 were installed in March 2003 during the modification of the chute. Wells 6 and 7 were installed after chute modification in August 2003. Pressure transducers and data recorders were installed in wells TC-1, 1, 2, 3, 4, and 5 in July 2003, and in wells 6 and 7 in September 2003. Water levels within wells were measured continually using a vented pressure transducer to 0.009-m accuracy (Global Water Instrumentation, Inc., 2002). Water levels were recorded hourly by a data logger and were checked with monthly manual measurements made using an electric water-level measuring tape to the nearest 0.003 m. All well measuring points were surveyed from a nearby benchmark to 0.003-m accuracy with respect to NAVD 88. Water levels were converted to altitude above NAVD 88 and reported to 0.003-m accuracy. Well depth and summary of water-level measurement frequency are listed in table 1.

Topographic data were obtained from the USACE and were produced from aerial photography (USACE, written commun., 2003). The horizontal datum for this mapping is North American Datum of 1983 (NAD 83). The projection is Universal Transverse Mercator Zone 15. The vertical datum is National Geodetic Vertical Datum of 1929 (NGVD 29), and the units of measurement are feet. The vertical datum was converted to NAVD 88 for this study.

The potentiometric surface is defined by the altitude to which water will rise in a tightly cased well. Potentiometric contour maps were created using well water-level data and surface-water stage data. The potentiometric surface at wells where depth to water was measured was used to estimate the potentiometric surface in distant areas from measured wells, but with similar geologic and topographic characteristics.

Seismic refraction surveys were conducted with a Geometrics Geode Seismic module and a 12 geophone array. Small explosive charges were used to produce the signal source for the surveys. Geophone spacing was 7.5 and 10 m. Because of the short spacing, each survey array is considered a point assessment of seismic stratigraphy. Shot-point locations were surveyed with a hand-held Global Positioning System (GPS) unit. Analysis of seismic-refraction data using the SIPQC V4.0 software package[1] (Rimrock Geophysics, Inc., 1999) provided thickness and seismic velocities for subsurface layers.

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[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Table 1. Well depths and summary of water-level measurement frequency.

[m, meters; -, no data]

Well number (fig. 1)	Well depth (m)	Periods of monthly measurements	Periods of hourly measurements	Total period of measurements
TC-1	13.5	06/01/1998 to 05/17/1999	07/07/1999 to 07/06/2000	06/01/1998 to 07/06/2000
		06/27/2001 to 06/10/2002	06/28/2001 to 06/13/2002	06/27/2001 to 06/13/2002
		06/02/2003 to 10/04/2004	07/03/2003 to 08/13/2004	06/02/2003 to 10/04/2004
1	12.4	06/01/1998 to 05/17/1999	-	06/01/1998 to 05/17/1999
		06/27/2001 to 06/10/2002	06/27/2001 to 12/28/2001	06/27/2001 to 06/10/2002
		06/02/2003 to 10/04/2004	07/03/2003 to 08/13/2004	06/02/2003 to 10/04/2004
2	11.6	06/01/1998 to 05/17/1999	-	06/01/1998 to 05/17/1999
		06/27/2001 to 06/10/2002	06/27/2001 to 12/28/2001	06/27/2001 to 06/10/2002
		06/02/2003 to 10/04/2004	07/03/2003 to 08/13/2004	06/02/2003 to 10/04/2004
3	12.3	06/01/1998 to 05/17/1999	-	06/01/1998 to 05/17/1999
		06/27/2001 to 06/13/2002	06/26/2001 to 12/28/2001	06/26/2001 to 06/13/2002
		06/02/2003 to 10/04/2004	07/03/2003 to 08/13/2004	06/02/2003 to 10/04/2004
4	7.7	03/27/2003 to 10/04/2004	07/02/2003 to 04/28/2004	03/27/2003 to 10/04/2004
5	8.1	03/27/2003 to 10/04/2004	07/02/2003 to 08/13/2004	03/27/2003 to 10/04/2004
6	12.3	09/03/2003 to 10/04/2004	09/04/2003 to 12/19/2003	09/03/2003 to 10/04/2004
7	12.5	09/03/2003 to 10/04/2004	09/04/2003 to 04/28/2004	09/03/2003 to 10/04/2004

Rainfall, River Altitude, and Ground-Water Altitude

Monthly rainfall from January 1998 to October 2004 is shown in figure 3. Total rainfall, normal rainfall, and the departure from normal rainfall for pre-chute, first-generation-chute, and second-generation-chute conditions are listed in table 2.

The hydrograph for the Missouri River at Overton Bottoms North and monthly ground-water-level measurement dates at Overton Bottoms North are shown in figure 4. Median river altitude was 173.9 m during pre-chute conditions, 172.2 m during first-generation-chute conditions, and 171.9 m during second-generation-chute conditions. Water-level data for the Missouri River and wells TC-1, 1, 2, and 3 for pre-chute, first-generation-chute, and second-generation-chute conditions and water-level data for wells 4, 5, 6, and 7 for second-generation-chute conditions are shown in figure 5. All data are digitally stored in the USGS National Water Information System (NWIS) database and are available at http://nwis.waterdata.usgs.gov. For pre-chute, first-generation-chute, and second-generation-chute conditions, when hourly ground-water altitude was recorded, the shape of the well hydrograph is a subdued image of the Missouri River hydrograph as ground-water altitude generally rose and fell with Missouri River altitude. Ground-water altitude for wells TC-1, 1, 2, and 3 consistently was above Missouri River altitude for pre-chute conditions, except when river altitude rose rapidly on June 24, 1998. Ground-water altitude during first-generation-chute conditions, like pre-chute conditions, was normally above river altitude, except when river altitude rose rapidly on September 19, 2001. For second-generation-chute conditions, ground-water altitudes for wells TC-1, 1, 2, and 3 also were above river altitude, except for several periods when river altitude rose rapidly. Ground-water altitudes for wells 4, 5, 6, and 7 were lower than for wells TC-1, 1, 2, and 3 for most of the period of measurement during second-generation-chute conditions; however, ground-water altitude for well 6 was less variable with change in river altitude than wells 4, 5, and 7.

Table 2. Total rainfall, normal rainfall, and departure from normal rainfall for pre-chute, first-generation-chute, and second-generation-chute conditions.

[m, meters]

	Total rainfall (m)	Normal rainfall (m)	Departure from normal rainfall (m)
Pre-chute June 1998 to May 1999	1.41	0.94	0.47
First-generation chute June 2001 to June 2002	1.24	1.08	.16
Second-generation chute June 2003 to October 2004	1.57	1.46	.11

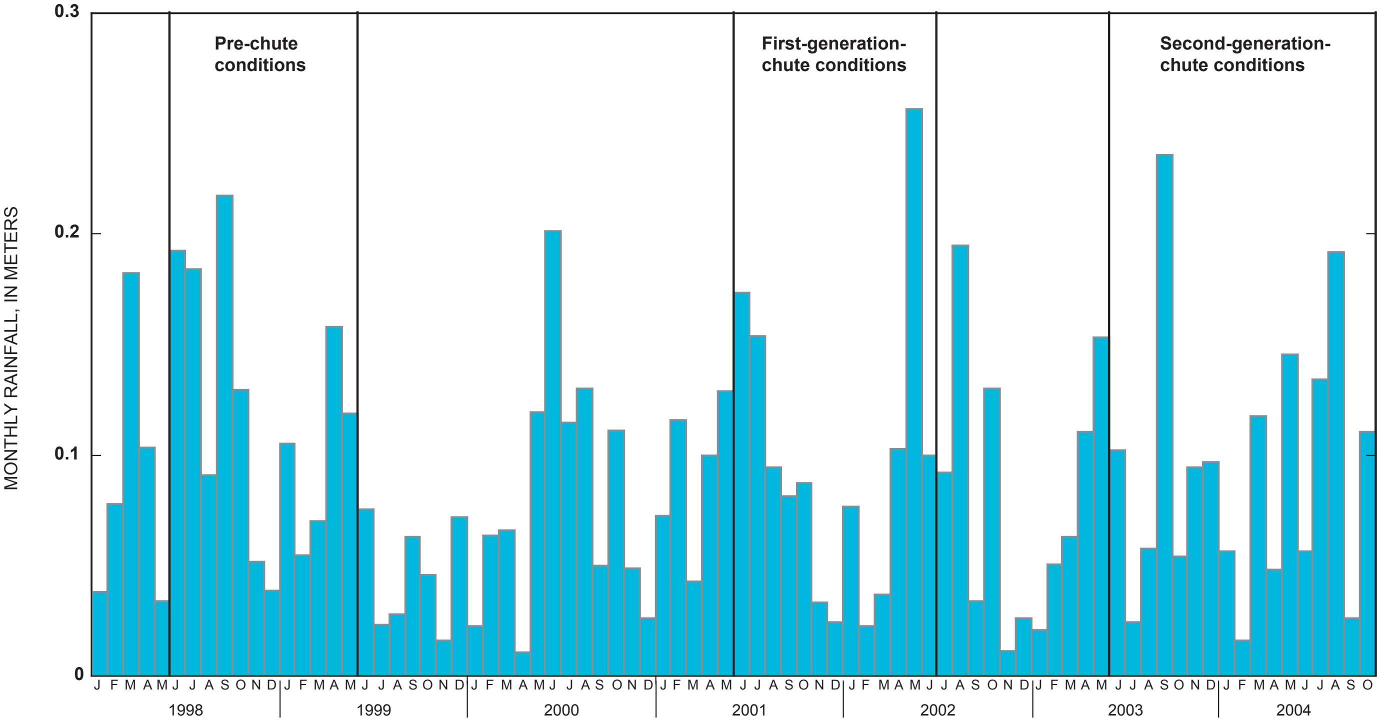

Figure 3. Monthly rainfall during pre-chute, first-generation-chute, and second-generation-chute conditions at or near Overton Bottoms North, Missouri, 1998-2004.

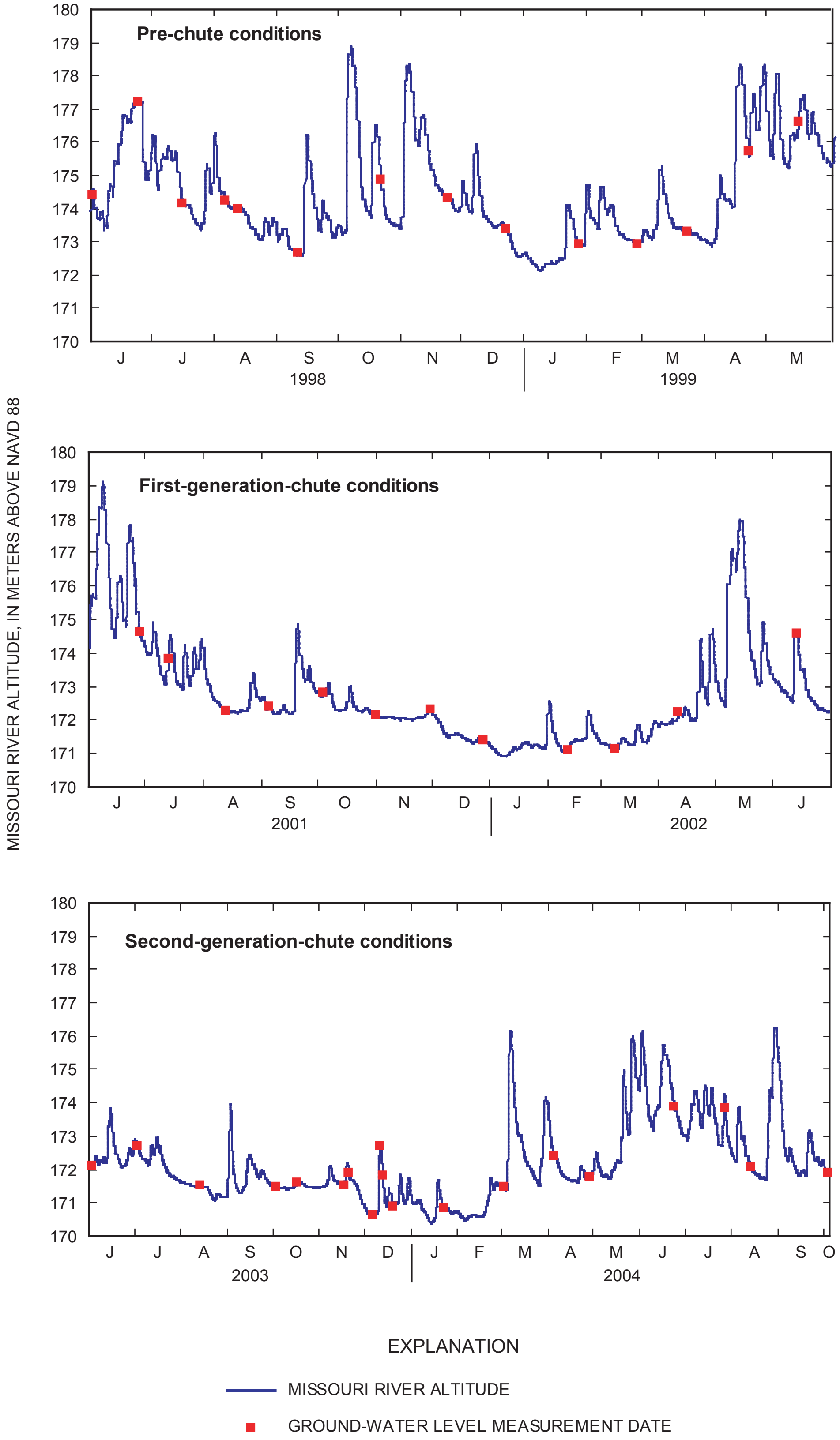

Figure 4. Missouri River altitude and ground-water level measurement dates for pre-chute, first-generation-chute, and second-generation-chute conditions at Overton Bottoms North, Missouri, 1998-2004.

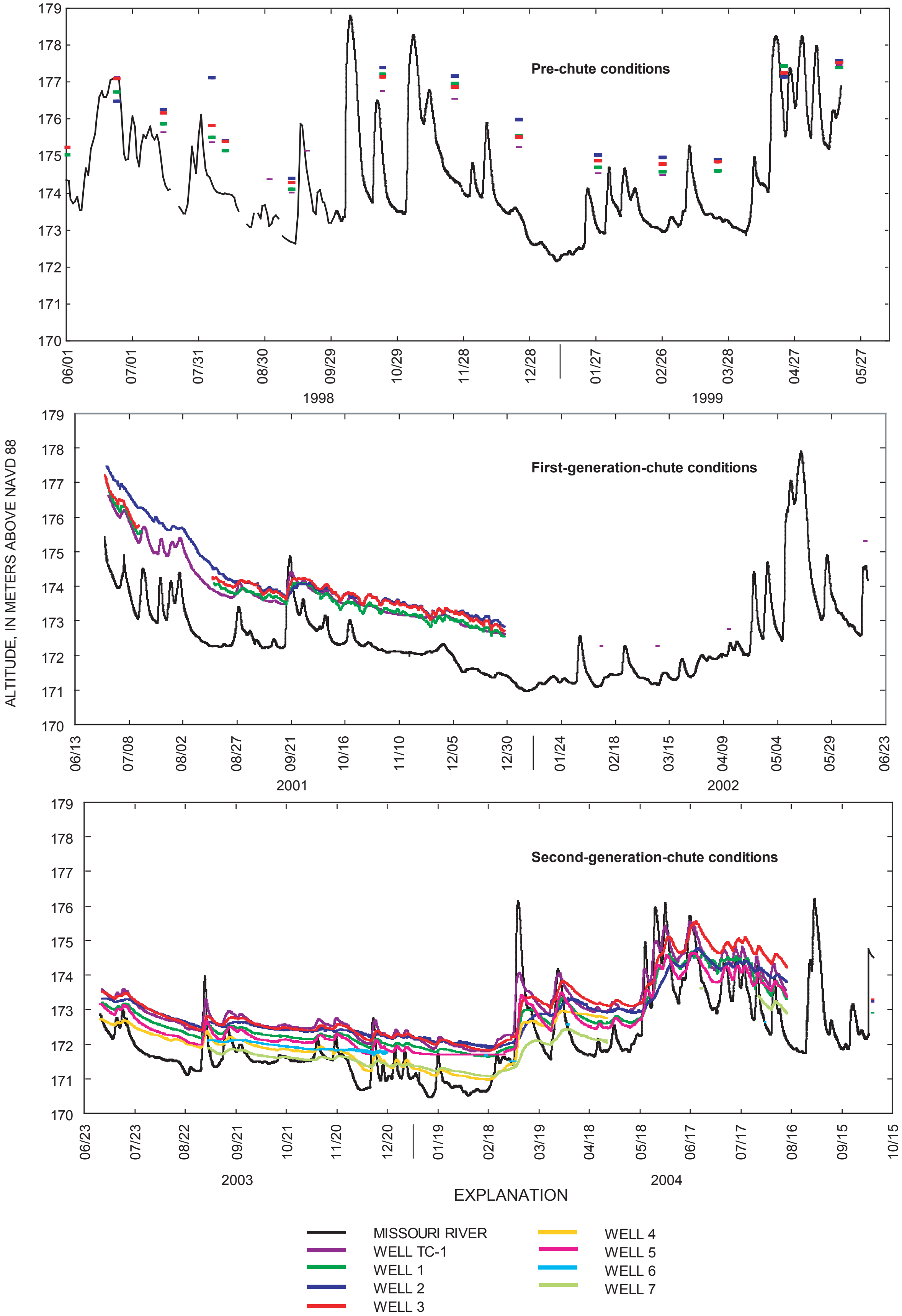

Figure 5. Missouri River at Moniteau Creek with wells for pre-chute, first-generation-chute, and second-generation-chute conditions at Overton Bottoms North, 1998-2004.

Water flowed in the first-generation chute much less frequently than in the second-generation chute. The deeper and wider second-generation chute allows the Missouri River to enter the chute at a lower river stage. During first-generation-chute conditions, water entered the chute only during high Missouri River stage (fig. 6); design specifications were to allow flow into the inlet 30 percent of the time, and into the outlet about 53 percent of the time (Jacobson and others, 2004). The inlet and outlet altitudes of the second-generation chute allows water to flow almost continuously and during second-generation-chute conditions, river stage at the second-generation chute inlet always was above the bottom of the chute.

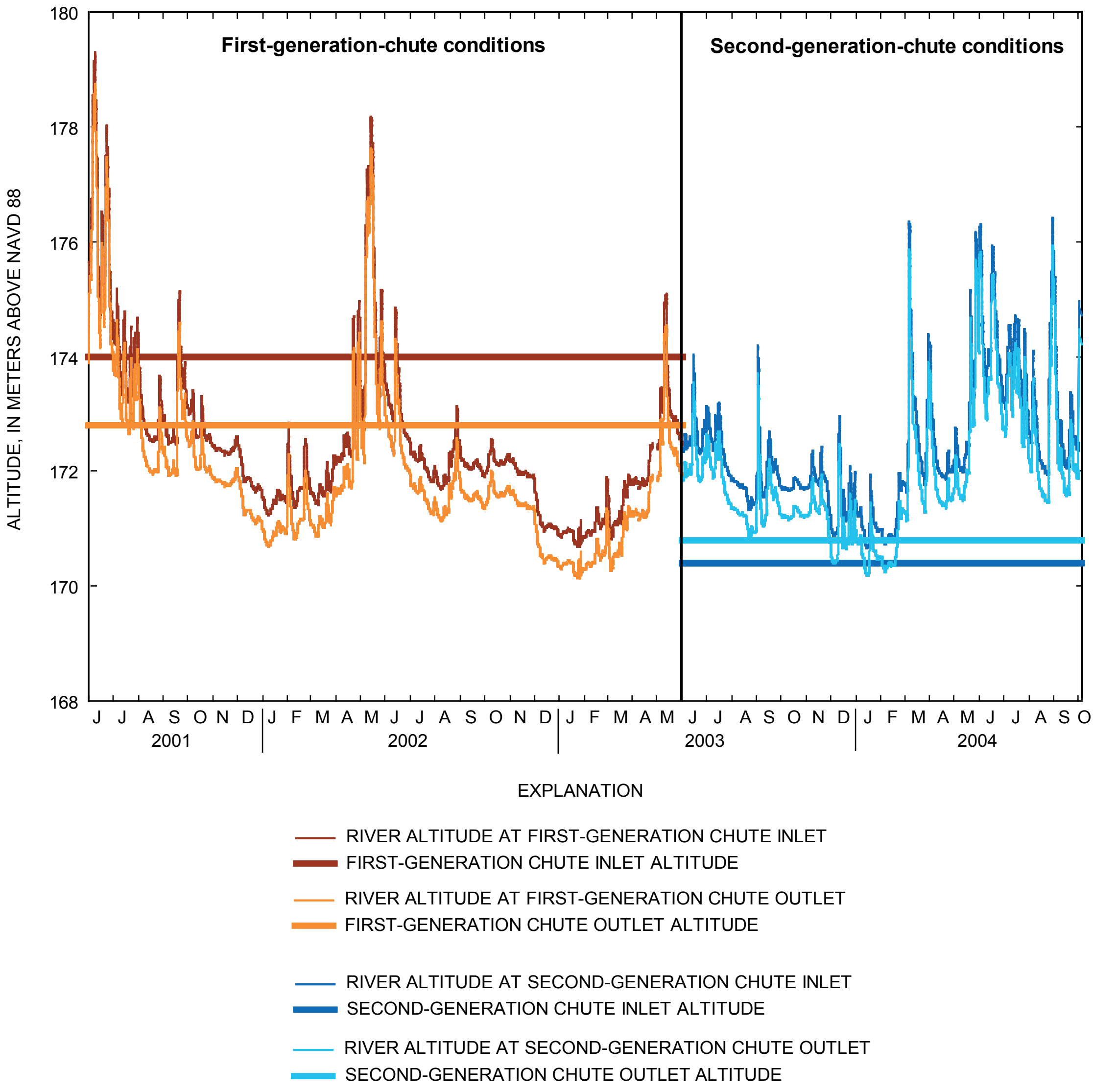

Figure 6. Missouri River altitude and chute inlet and chute outlet altitudes for first-generation-chute and second-generation-chute conditions at Overton Bottoms North, Missouri, 2001-2004.

Potentiometric Surfaces and Depth to Ground Water

Synoptic ground-water level and surface-water altitude data were used to prepare potentiometric surface maps for pre-chute, first-generation-chute, and second-generation-chute conditions to quantify and characterize changes in the potentiometric surface caused by construction and deepening of the chute. Depth to ground-water maps were constructed by subtracting the altitude of the potentiometric surface from land-surface altitude. The depth to ground water depicted on the depth to ground-water maps was calculated from interpolated potentiometric surfaces. Because there is uncertainty in the creation of a potentiometric surface, there also is uncertainty in the depth to ground-water maps created using potentiometric surfaces; these maps are approximate in nature.

The potentiometric surface and depth to ground water for pre-chute conditions on June 24, 1998, October 22, 1998, and March 23, 1999, are shown in figures 7, 8, and 9. On June 24, 1998, the low-lying areas of Overton Bottoms North, including the area that would become the chute, were inundated (fig. 7); however, had the pre-1993 levee been intact flooding would not have occurred. River altitude increased about 3.5 m from the first week of June 1998 until June 24, 1998, when the river was at 177.19 m (fig. 3). Depth to ground water was 3 m or less for the entire study area and for more than one-half of the study area, depth to ground water was less than 1 m. The highest ground-water altitudes were near the river, and the lowest were near the southwest edge of the flood plain close to Interstate 70, the farthest distance from the river, indicating recharge to the aquifer from the river. Hydrologic section A–A’ (fig. 7) shows the potentiometric surface slightly sloping away from the river.

On October 22, 1998, Missouri River altitude was about 175 m, and a larger part of Overton Bottoms North was inundated (fig. 8). Missouri River altitude was decreasing from a peak of 178.8 m on October 7, 1998 (fig. 3). Depth to ground water was less than 3 m for most of Overton Bottoms North, and for more than one-half of the study area, depth to ground water was less than 1 m. The largest depths to ground water were along the bank of the Missouri River, where ground-water altitudes were lowest and land-surface altitude was higher along the remnant levee. The highest ground-water altitude was near the town of Overton, Missouri, and the lowest ground-water altitude was near the Missouri River. Hydrologic section A–A’ (fig. 8) shows the potentiometric surface sloped towards the river as river stage was decreasing and water drained from the aquifer into the river.

On March 23, 1999, the ground-water altitudes were substantially less than previous measurements, and less than land-surface altitude for the entire study area (fig. 9). Missouri River altitude decreased from about 175.28 m on March 10 to 173.32 m by March 23, but remained stable for the week before ground-water level measurements made on March 23 (fig. 3). Depth to ground water was between 1 and 5 m for most of the study area, and between 2 and 3 m for more than one-half of the study area. As of October 22, 1998, the highest ground-water altitudes were near the town of Overton; the lowest were near the Missouri River. The potentiometric surface sloped towards the river along hydrologic section A–A’ as river stage was decreasing and water drained from the aquifer into the river.

The potentiometric surface and depth to ground water for June 28, 2001, September 5, 2001, and June 13, 2002 are shown in figures 10, 11, and 12 for first-generation-chute conditions. On June 28, 2001 (fig. 10), low-lying areas of Overton Bottoms North were still inundated from the Missouri River inundation on June 8, 2001, when the river was 179.02 m (fig. 3). Depth to ground water was less than 3 m for most of the study area, and less than 1 m for more than one-half of the study area. The highest ground-water altitude was located near the town of Overton and, although ground-water level was not measured, a ground-water mound most likely was centered on the island that was created with the construction of the first-generation chute. A steep ground-water gradient is indicated by the closely spaced potentiometric contours on both sides and parallel to the first-generation chute compared to the slight gradient between the uplands and well 1. Hydrologic section A–A’ (fig. 10) shows the potentiometric surface sloped towards the first-generation chute and the Missouri River as water drained from the aquifer.

On September 5, 2001, the depth to ground water was greater than 3 m for most of the study area and below the channel bottom of the first-generation chute (172.8 to 174 m) (fig. 11). The altitude of the Missouri River along the Overton Bottoms North reach had decreased from about 173.4 m on August 27, 2001 to 172.38 m on September 5, 2001 (fig. 3). Depth to ground water was between 1 and 2 m below the bottom of the first-generation chute. The highest ground-water altitude was near the town of Overton; the lowest was near the Missouri River. Hydrologic section A–A’ (fig. 11) shows the potentiometric surface sloped towards the river as river stage was decreasing and water drained from the aquifer into the river.

On June 13, 2002, the depth to ground water was greater than 1 m for most of the study area, but was between 0 and 1 m near the first-generation chute and other low-lying areas near well TC-1. Water was flowing in the first-generation chute (fig. 12). The altitude of the Missouri River had increased from about 172.56 m on June 11, 2002 to 174.58 m on June 13, 2002 (fig. 3). Highest ground-water altitude was near well 3; the lowest was near the Missouri River. The deflection of the potentiometric contours near the first-generation chute indicates ground water was draining from the aquifer into the chute from both sides. The large space between potentiometric contours indicates a low ground-water gradient. Hydrologic section A–A’ (fig. 12) shows the potentiometric surface sloped towards the first-generation chute and the Missouri River as water drained from the aquifer, although the slope of the ground-water surface was very slight.

The potentiometric surface and depth to ground water for July 3, 2003, December 11, 2003, and June 23, 2004, are shown in figures 13, 14, and 15 for second-generation-chute conditions. On July 3, 2003, the depth to ground water was greater than 3 m for most of the study area and greater than 4 m for more than one-half of the study area (fig. 13). The altitude of the Missouri River had decreased from about 173.83 m on June 15 to 172.69 m by July 3 (fig. 3). Depth to ground water was less than 3 m for low-lying areas adjacent to the second-generation chute and well TC-1. Depth to ground water was less than 2 m along the upstream part of the old channel of the first-generation chute. Highest ground-water altitude was between well 3 and the edge of the flood plain to the southwest. A ground-water mound centered on the island created by the construction of the second-generation chute most likely formed during higher river-altitude conditions of June 2003. Lowest ground-water altitude, adjacent to the Missouri River and the second-generation chute, indicates drainage from the aquifer as river altitude decreased. The large distance between potentiometric contours indicates a low ground-water gradient across the study area. Hydrologic section A–A' (fig. 13) shows the potentiometric surface sloped towards both the Missouri River and the second-generation chute as ground water drained from the aquifer.

On December 11, 2003, after a period of low river altitude, the depth to ground water was greater than 3 m for almost the entire study area, and greater than 5 m for more than one-half of the study area (fig. 14). The altitude of the Missouri River slowly had decreased from 172.19 m on November 19 to 170.68 m on December 9 then increased rapidly to 172.72 m on December 11, 2003 (fig. 3). Depth to ground water was between 2 and 3 m in most low-lying parts of the study area, and less than 2 m along the upstream part of the old channel of the first-generation chute. Highest ground-water altitude was adjacent to the Missouri River and the second-generation chute as water moved into the aquifer from the river. The two areas of low ground-water altitude were caused by the higher river altitude raising ground-water altitude near the river and the chute. Lowest ground-water altitude was on the south side of the study area near Interstate 70, and a ground-water depression was centered on the island created by the construction of the second-generation chute. The large distance between potentiometric contours indicates a low ground-water gradient over most of the study area. The steeper gradient near the Missouri River and the second-generation chute indicates rapid recharge to the aquifer was occurring as ground-water altitude adjusted to the rapid change in river stage. Hydrologic section A–A' (fig. 14) shows the potentiometric surface sloped away from the Missouri River and the second-generation chute as surface water recharged the aquifer.

On June 23, 2004, the depth to ground water was less than 4 m for almost the entire study area, and less than 3 m for about one-half of the study area (fig. 15). The altitude of the Missouri River increased from 171.81 m on May 8 to more than 175.71 m on June 16, and decreased to 173.81 m on June 23, 2004 (fig. 3). Depth to ground water was less than 2 m for low-lying parts of the study area. Highest ground-water altitude was centered near well TC-1, and may indicate focused recharge near the wetland or low permeability resulting in a perched water table. A ground-water mound was centered on the island created by the construction of the second-generation chute most likely formed during higher river-altitude conditions of May 2004. The large distance between potentiometric contours indicates a low ground-water gradient over most of the study area. The steeper ground-water gradient between well 1 and the second-generation chute was caused by the recent decrease in river altitude. Hydrologic section A–A' (fig. 15) shows the potentiometric surface sloped towards the Missouri River and the second-generation chute as ground water drained from the aquifer.

Comparing depth to ground water and potentiometric surfaces for pre-chute, first-generation-chute, and second-generation-chute conditions shows the variability of the surface-water/ground-water interaction at the study site. Although the effect of chute construction on ground-water flow is shown by the drainage of ground water into the chute, especially during second-generation-chute conditions, the constantly changing river stage, variable rainfall, and rapid response of ground water to these changes illustrate the constantly changing nature of ground-water flow at the study site.

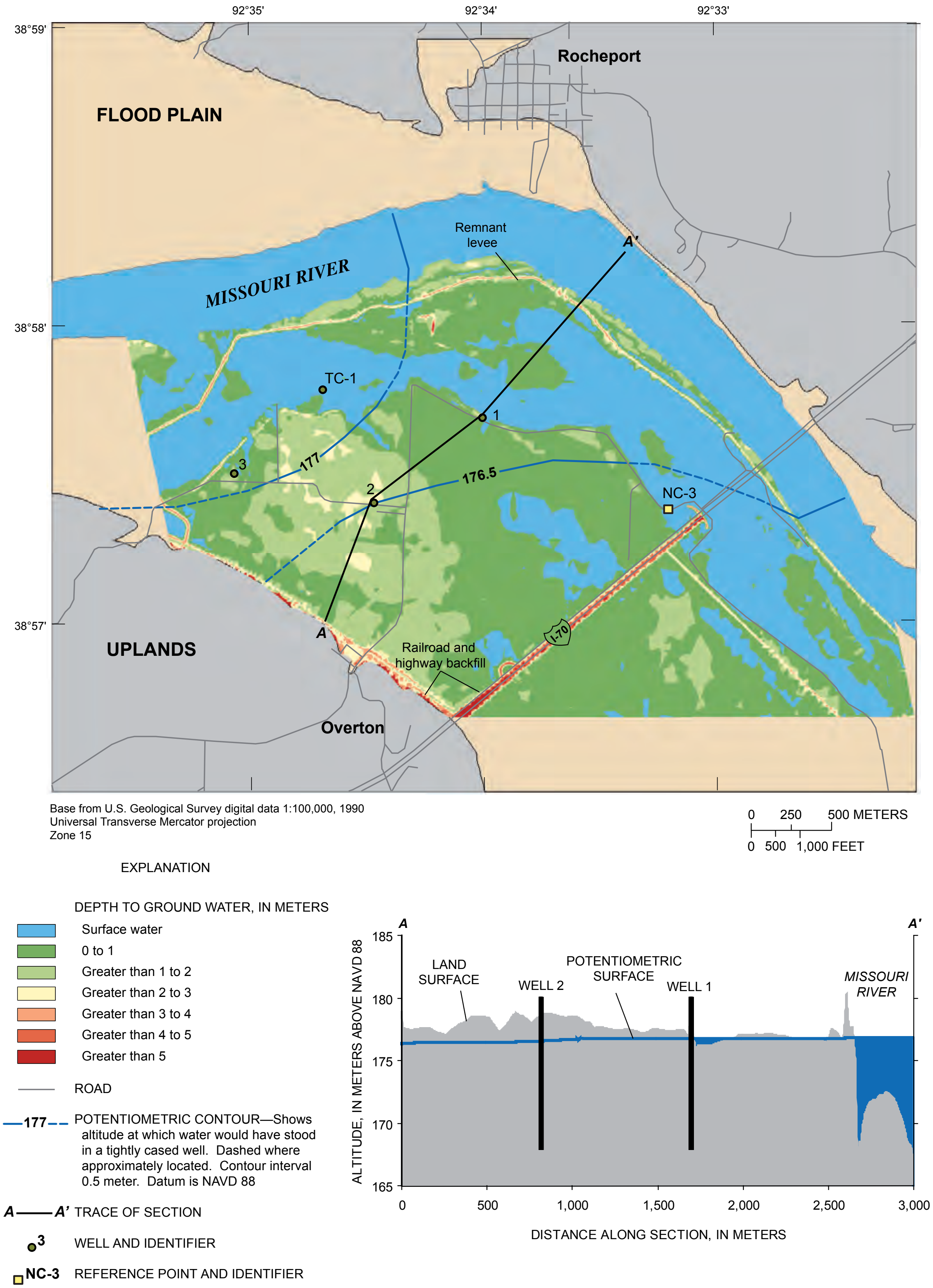

Figure 7. Potentiometric contours, depth to ground water, and hydrologic section A–A′ for pre-chute conditions, Overton Bottoms North, Missouri, June 24, 1998.

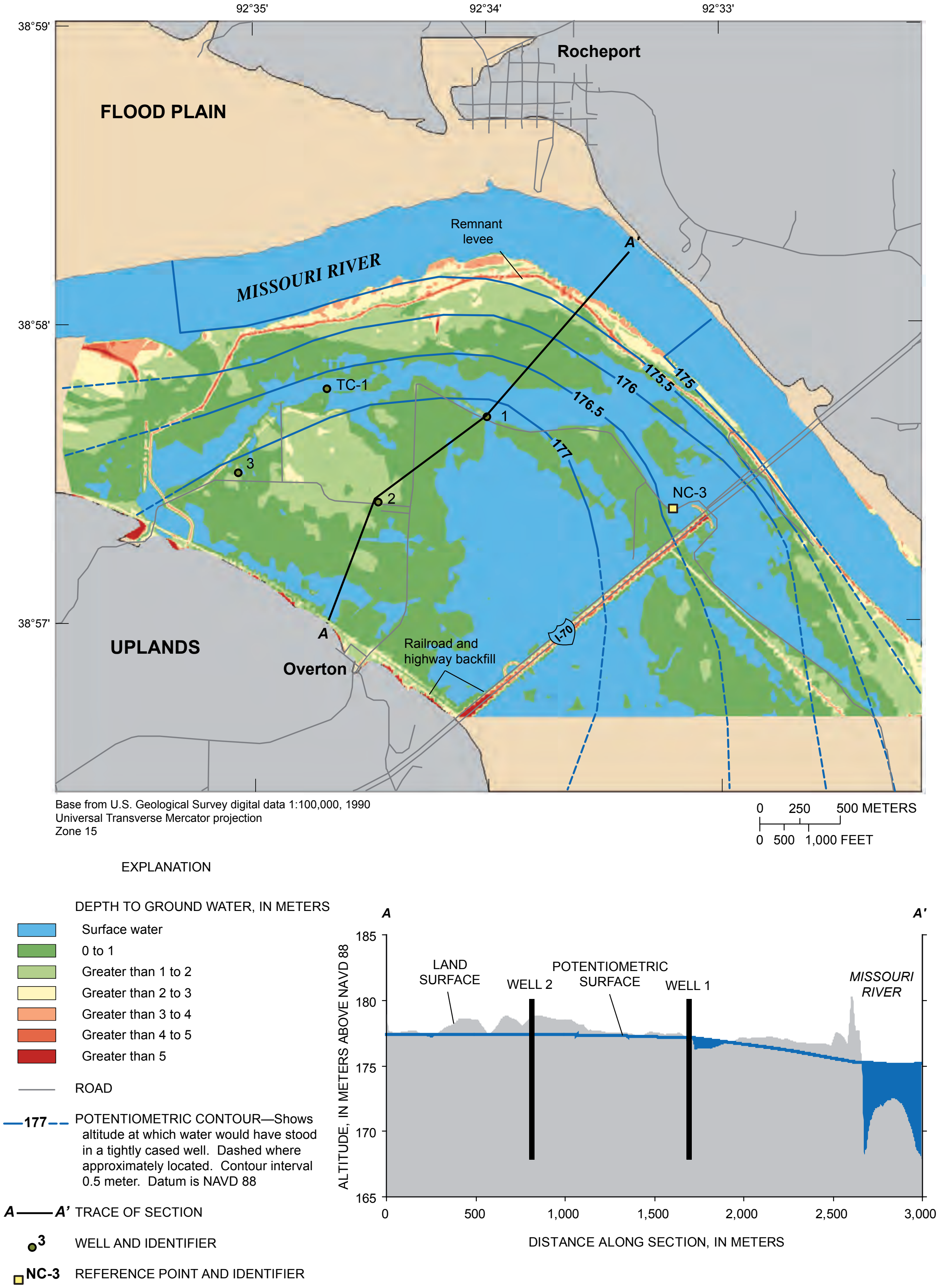

Figure 8. Potentiometric contours, depth to ground water, and hydrologic section A–A′ for pre-chute conditions, Overton Bottoms North, Missouri, October 22 , 1998.

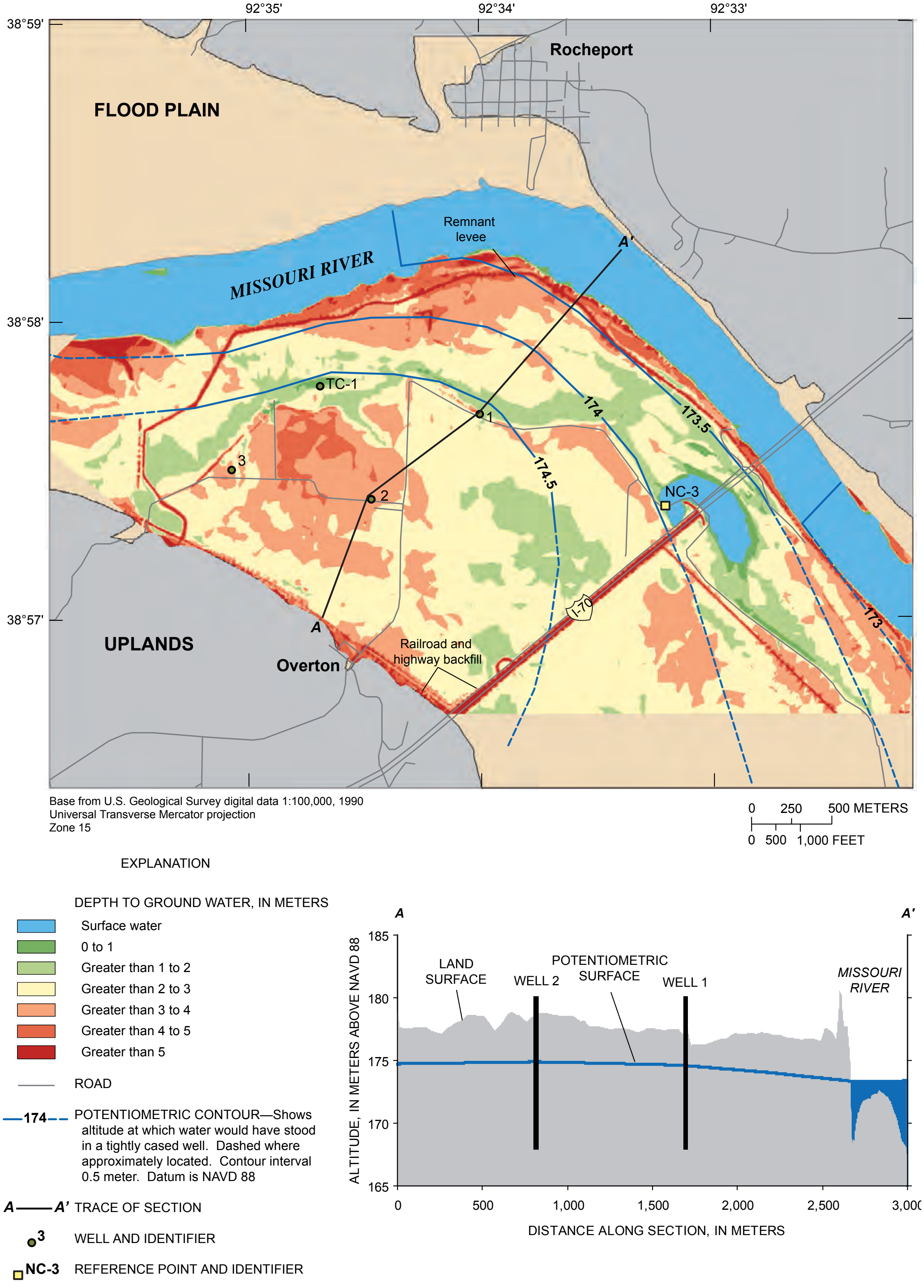

Figure 9. Potentiometric contours, depth to ground water, and hydrologic section A–A' for pre-chute conditions, Overton Bottoms North, Missouri, March 23, 1998.

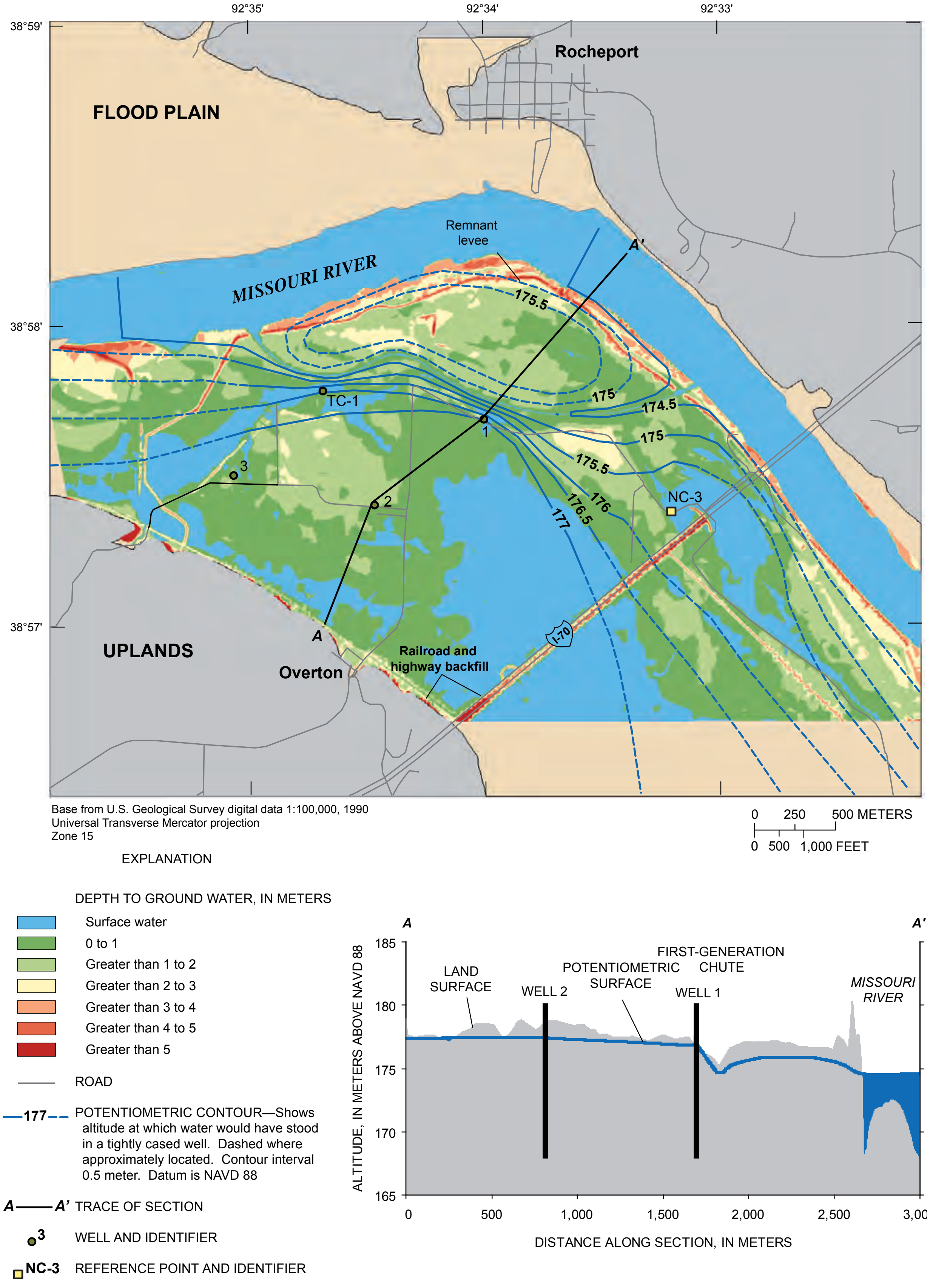

Figure 10. Potentiometric contours, depth to ground water, and hydrologic section A–A' for first-generation-chute conditions, Overton Bottoms North, Missouri, June 28, 2001.

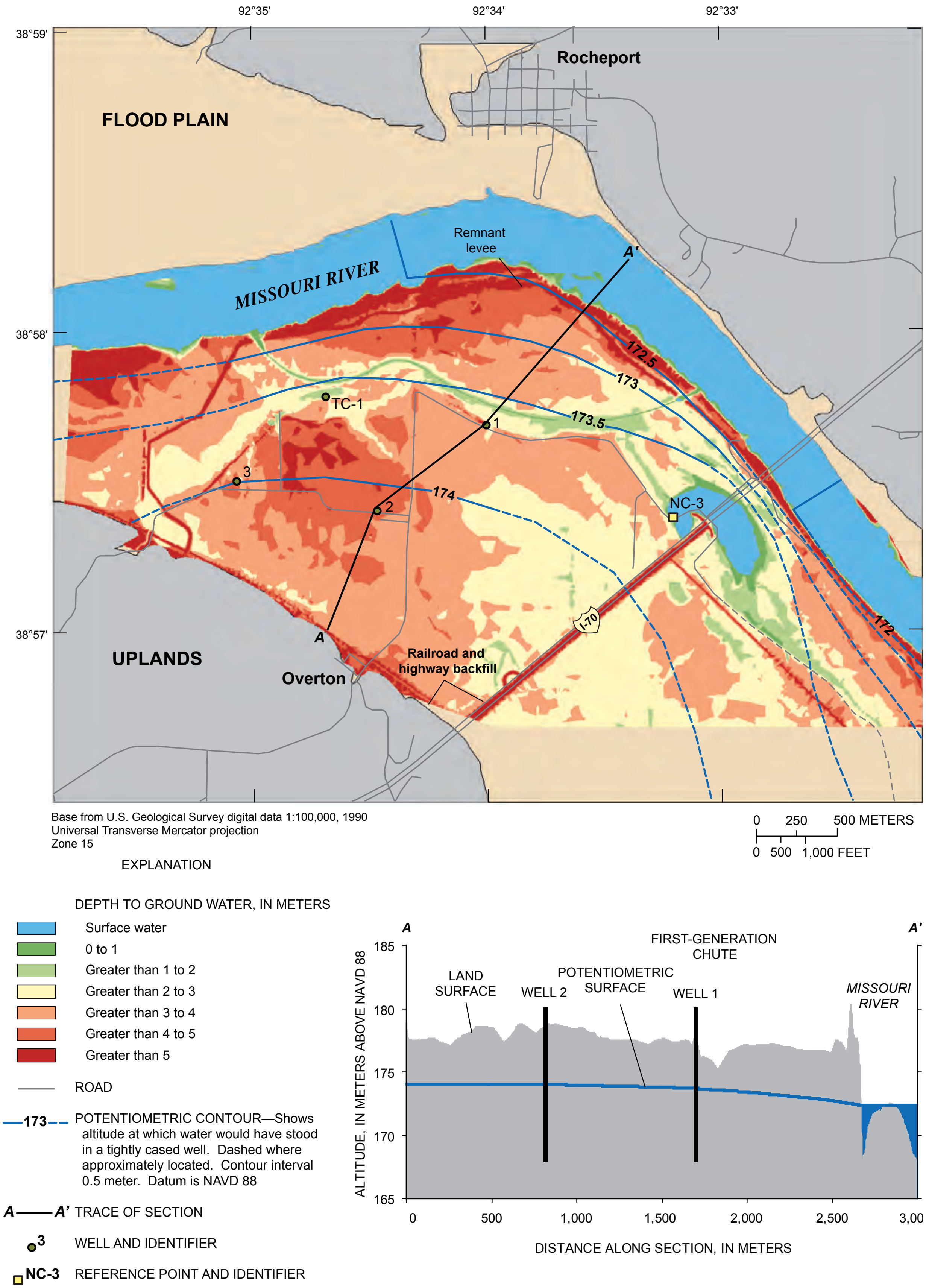

Figure 11. Potentiometric contours, depth to ground water, and hydrologic section A–A′ for first-generation-chute conditions, Overton Bottoms North, Missouri, September 5, 2001.

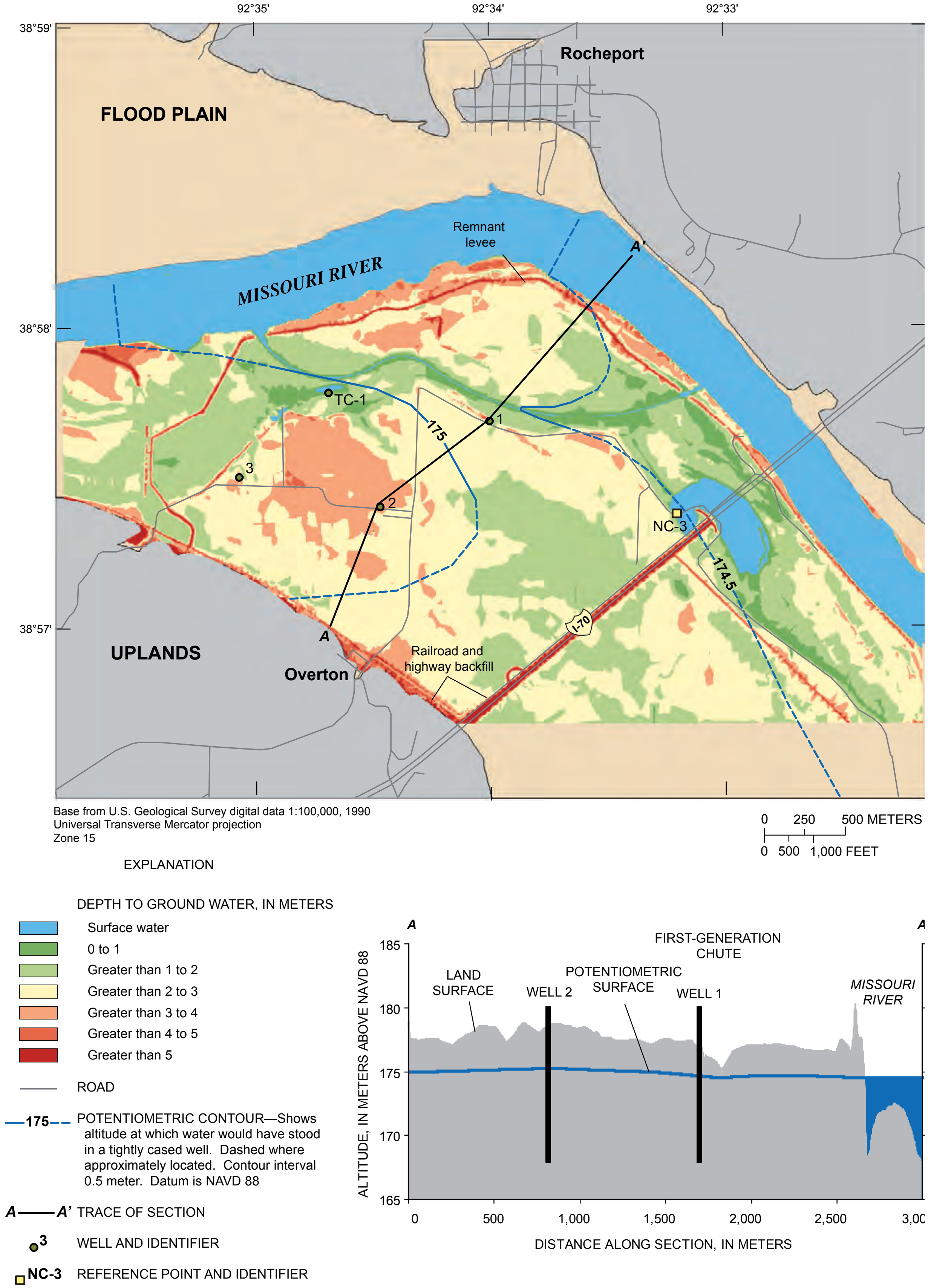

Figure 12. Potentiometric contours, depth to ground water, and hydrologic section A–A′ for first-generation-chute conditions, Overton Bottoms North, Missouri, June 13, 2002.

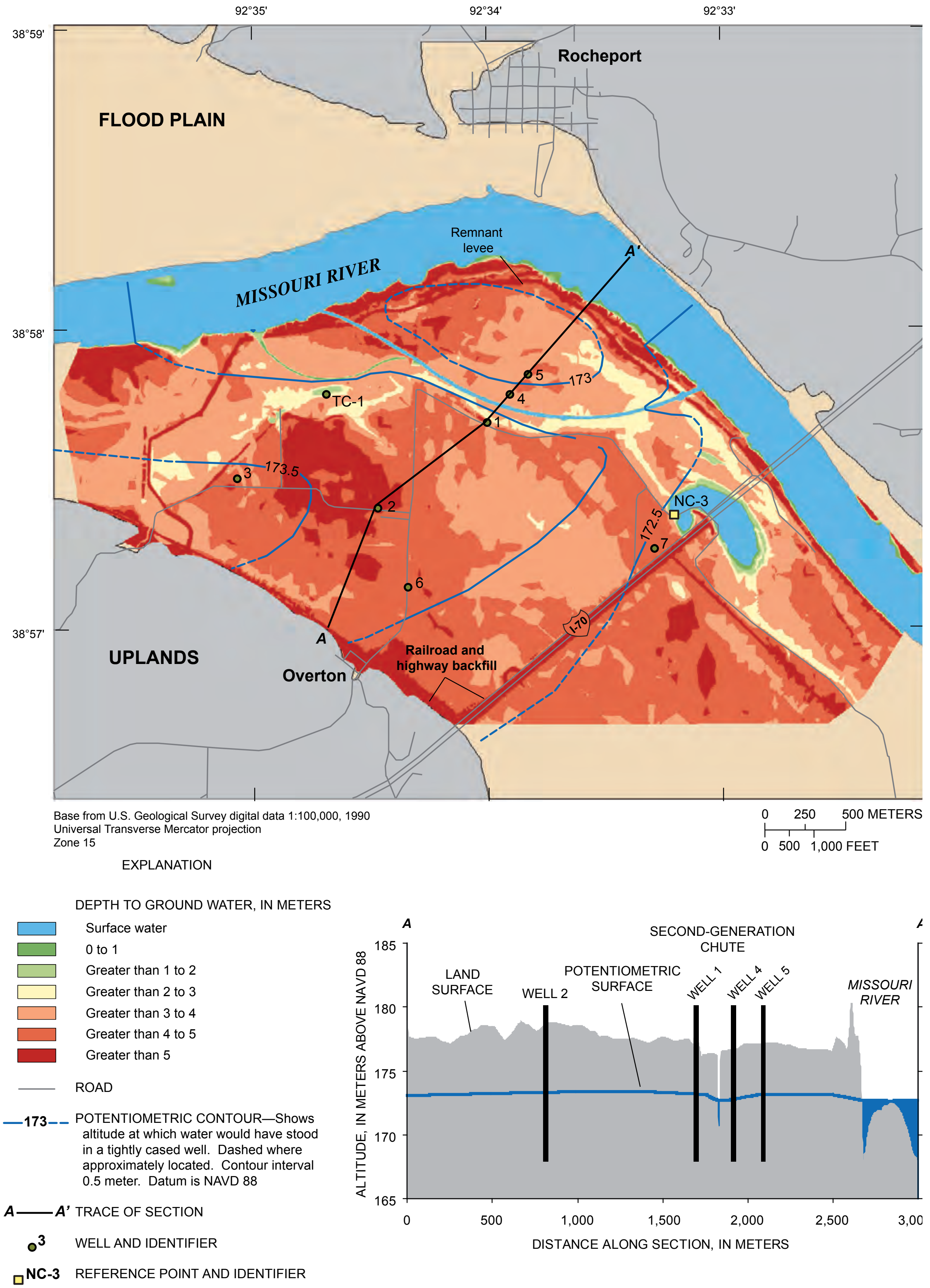

Figure 13. Potentiometric contours, depth to ground water, and hydrologic section A–A' for second-generation-chute conditions, Overton Bottoms North, Missouri, July 3, 2003.

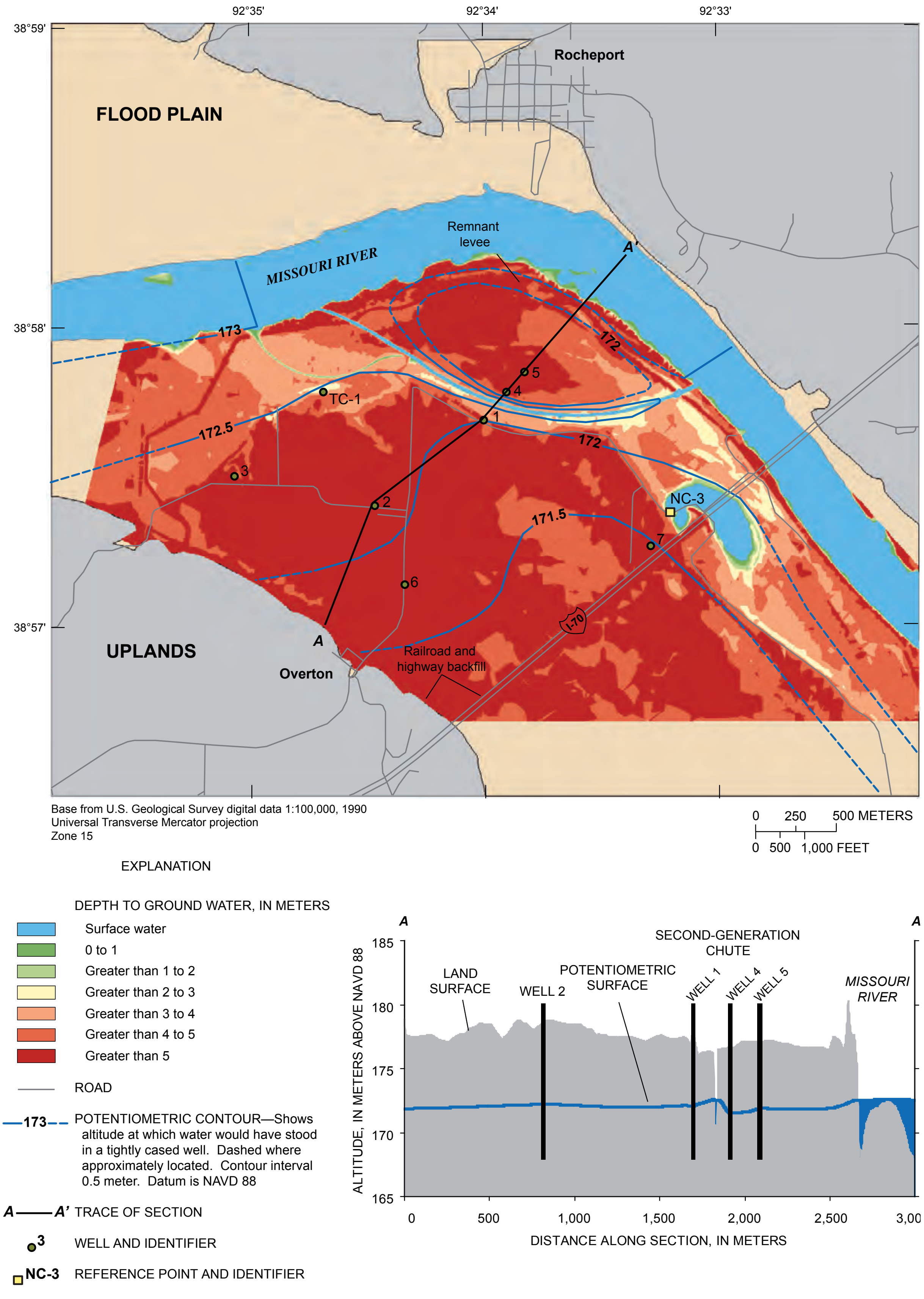

Figure 14. Potentiometric contours, depth to ground water, and hydrologic section A–A' for second-generation-chute conditions, Overton Bottoms North, Missouri, December 11, 2003.

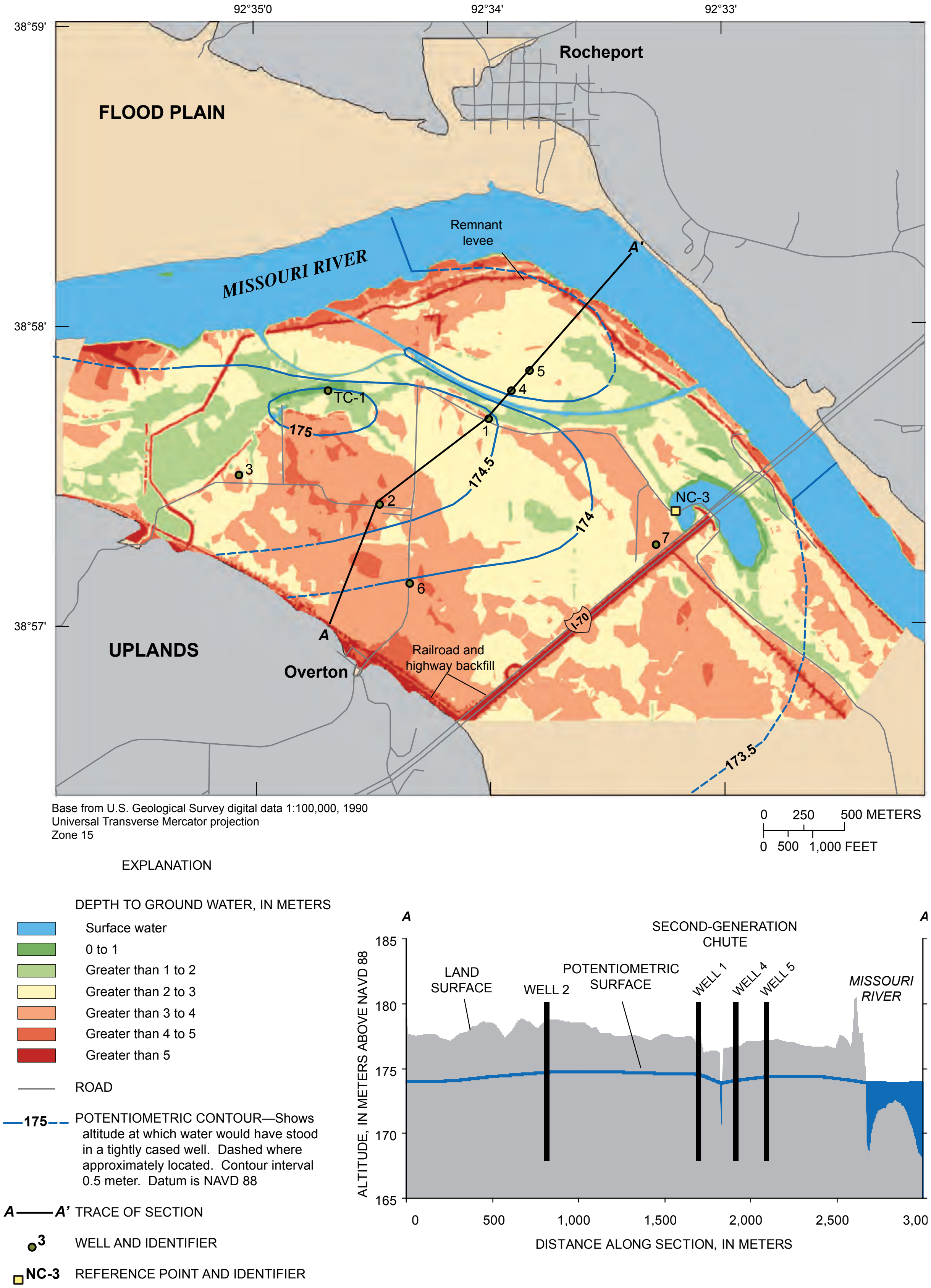

Figure 15. Potentiometric contours, depth to ground water, and hydrologic section A–A' for second-generation-chute conditions, Overton Bottoms North, Missouri, June 23, 2004.

Seismic Analysis

A seismic refraction survey of the study area was conducted April 9, 2004, to determine the thickness of the silt/clay top stratum and the depth to the bedrock surface at seven sites (fig. 16). At all sites, an interface between a lower velocity layer and a higher velocity layer was encountered, generally between 5 and 15 m deep (fig. 17). A second interface between layers of different velocity layer was detected at site 4 at about 20 m. At site 6, depth to an irregular interface between layers of different velocity ranged between 20 and 40 m.

The velocities of sound for the alluvial deposits expected to be encountered at Overton Bottoms North are listed in table 3. The range of velocity of sound in unsaturated material generally is lower than the range for saturated material, although the velocity of sound in clay can exceed the velocity of sound for saturated sand and gravel. For most materials listed in table 3, the upper end of the velocity range is associated with more dense materials located at depth.

The silt/clay and sand materials have similar velocities of sound when unsaturated, and therefore cannot be reliably discriminated. The first interface detected for most seismic survey sites was probably the boundary between unsaturated and saturated alluvial sand; the shallowest depths for the velocity interface are generally deeper than the average thickness for silt/clay top stratum documented in the same area (this volume, chapter 2, fig. 5). The average depth, depth range, and average altitude of detected velocity interfaces for each seismic survey site and the depth to and altitude of the water table measured in nearby monitoring wells on April 9, 2004, are listed in table 4. For sites 1, 2, 3, 4, and 7, the altitude of the first velocity interface is similar to the altitude of the water table measured at nearby wells. This indicates that the first velocity interface at these locations is most likely the water table, although a lithologic change also could be indicated. Site 5 and well 1 are at the same location. For site 5, the altitude of the first velocity interface is 5.88 m below the altitude of the water table at well 1, indicating that the first velocity interface there is most likely a change in lithology. Borehole 82, documented in Holbrook and others (this volume, chapter 2), was located adjacent to site 5; borehole 85 ended in sand 3.7 m below the ground surface, well above the velocity interface.

For site 6, the altitude of the first velocity interface is 9.9 m below the altitude of the water table at well 1, 9.8 m below the altitude of the water table at well 4, and 9.7 m below the altitude of the water table at well 5, indicating that the first velocity interface at site 6 most likely is a change in lithology. A deeper velocity interface detected at sites 4 and 6 is at depths typical of bedrock beneath the Missouri River alluvial aquifer. At site 4 this may indicate a change in lithology within the alluvium and at site 6 the higher velocity (greater than 4,800 m/s, meters per second) indicates the underlying material is most likely limestone. If so, the aquifer is approximately 20 to 35 m thick at site 6.

Table 3. Compressional velocity of sound in common Earth materials.

[m/s, meter per second; --, no data; modified from Haeni, 1986]

Material	Unsaturated velocity (m/s)	Saturated velocity (m/s)
Weathered surface material	120–210[1], 305–610[2]	--
Clay	915–2,740[2]	--
Loess silt and silty sand	230–760[3]	--
Alluvial sand	300–1,220[3]	610–1,830[2], 1,070–1,830[3]
Alluvial sand and gravel	360–490[1], 460–1,525[3]	1,220–1,830[1], 1,525–2,290[3]
Water (sound velocity of saturated materials should be equal to or greater than sound velocity of water)	1,460[1], 1,430–1,680[2]	--
Limestone	2,130–6,100[2]	--

[1] Clark (1966, p. 204).

[2] Jakosky (1950, p. 660).

[3] Koloski and others (1989).

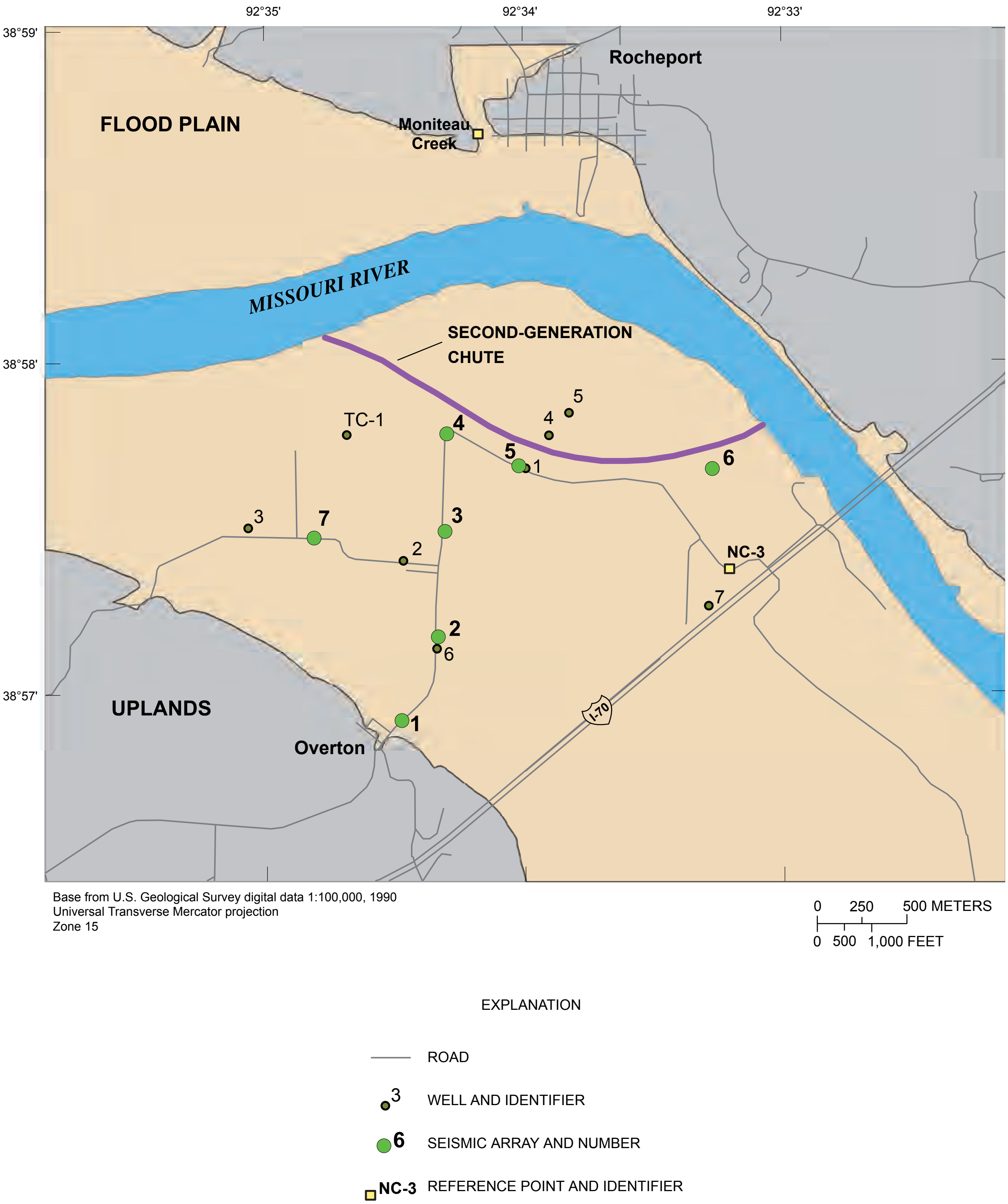

Figure 16. Locations of seismic refraction sites at Overton Bottoms North, Missouri, April 9, 2004.

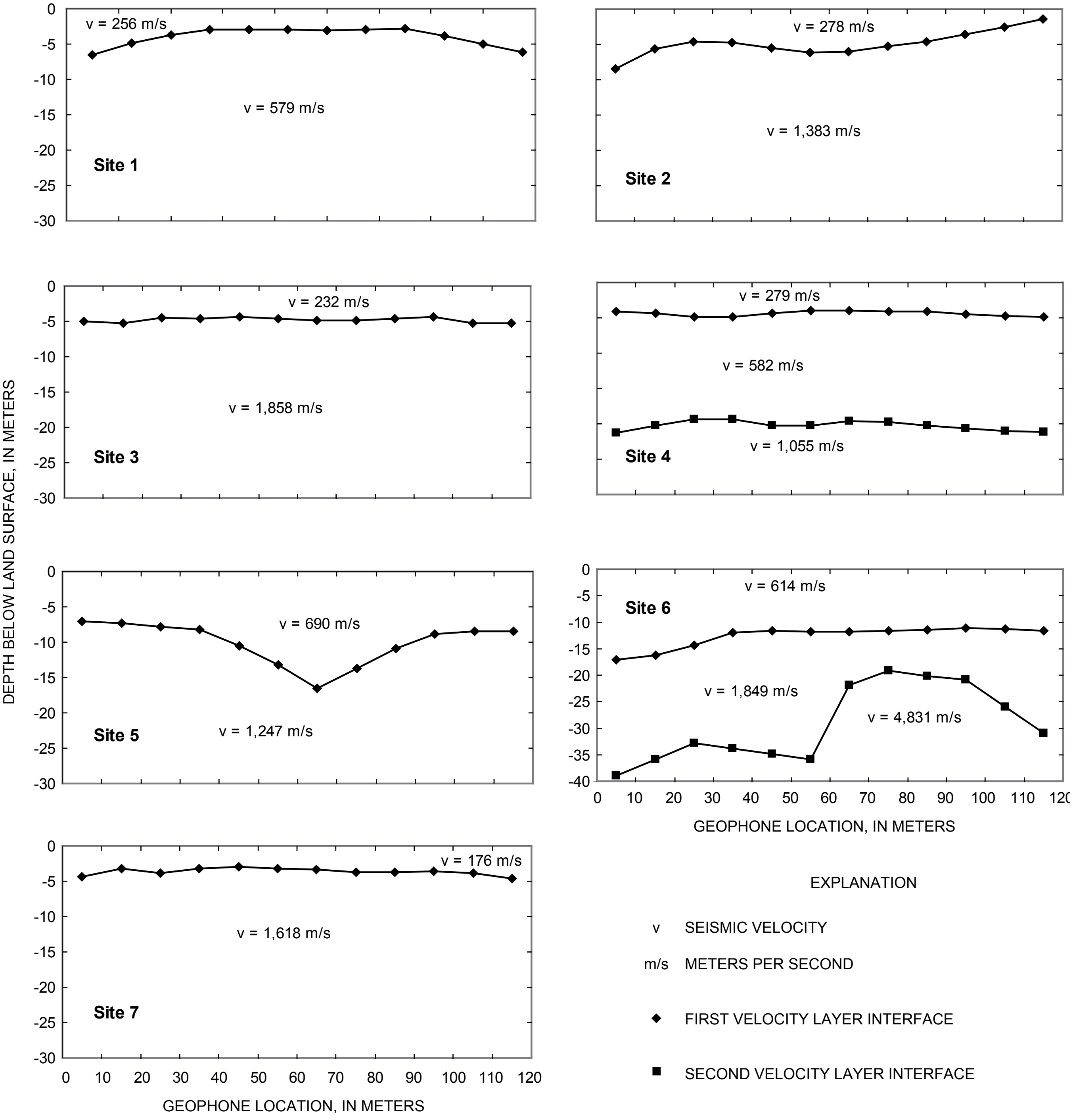

Figure 17. Interpreted seismic sections and velocities of sound from seven seismic refraction survey sites at Overton Bottoms North, Missouri, April 9, 2004.

Table 4. Comparison of seismic-velocity-interface data and water-level data at Overton Bottoms North, Missouri, April 9, 2004.

[m, meter; --, no data]

		First velocity interface			Second velocity interface					
Site number (fig. 16)	Altitude (m)	Average depth (m)	Depth range (m)	Average altitude (m)	Average depth (m)	Depth range (m)	Average altitude (m)	Nearest wells	Depth to water table 04/09/2004 (m)	Altitude (m)
1	178.2	4.0	2.8 to 6.6	174.2	--	--	--	Well 6	4.5	172.6
2	177.5	4.9	1.4 to 8.5	172.6	--	--	--	Well 6	4.5	172.6
3	177.9	4.8	4.3 to 5.3	173.1	--	--	--	Well 2	7.2	173.3
4	177.7	4.4	4 to 4.9	173.1	20.2	19.3 to 21.3	157.5	Well TC-1	9.1	173.3
								Well 1	6.3	173.0
5	177.2	10.1	7.1 to 16.5	167.1	--	--	--	Well 1	6.3	173.0
6	175.7	12.7	11.1 to 17.1	163.1	29.3	19.2 to 38.9	146.5	Well 1	6.3	173.0
								Well 4	7.8	172.9
								Well 5	9.0	172.8
7	178.6	3.6	2.9 to 4.6	175.0	--	--	--	Well 3	6.9	173.5

Relations Among Chute Size, River Altitude, and Ground-Water Altitude

Ground-water altitude is closely related to river altitude at Overton Bottoms North (fig. 5). Well and river hydrographs for pre-chute, first-generation-chute, and second-generation-chute conditions indicate the differences in the hydrographs for the three conditions. Although rainfall was slightly greater during pre-chute conditions (table 2), the difference in rainfall among pre-, first-generation-, and second-generation-chute conditions was assumed to be too small to greatly influence ground-water altitude. Recharge for the Missouri River alluvial aquifer has been estimated to be between 2 and 25 percent of rainfall (Fischel and others, 1953; Hedman and Jorgensen, 1990). Compared to pre-chute conditions, rainfall was 0.31 m less during first-generation-chute conditions and 0.36 m less during second-generation-chute conditions. Assuming recharge is 20 percent of rainfall, then 0.062 m less water recharged the aquifer for first-generation-chute conditions than for pre-chute conditions, and 0.072 m less water recharged the aquifer for second-generation-chute conditions than for pre-chute conditions. Typical porosity values for alluvial deposits are 40 to 70 percent for clay, 35 to 50 percent for silt, 25 to 50 percent for sand, and 25 to 40 percent for gravel (Freeze and Cherry, 1979). Dividing each recharge difference by a typical porosity for the aquifer (30 percent) estimates the decrease in ground-water level caused by the decrease in recharge. For first-generation-chute conditions, the ground-water level decrease caused by reduced recharge from rainfall could be as much as 0.21 m during 13 months, or 0.016 m/month (meter per month) relative decrease in ground-water level. For second-generation-chute conditions, the ground-water level decrease potentially caused by reduced recharge could be as much as 0.24 m during 17 months or 0.014 m/month decrease in ground-water level.

Water flow in the chute occurred less frequently during first-generation-chute conditions than during second-generation-chute conditions. During first-generation-chute conditions, water flowed in the chute from upstream 11 percent of the time; it was in backwater (that is flowing in from only the outlet) 6 percent of the time and dry 83 percent of the time. During second-generation-chute conditions water flowed in the chute 96 percent of the time; it was in backwater 4 percent of the time and was never dry. The wider and deeper second-generation chute increased the interaction between surface water and ground water at the study area, because it flowed most of the time and the bottom of the chute was below the water table.

Median river altitude was 173.9 m during pre-chute conditions, 172.2 m during first-generation-chute conditions, and 171.9 m during second-generation-chute conditions. A direct comparison of ground-water altitude of wells TC-1, 1, 2, and 3 between pre-chute, first-generation-chute, and second-generation-chute conditions does not take into account the decrease in river altitude from pre-chute to second-generation-chute conditions and overestimates the effect of chute construction on the decrease in ground-water altitude. A comparison of the difference between ground-water altitude and river altitude among the three periods more closely indicates the relative effect of chute construction on ground-water altitude by partially removing the effect of river stage. In addition, variations in the pre-chute, first-generation-chute, and second-generation-chute hydrographs introduce uncertainty into the analysis. When river altitude decreases, the difference between ground-water altitude and river altitude is greater because river altitude decreases faster than ground-water altitude responds. Similarly, when river altitude increases, the difference between ground-water altitude and river altitude is less. Falling, rising, and steady river altitude conditions were determined based on the cumulative change in river altitude during the 5 days preceding the ground-water altitude measurement. The 5-day period and the amount of change in river stage were determined through trial and error to provide a period long enough to have an effect on ground-water altitude and ensure the amount of river altitude change was sufficient to measurably change ground-water altitude. If river altitude decreased more than 0.1 m during this period, river-altitude conditions were falling. If river altitude increased more than 0.1 m during this period, river-altitude conditions were rising. If river altitude did not change more than 0.1 m during this period, river-altitude conditions were steady. The boxplots of the difference between measured ground-water altitude and river altitude for combined river-altitude conditions and for falling, rising, and steady river-altitude conditions are shown in figure 18.

The change in the difference between ground-water and river altitude from pre-chute to first-generation-chute to second-generation-chute conditions indicates the effect on ground-water altitude of chute construction at Overton Bottoms North. The change in median difference between chute conditions for wells TC-1, 1, 2, and 3 for each river-altitude condition are listed in table 5.

The increase in the median difference between ground-water and river altitude at well TC-1 from pre-chute to second-generation-chute conditions for combined river-altitude conditions was 0.09 m (table 5). For all river-altitude conditions, the median difference between ground-water and river altitude at well TC-1 was smaller during pre-chute conditions than during first-generation-chute conditions (fig. 18). This increase in the water level difference indicates that the first-generation chute either increased recharge to the aquifer or caused less drainage from the aquifer to the river near well TC-1.

Because the first-generation chute was close to well TC-1, a more rapid ground-water altitude response to river stage at TC-1 (via the chute) would be expected when river water flowed in the chute, resulting in a smaller difference between ground-water and river altitude. However, chute construction allowed the Missouri River to inundate Overton Bottoms North more frequently, and at a lower stage, because the chute breached the levee that previously had protected the flood plain from flooding. The top of the breached levee was approximately 180 m. River altitude (fig. 3) exceeded land-surface altitude (fig. 2) near TC-1 during most of June 2001. Well TC-1 is located in a low-lying wetland area of Overton Bottoms North, where flood water ponds and does not rapidly drain from the area as river altitude decreases. Inundation of the flood plain and topographic capture of flood waters in June 2001 and high river altitude likely increased ground-water recharge and raised ground-water altitude. After this period of inundation, river altitude fell from June 2001 to January 2002, and the median difference between ground-water and river altitude became large because the river altitude decreased more quickly than ground-water altitude could respond.

For all river-altitude conditions, the median difference between ground-water and river altitude at well TC-1 was the same or larger during first-generation-chute conditions than during second-generation-chute conditions, and the median difference was smaller for pre-chute conditions than for second-generation-chute conditions. The path of the second generation chute is farther from TC-1 than the path of the first-generation chute. Construction of the second-generation chute decreased the median difference between ground-water and river altitude for second-generation-chute conditions compared to first-generation-chute conditions, most likely because the bottom of the second-generation chute intersects more transmissive sand deeper in the aquifer than the first-generation chute causing a quicker ground-water altitude response to river-altitude change. However, the flood plain was inundated several times in June and July 2004, and flood water and high river stage during these events increased ground-water altitude. The increase in ground-water altitude compared to river altitude at well TC-1 during first-generation-chute and second-generation-chute conditions indicates that inundation of the flood plain in the absence of protective levees and focused recharge in this low-lying area increased the ground-water altitude more than the drainage of the aquifer into the first- or second-generation chute decreased the ground-water altitude.

Table 5. Change in media difference between ground-water and river altitude for wells TC-1, 1, 2, and 3 for combined, falling, rising, and steady river-altitude conditions.

[m., meter]

	Median ground-water altitude change (m)											
	Well TC-1			Well 1			Well 2			Well 3		
River-altitude condition	**Pre-chute to first-chute**	**First-chute to second-chute**	**Pre-chute to second-chute**	**Pre-chute to first-chute**	**First-chute to second-chute**	**Pre-chute to second-chute**	**Pre-chute to first-chute**	**First-chute to second-chute**	**Pre-chute to second-chute**	**Pre-chute to first-chute**	**First-chute to second-chute**	**Pre-chute to second-chute**
Combined	0.25	-0.16	0.09	-0.22	-0.39	-0.61	-0.35	-0.54	-0.89	-0.20	-0.29	-0.49
Falling	.18	-.14	.04	-.27	-.32	-.59	-.38	-.51	-.89	-.25	-.18	-.43
Rising	.37	-.35	.02	-.22	-.46	-.68	.16	-.93	-.77	-.13	-.35	-.48
Steady	.18	0	.18	-.11	-.27	-.38	-.12	-.29	-.41	-.12	-.21	-.33

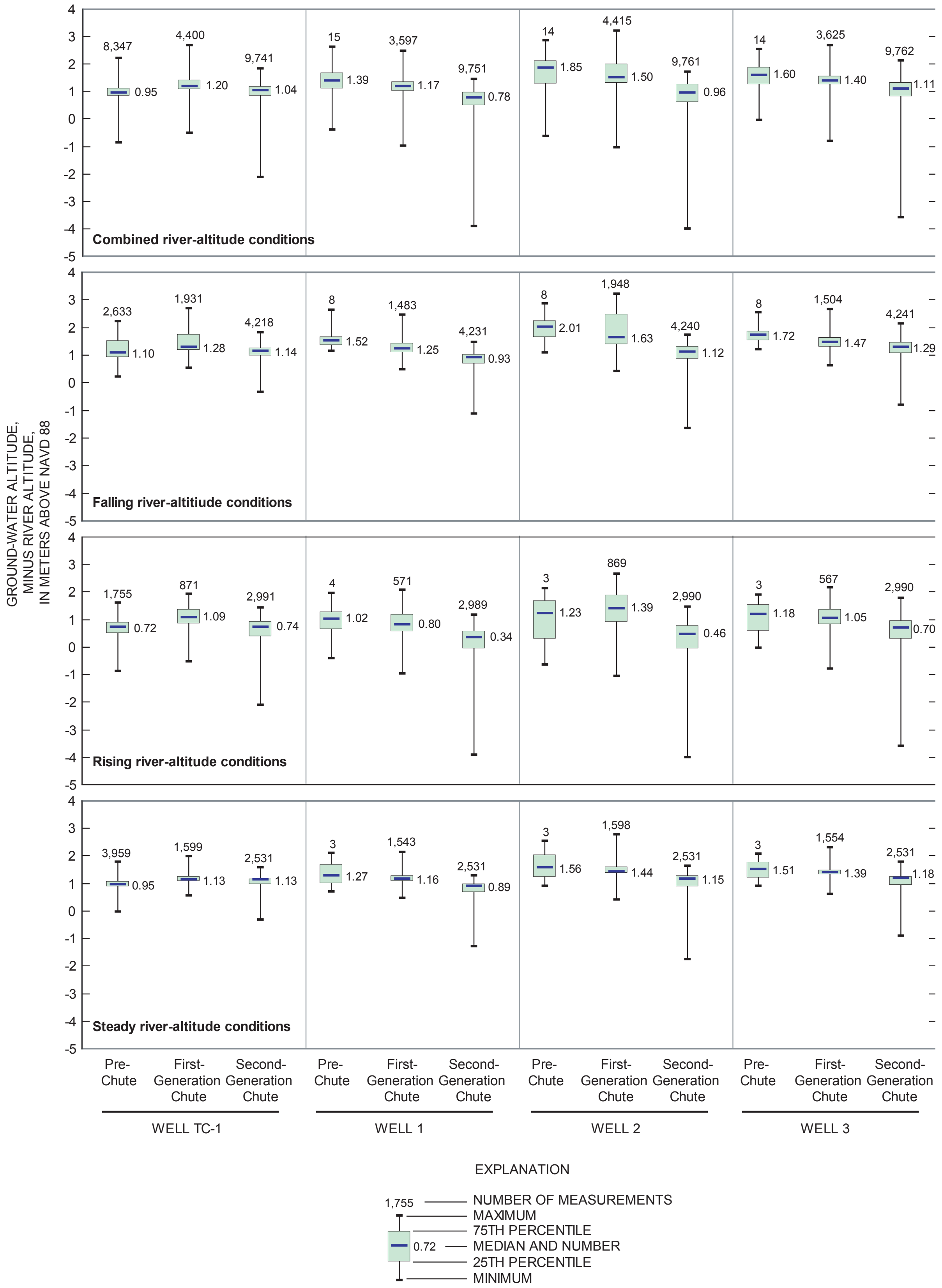

Figure 18. The maximum, 75th percentile, median, 25th percentile, and minimum of the difference between measured ground-water altitude and river altitude for combined, falling, rising, and steady river-altitude conditions, Overton Bottoms North, Missouri.

Although the second-generation chute decreased ground-water altitude from first-generation-chute conditions, the increased distance of well TC-1 from the second-generation chute decreased the rate of response of ground water to changes in river altitude and raised ground-water altitude at well TC-1.

Well 1 is 120 m from the chute and is, therefore, one of the best wells for characterizing chute effects on ground-water altitude near the chute. The change in median ground-water altitude at well 1 from pre-chute to second-generation-chute conditions for combined river-altitude conditions was -0.61 m (table 5). For all river-altitude conditions the median difference between ground-water and river altitude decreased from pre-chute to first-generation-chute and from first-generation-chute to second-generation-chute conditions for well 1, indicating the construction of the first-generation chute and the second-generation chute caused ground-water altitude to more closely follow changes in river altitude (fig. 18). Ground-water recharge from flood inundation during pre-chute and first-generation-chute conditions did not have the large effect on ground-water altitude at well 1 as at well TC-1. Well 1 is located on higher ground than TC-1, and flood water typically drains from the area as river altitude decreases (fig. 2). The path of the first-generation chute and second-generation chute are identical near well 1. The decrease in the difference between ground-water and river altitude most likely occurred because the bottom of the second-generation chute intersects the more transmissive sand of the aquifer, allowing ground-water altitude to more closely track river and chute altitude.

Well 2 is 1,350 m from the Missouri River, 875 m from the second-generation chute, and 820 m from the first-generation chute. The change in median ground-water altitude at well 2 from pre-chute to second-generation-chute conditions for combined river-altitude conditions was -0.89 m (table 5). For combined, falling, and steady river-altitude conditions, the median difference between ground-water and river altitude decreased from pre-chute to first-generation-chute and from first-generation-chute to second-generation-chute conditions for well 2, indicating the construction of the first-generation chute and then the second-generation chute caused ground-water altitude to more closely follow changes in river altitude (fig. 18). However, for rising river-altitude conditions the median difference between ground-water and river altitude for well 2 increased from pre-chute to first-generation-chute conditions, and then decreased from first-generation-chute to second-generation-chute conditions. This is similar to the response of ground-water altitude for well TC-1 during all river-altitude conditions. Inundation of the flood plain in June 2001 (fig. 5) recharged the aquifer and caused higher than normal ground-water altitude near well 2. High ground-water altitude and small increases in river altitude during first-generation-chute conditions caused the increase in the median difference between ground-water and river altitude at well 2 between pre-chute and first-generation-chute conditions for rising river-altitude conditions.

Well 3 is 920 m from the Missouri River, 1,150 m from the second-generation chute, and 745 m from the first-generation chute. The change in median ground-water altitude at well 3 from pre-chute to second-generation-chute conditions for combined river-altitude conditions was -0.49 m (table 5). For all river-altitude conditions the median difference between ground-water and river altitude decreased from pre-chute to first-generation-chute, and from first-generation-chute to second-generation-chute conditions for well 3. The construction of the first-generation chute and the second-generation chute caused ground-water altitude to more closely follow changes in river altitude (fig. 18). The response of well 3 to hydrologic changes at Overton Bottoms North is similar to that of well 1. Ground-water recharge from flood inundation during pre-chute and first-generation-chute conditions did not have the large effect on ground-water altitude at well 3 as it did for well TC-1 and well 2. Well 3 is on high ground and flood water drains from the area after inundation as river altitude decreases (fig. 2). The path of the second-generation chute is farther from well 3 than the path of the first-generation chute. The decrease in the difference between ground-water and river altitude most likely occurred because the bottom of the second-generation chute intersects the more transmissive sand of the aquifer, allowing ground-water altitude near well 3 to more closely track river and chute altitude.

A transect constructed from wells 1, 4, and 5 perpendicular to the axis of the second-generation chute illustrates the spatial and temporal variability of ground-water altitudes. Hydrologic section A–A' (figs. 13 to 15) shows the potentiometric surface across this transect for selected times during second-generation-chute conditions. Hourly monitoring of ground-water levels in these wells measured the ground-water altitude response to changes in water-level altitude in the chute. The altitude of the water level in the chute, ground-water altitude, water depth in the chute, depth from land surface to ground water, and the minimum, 25th percentile, median, 75th percentile, and maximum depth to ground water for wells 1, 4, and 5 from June 28, 2003 to August 21, 2004, are shown in figure 19. Median depth to ground water was 5.04 m at well 1, 4.62 m at well 4, and 4.26 m at well 5.

Ground-water and river-altitude conditions were similar on March 23, 1999 (fig. 9) and June 23, 2004 (fig. 15). A comparison of hydrologic section A–A' for these two times indicates the decrease in ground-water altitude caused by the second-generation chute near wells 1, 4, and 5. From pre-chute to second-generation-chute conditions, median ground-water altitude decreased 0.61 m at well 1. Wells 4 and 5 were not installed until the second-generation chute was constructed and pre-chute ground-water altitude data were not available. However, hydrologic conditions at well 1 are similar to wells 4 and 5, and ground-water altitude most likely decreased a like amount. An estimate of median depth to ground water during pre-chute conditions at these wells can be made by subtracting the median decrease calculated for well 1 (0.61 m) from the median depth to ground water calculated from hourly ground-water altitude measurements. The estimated median depth to ground water during pre-chute conditions was 4.43 m for well 1, 4.01 m for well 4, and 3.65 m for well 5.

The transect illustrates the fine-scale dynamics of ground-water and surface-water interactions that can be expected in an alluvial flood-plain environment (fig. 19). Near simultaneous peaks for surface water and ground-water wells indicate rapid interaction through transmissive sediments. However, responses can also be spatially variable. For example, during low-water conditions June, 2003 to December, 2003, ground-water altitudes adjacent to the chute in well 1 were higher than those in well 5, located about twice the distance from the chute on the island. During and after the April 2004 flood, however, the relative altitudes were reversed with ground water ponded under the island and presumably draining toward wells 4 and 5. In general, ground water was mounded at shallower depths below the ground surface in the middle of the island (well 5) compared to wells adjacent to the chute (fig. 19).

Chute construction has resulted in a decrease in the difference between ground-water altitude and river altitude in most areas of Overton Bottoms North. The decrease in the difference between ground-water and river altitude is most notable for second-generation-chute conditions. However, chute construction has allowed the Missouri River to inundate Overton Bottoms North more frequently, and at a lower stage, because the levee that previously protected the flood plain was breached at the chute inlet and outlet. If the levee was still in place, and no chutes existed, the Missouri River would not have inundated the flood plain at Overton Bottoms North during the study period. The construction of the chutes has resulted in more frequent surface recharge to the aquifer from flood inundation in low-lying areas. The increase in the difference between ground-water and river altitude was greatest during first-generation-chute conditions, when surface recharge from flood water caused ground-water altitude to increase more than drainage of the aquifer to the first-generation chute, and the Missouri River caused ground-water altitude to decrease.

The decrease in the difference between ground-water and river altitude from pre-chute to second-generation-chute conditions for most areas of Overton Bottoms North indicates that ground-water altitude more closely corresponds to river altitude with the presence of a second-generation chute. Ground-water altitude in areas of the aquifer closer to the river typically respond to river-altitude fluctuations more rapidly than areas farther from the river. Rising river altitude causes ground-water altitude to increase as water goes into bank storage, and falling river altitude causes ground-water altitude to decrease. At Overton Bottoms North, construction of the second-generation chute added another river channel in the study area more inland from the main river channel. This increased the effect of river-altitude changes on ground-water altitude by adding more opportunity for exchange between surface and ground water, resulting in more variable ground-water altitude after the chute was constructed.

During low river stages, the decrease in ground-water altitude with respect to river altitude will most likely reduce or eliminate the effect of ground water on wetland recharge and drainage, especially those that are located near the second-generation chute. However, the reconnection of the flood plain with the Missouri River caused by chute construction and removal of levee protection will increase the effect of high river stage on wetland stage by increasing flood frequency. More frequent flood inundation of low-lying areas combined with slow wetland drainage may increase the area occupied by wetlands during periods of high river stage. When river stage remains low, lack of inundation and a lower ground-water altitude will most likely reduce the water that is available to wetlands. Therefore, chute construction at Overton Bottoms North had the net effect of making wetlands drier during dry periods, and breaching of the levees caused the wetlands to be wetter during and immediately after flood periods.

Summary

Overton Bottoms North is located along the Missouri River near the towns of Rocheport and Overton, Missouri, and was acquired by the USACE after the floods of 1993 and 1995. In 2000, the USACE constructed a chute at Overton Bottoms North to provide shallow water habitat in the Missouri River for native fish. The USGS collected pre-chute hydrologic data between June 1998 and May 1999, and between June 1999 and July 2000. Hydrologic monitoring resumed at Overton Bottoms North after construction of this first-generation chute; data were collected between June 2001 and June 2002. In 2003, the side-channel chute was deepened, widened, and realigned. Hydrologic data for this second-generation chute were collected between June 2003 and October 2004.

The hydrology at Overton Bottoms North is affected by intermittent seasonal flooding, the interchange of water between the Missouri River and wetlands via ground-water flow during normal river stage, flow in the chute, and local precipitation. Shallow wetlands are most affected by rainfall and flood inundation, whereas deeper wetlands and scours are most affected by ground-water fluctuations caused by river- and chute-stage changes. Variability in rainfall during the three monitoring periods was considered to have a minimal effect on ground-water altitudes.

A seismic refraction survey of the study area was conducted April 9, 2004, to determine the thickness of the silt/clay top stratum and the depth to the bedrock surface at seven sites. At all sites, an interface between a lower velocity layer and a higher velocity layer was encountered, generally between 5 and 15 m deep; however, typical velocities and comparisons with borehole data indicated that this velocity interface probably resulted from the contrast between saturated and unsaturated alluvium rather than a lithologic difference. Depth to a second velocity interface was detected at site 4 at about 20 m. At site 6, depth to a second irregular interface ranged between 20 and 40 m. These velocity interfaces probably resulted from lithologic contrasts within the alluvium and the contact of alluvium on limestone bedrock.

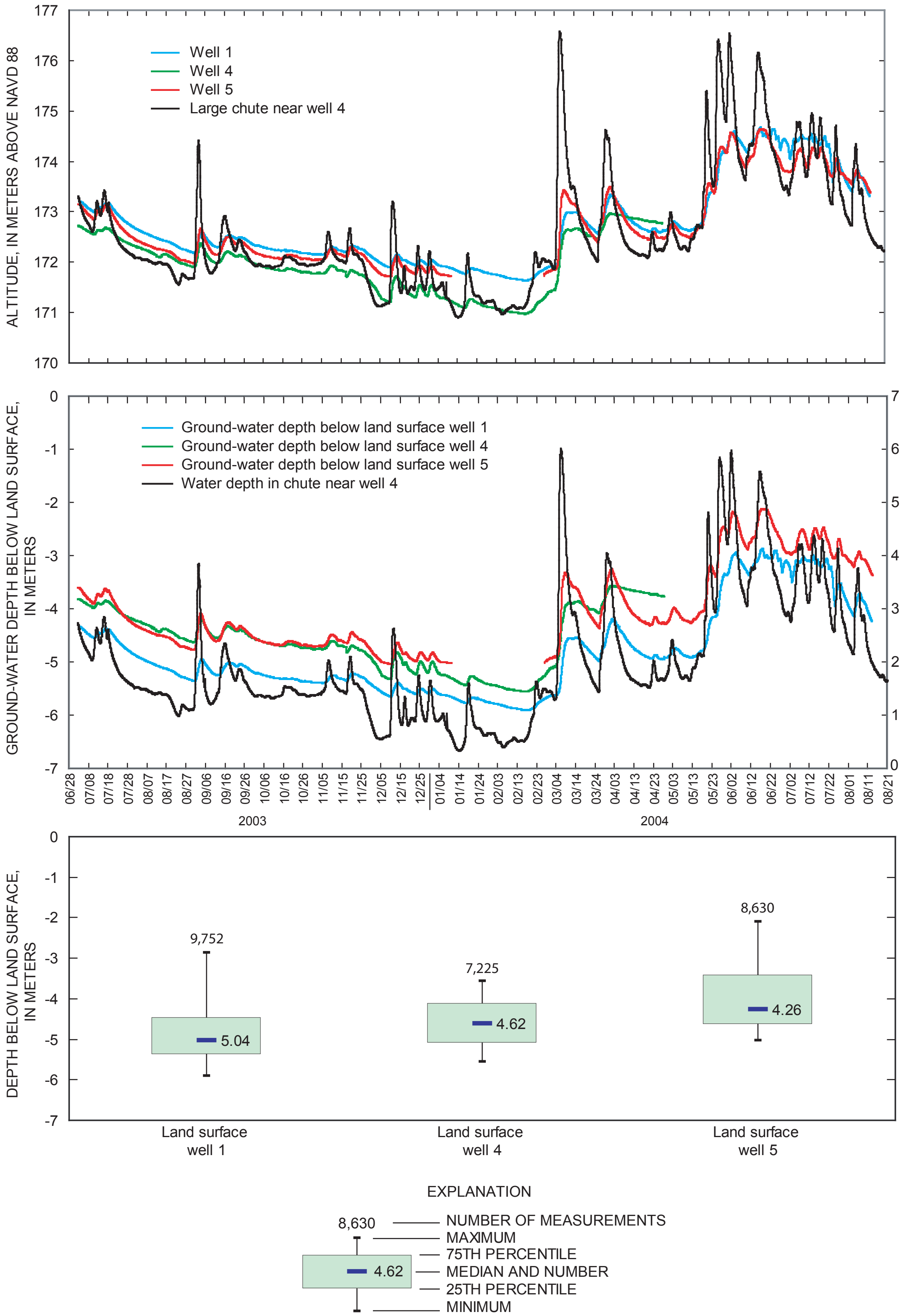

Figure 19. Chute and ground-water altitude, water depth in chute, depth to ground water below land surface, and the minimum, 25th percentile, median, 75th percentile, and maximum depth to ground water below land surface for wells 1, 4, and 5 during second-generation-chute conditions at Overton Bottoms North, Missouri, from June 28, 2003 to August 21, 2004.

Comparing depth to ground water and potentiometric surfaces for pre-chute, first-generation-chute, and second-generation-chute conditions shows the variability of the surface-water/ground-water interaction at the study site. Although the effect of chute construction on ground-water flow is shown by the drainage of ground water into the chute, especially during second-generation-chute conditions, the constantly changing river stage, variable rainfall, and rapid response of ground water to these changes illustrate the constantly changing nature of ground-water flow at the study site.

Ground-water altitude is closely related to river-stage altitude at Overton Bottoms North. Water flow in the chute occurred less frequently during first-generation-chute conditions than during second-generation-chute conditions. The wider and deeper second-generation chute increased the interaction between surface water and ground water at the study area because it flowed most of the time, and the bottom of the chute was below the water table.

Effects of river altitude on ground-water altitude varied systematically with stage of chute construction. Depth to ground water was least for pre-chute conditions, greater for first-generation-chute conditions, and largest for second-generation-chute conditions at most wells.

Ground-water response, however, also depended on topographic characteristics of a site and distance from the chute or river. For example, well TC-1 (located in a low-lying wetland area adjacent to the first-generation chute), showed an increase of 0.09 m in the median difference between ground-water altitude and river altitude from pre-chute to second-generation-chute conditions. In contrast, for wells 1, 2, and 3 (located at higher land-surface altitudes), the differences were -0.61 m, -0.89 m, and -0.49 m, respectively, indicating overall lowering of the ground-water altitude relative to the river. In the case of TC-1, inundation of the flood plain by the Missouri River in the absence of protective levees increased the ground-water altitude more than drainage of the aquifer into the first- or second-generation chute decreased ground-water altitude. For wells 1, 2, and 3, generally declining differences between ground-water and river altitudes pre-chute-, to first-generation-chute-, to second-generation-chute conditions are attributed to enhanced drainage into the chutes. In particular, intersection of the bottom of the second-generation chute with the highly transmissive sand of the alluvial aquifer appears to have increased the hydrologic interaction between the chute and ground water.

A transect of three wells (1, 4, and 5) perpendicular to the axis of the side-channel chute confirmed the fine-scale variability of ground-water dynamics in the flood-plain environment. The data showed that ground-water altitudes responded rapidly to surface-water fluctuations, indicating flow through very transmissive sediment. Moreover, the data documented the tendency for ground-water depths to be slightly less in wells away from the chute.

Chute construction has resulted in a decrease in the difference between ground-water and river altitude in most areas of Overton Bottoms North. However, chute construction has allowed the Missouri River to inundate the area more frequently and at a lower stage because the levee that previously protected the flood plain was breached at the chute inlet and outlet. If the levee was still in place, and no side-channel chutes existed, the Missouri River would not have inundated the flood plain at Overton Bottoms North during the study period. Chute construction has resulted in more frequent surface recharge to the aquifer from flood inundation in low-lying areas.

The decrease in the difference between ground-water and river altitude from pre-chute to second-generation-chute conditions for most areas of Overton Bottoms North indicates that ground-water altitude more closely corresponds to river altitude after construction of the chutes. Construction of the second-generation chute added another river channel in the study area more inland from the main river channel. This increased the effect of river altitude changes on ground-water altitude resulting in more variable ground-water altitude after the chute was constructed.

During low river stages, the decrease in ground-water altitude with respect to river altitude most likely will diminish ground water recharge of wetlands, especially those that are located near the second-generation chute. However, the reconnection of the flood plain with the Missouri River caused by chute construction and removal of levee protection will increase the effect of high river stage on wetland stage by allowing more frequent flooding and recharge of the aquifer through the chute banks. More frequent flood inundation of low-lying areas combined with slow wetland drainage may increase the area occupied by wetlands during periods of high river stage. When river stage remains low, lack of inundation and a lower ground-water altitude will most likely decrease water available to wetlands. Therefore, chute construction at Overton Bottoms North had the net effect of making wetlands drier during dry periods and breaching of the levees caused wetlands to be wetter during and immediately after flood periods.

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