Columbia Environmental Research Center

Physical Habitat Dynamics in Four Side-channel Chutes, Lower Missouri River

By Robert B. Jacobson, Harold E. Johnson, Mark S. Laustrup, Gary J. D'Urso, and Joanna M. Reuter

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Altitude, as used in this report, refers to distance above the vertical datum.

Conventional Units: Scientists writing about U.S. rivers face a dilemma because the scientific community expects adherence to the System International (S.I.) units of measure whereas managers and the public relate almost exclusively to conventional and customary units of measure. Because of the importance of communicating results to stakeholders on the Missouri River, this report presents discharges in customarily used units of cubic feet per second, and river locations in terms of river miles. Depths, other horizontal dimensions, and velocities, however, are presented in S.I. units of meters and meters per second. The conversion table above can be used to convert between units. River miles begin at 0 at the junction of the Missouri River with the Mississippi River at St. Louis, and increase in the upstream direction. Reference to left (L) and right (R) bank locations relate to direction while facing downstream.

Physical Habitat Dynamics in Four Side-channel Chutes, Lower Missouri River

By Robert B. Jacobson, Harold E. Johnson, Mark S. Laustrup, Gary J. D'Urso, and Joanna M. Reuter

Abstract

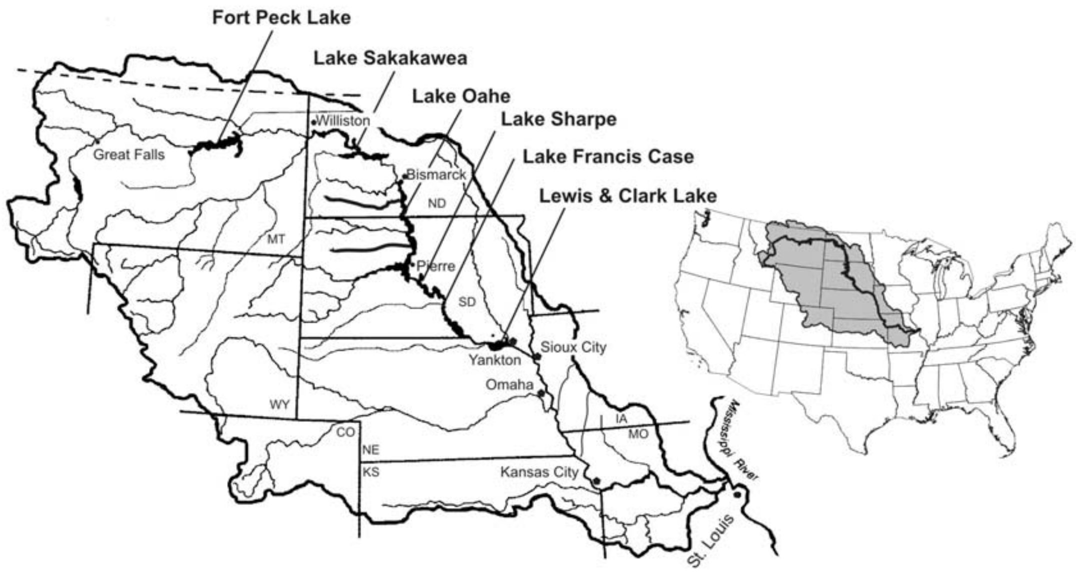
Construction of side-channel chutes has become a popular means to rehabilitate habitat of the Lower Missouri River. We studied various aspects of hydrology, hydraulics, and geomorphology of four side-channel chutes to document a range of existing conditions in the Lower Missouri River. The Cranberry Bend side-channel chute has existed for at least 40 years and is an example of a persistent, minimally engineered chute. The Lisbon Bottom side-channel chute is a young chute, created by extreme floods during 1993 – 1996, and allowed to evolve with minimum engineering of inlet and outlet structures. The Hamburg Bend and North Overton Bottoms side-channel chutes were constructed in 1996 and 2000, respectively, as part of the Missouri River Bank Stabilization and Navigation Fish and Wildlife Mitigation Project.

These side-channel chutes provide increased areas of sandbars and shallow, slow water – habitats thought to be substantially diminished in the modern Missouri River. Depths and velocities measured in side-channel chutes are also present in the main channel, but the chutes provide more areas of slow, shallow water and they increase the range of discharges over which shallow, slow water is present. The 3.6 km long Lisbon Bottom chute provides as much as 50% of the entire shallow water habitat that exists in the encompassing 15 km reach of the river. At Cranberry Bend and Lisbon Bottom, the side-channel chutes provided 10 – 40% of the available sandbar area in the reach, depending on discharge.

Each of the side-channel chutes shows evidence of continuing erosion and deposition. The longevity of the Cranberry Bend chute attests to dynamic stability – that is, a chute that maintains form and processes while shifting in position. The Hamburg chute similarly shows evidence of lateral movement and construction of flood plain to compensate for erosion. The Lisbon Bottom chute – the most intensively studied chute – appears to have achieved an equilibrium width and continues to migrate slowly; however, evidence of aggradation indicates that the chute has not reached an ultimate form, and may be continuing to adjust to altered hydrology and sediment availability. The North Overton Bottoms chute is the newest in the study. In its originally constructed form, the North Overton Bottoms pilot chute was extremely stable, even while being subjected to two floods in excess of 2-year recurrence interval and after accumulating large, potentially destabilizing large woody debris jams. Ongoing adaptive re-engineering of the North Overton Bottoms chute has prevented assessment of how the chute might have adjusted its form in the absence of intervention.

Introduction

This report presents a comparative study of habitat characteristics of four side-channel chutes on the Lower Missouri River (fig. 1). While substantial sums of money are being spent on construction of side-channel chutes to mitigate habitat losses on the river (U.S. Army Corps of Engineers, 2003), little is known quantitatively about the contribution of these chutes to total habitat availability, and how geomorphic adjustments of chutes may alter habitat availability over time.



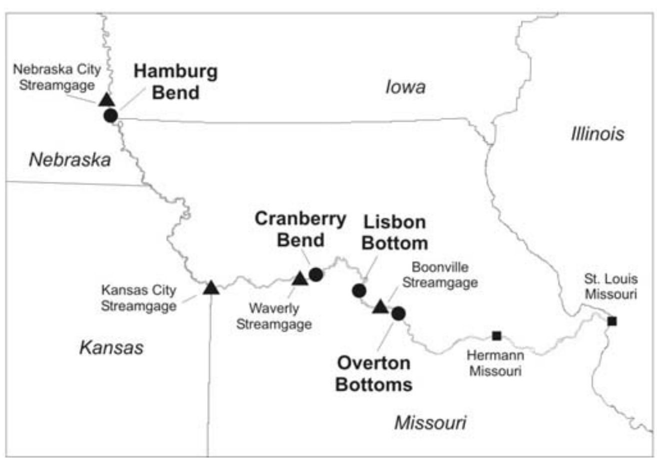


Figure 1. Missouri River basin, the Lower Missouri River, and locations of the four side-channel chutes and streamflow-gaging stations addressed in this study. The Lower Missouri River is the part of the river downstream of Gavins Point Dam near Yankton, South Dakota, and extending to the junction with the Mississippi River near St. Louis.

Even less is known about the biological performance of these chutes, especially in terms of how habitats are used by native, endangered, and invasive species. For example, one of the goals for rehabilitation of side-channel chutes is to provide additional shallow-water habitat (SWH, nominally defined as less than 1.5 m deep and less than 0.75 m/s current velocity) and increase habitat complexity to meet the needs of the endangered pallid sturgeon (*Scaphirhynchus albus*) and avoid jeopardy under the Endangered Species Act. At the same time that resource managers are trying to support the pallid sturgeon, the Lower Missouri River is experiencing an unprecedented population explosion of invasive Asian carp, principally bighead (*Aristichthys nobilis*) and silver (*Hypophthalmichthys molitrix*) carp. Although there is substantial uncertainty about how sandbar and aquatic habitat in side-channel chutes will contribute to populations of invertebrates, fish, birds, and amphibians, it is well understood that physical habitat provides the template upon which river ecosystems are built. This report is intended to increase general understanding of habitat dynamics in side-channel chutes, and to improve the scientific basis for design, construction, and management of rehabilitation projects on large rivers.

Aquatic Habitat Dynamics in Side-channel Chutes

Habitat is defined, in general, as the three-dimensional structure in which organisms live (Gordon and others, 1992). Aquatic habitat typically includes physical and chemical characteristics of the space occupied by organisms, however this report is confined to physical characteristics, including water depth, flow velocity, and substrate. Physical aquatic habitat results from interaction of water with the morphology of the stream channel and adjacent flood plains. River hydrologic characteristics determine how much water is in the channel, when, and for how long. River geomorphic characteristics determine how the water is distributed across the channel, thereby creating the spatial distribution of depth, velocity, and substrate.

Physical aquatic habitat characteristics vary through time because of changes in river discharge and because erosion and deposition alter the morphology of the river bottom. Aquatic habitat dynamics can be divided into two general time domains representative of hydrologic and geomorphic processes. Habitat dynamics associated with hydrologic variation, without changes in channel morphology, are considered to be in the hydrodynamic time domain, whereas habitat variations associated with erosional and depositional changes in morphology are considered to be in the geomorphic dynamics time domain. Modeling of habitat variation with discharge in instream-flow studies typically is based on the assumption that channel morphology does not change over the range of flows, or on the assumption that geomorphic processes in one area of the channel are compensated by changes in other parts to achieve a net equilibrium morphology (Bovee, 1982). Instream-flow studies also often focus on a range of low flows where it can be assumed that geomorphic processes are minimized. Although it is a common and convenient practice to consider each of these time domains separately, the assumption that the processes are independent is difficult to support in rivers undergoing rapid adjustment to new flow conditions or in rivers where bed sediment is transported by relatively frequent flows. Both of these conditions exist in the Lower Missouri River where bed sediment is dominated by frequently transported sand and channel morphology is being actively altered to rehabilitate the river. Complete understanding of habitat dynamics requires assessment of both hydrologic and geomorphic components.

If applied over enough time to sample temporal variation and over enough area to sample spatial variation, the hydrologic and geomorphic habitat assessments documented in this report can provide robust, quantitative measures of habitat availability. Ultimately, however, most management, social, and ecological interests focus on the biological endpoints of altered ecosystems, rather than the physical habitat template. Aquatic ecosystems can adjust to biotic and chemical factors as well as physical factors in many complex ways. Nevertheless, because physical habitat determines the foundation of the aquatic system, some general biological dependencies can be inferred.

At a very general level, ecologists generally accept that biological diversity is associated with habitat diversity because a greater range of physical environments potentially allows more species to thrive in the stream channel (Gorman and Karr, 1978; Schlosser, 1987; Jeffries and Mills, 1990). A greater diversity of elevations within a river reach, for example, assures that some aquatic habitat will be available over a larger range of flows than if the elevations were all nearly the same. Therefore, physical processes that homogenize habitat are usually considered detrimental to the ecosystem, and habitat rehabilitation typically attempts to increase physical habitat diversity.

Physical Habitat Loss and Rehabilitation, Lower Missouri River

The lower Missouri River (generally defined as the Missouri River downstream of Gavins Point dam at Yankton, South Dakota, fig. 1) is a large, multiple-use river system draining 1,300,000 km^2 (525,000 mi^2) at its mouth (U.S. Army Corps of Engineers, 1998a). The river has been regulated since 1954 by the Missouri River Reservoir system, the largest reservoir system in the nation, with nearly 92,500 km^3 (75 million acre feet) of water storage. Clearing, snagging, and stabilization of the Missouri River began in the early 1800’s to improve conditions for steamboat navigation. Most of the river’s hardened engineering structures, however, are the direct result of the Missouri River Bank Stabilization and

Navigation project, part of the Pick-Sloan act of 1944 (Ferrell, 1993). Wing dikes and revetments have stabilized the riverbanks, and narrowed and focused the thalweg to maintain a self-dredging navigation channel from St. Louis, Missouri, 1,200 km (735 miles) upstream to Sioux City, Iowa. The result has been to create a narrow, swift, and deep channel from what was historically a shallow, shifting, braided river.

Management of the Missouri River system for economic benefits has been associated with substantial loss of habitats and native riverine biota, as much as 100,000 acres (about 400 km^2; Funk and Robinson, 1974; Hesse and Sheets, 1993). Recognition of the scope of habitat loss has increased interest on rehabilitating parts of the Missouri River (Latka and others, 1993). Approaches and designs vary widely, but they can be described generally as resulting from three sets of questions:

- What are the rehabilitation objectives? Is the intent to recover some naturally dynamic ecosystem functions, to create specific habitats for recreational species, or to create specific habitats for threatened and endangered species?
- Should rehabilitation focus on altering system hydrology, through reservoir release policies, or on altering riverine geomorphology? Hydrology determines the magnitude, timing, and duration of flows in the river corridor. Geomorphology, however, determines how that water is allowed to be distributed in space and create aquatic habitats. On intensively engineered rivers, hydrologic alterations alone may not be sufficient to produce more available habitat.
- Should rehabilitation employ passive or intensive approaches? Passive approaches allow the river to create dynamic habitats, presumably at least cost, but result in less control over the characteristics and timing of habitats. Intensive approaches – for example, diking wetlands and pumping water to create optimum waterfowl habitat – result in stable, controlled habitats, generally at greater cost.

Rehabilitation strategies on the Missouri River fall into several distinct categories, covering a range of passive to intensive approaches (table 1).

Table. 1. General strategies, objectives, and approaches to habitat rehabilitation, Lower Missouri River.

Rehabilitation Strategy	Objectives	Approach
Flow modifications	Naturalize flows to provide timing of habitat availability and environmental cues for reproduction and recruitment of native species	Alter reservoir release patterns
Intensively managed wetlands	Provide specific wetland habitats and associated food sources at specific times of the year to support, mostly, waterfowl production	Construct leveed wetland compartments; manipulate interior drainage; pump or drain as needed to optimize water levels; plant food crops for water fowl
Passive (opportunistic) wetlands	Provide general wetland habitats at least cost	Remove levees to increase frequency and area of flooding
Side-channel chutes	Provide off-channel aquatic habitats; increase hydrologic connection of valley bottom to main channel	Construct off-channel chute; inlets and outlets variably designed to achieve hydroperiod and sediment transport objectives
Shallow-water within channel	Provide shallow, slow current velocity habitat along margins of main channel.	Increase top width; remove revetment and allow lateral erosion; manipulate wing dikes to achieve diversity of habitat.

Each of these approaches has different costs and different potential for ecological and economic benefits. Design criteria for off-channel aquatic habitats (side-channel chutes and shallow water and sandbars adjacent to the main channel) generally have been based on the premise that rehabilitation should work to reverse the engineered simplification of the channel and thereby to provide greater channel complexity. In addition, it has been accepted that engineering of the Lower Missouri River channel has increased current velocities and depths at the expense of slow, shallow water that is stated to be important for survival of young and juvenile native fishes (U.S. Fish and Wildlife Service, 2000). Hence, efforts have been focused on recreating side-channel chutes and increasing channel top width to increase habitat diversity and provide more slow, shallow water (Harberg and others, 1993; Latka and others, 1993).

Techniques of rehabilitating side-channel chutes are informed by little theory or empirical experience. Generally, design is intended to create the correct balance of water and sediment in the chute and in the navigation channel, so sediment transport capacity is maintained in both channels. In an analysis of river avulsion processes, Slingerland and Smith (1998) showed that stability of a side-channel chute depended on the ratio of the chute slope to the main channel slope, the ratio of the height of the lip of the chute to flow depth in the main channel, and particle size of the moving bed layer in the main channel. These factors determine the balance between sediment flux through the chute and sediment flux down the main channel. Their analysis supports the idea that long-term evolution of a chute will be dependent on the interplay of sediment load, sediment particle-size distribution, and chute geometry.

In contrast, designers of secondary channels on the Rhine River in the Netherlands have concluded that secondary channel systems are inherently unstable over the long term, and will tend either to fill up with sediment or pirate the main channel (Schropp, 1995; Barneveld and others, 1994). Designs for secondary channels on the Rhine aim to keep all sediment from entering the secondary channel to prevent sedimentation, although it is recognized that low sediment transport in the secondary channel increases the chance that harmful aggradation will occur in the main channel and may lead to excessive incision of the secondary channel (Schropp, 1995). Barneveld and others (1994) argue that careful modeling of discharge and sediment transport can help design a balance of channel dimensions and water/sediment distribution. However, such designs are believed to achieve a secondary channel that would be in equilibrium for no more than several years, after which dredging of the secondary channel would be necessary. The disagreement between the Rhine design experience and the theoretical analysis of Slingerland and Smith (1998) indicates the need for empirical documentation of field-scale experiments.

In addition to the uncertainties in how physical characteristics of side-channel chutes will evolve, there is considerable uncertainty about the ecological benefits of river rehabilitation projects and their long-term performance (Federal Interagency Stream Restoration Working Group, 1998). The uncertainty is greater for large rivers than for small rivers because of inherent spatial and temporal complexities, the relative lack of empirical data, and shortcomings of predictive computational models or theoretical framework (Cals and others, 1998, Shields, 1989; Holly and Ettema, 1993; Lubinski and Gutreuter, 1993; Burke and Robinson, 1979). A further complication is the potential for rehabilitation projects to be colonized by invasive or nuisance species.

Purpose and Scope

The purpose of this report is to explore various hydrologic and geomorphic aspects of physical habitat dynamics in side-channel chutes in the Lower Missouri River. The report is intended to add empirical understanding needed for evaluating the benefits, costs, and performance of side-channel chute rehabilitation projects on large, multipurpose river systems. This report provides descriptions and measurements as a beginning to understanding habitat dynamics in chutes; the report is not comprehensive and can be considered documentation of progress of ongoing studies. A mix of nearly natural to highly engineered side-channel chutes has been chosen to represent the range of existing conditions on the Lower Missouri River.

Four side-channel chutes have been selected for this study (fig. 1; table 2). The scale of scientific effort varies among the chutes because different management questions apply in different areas and because of logistical constraints. This report combines results from work supported by U.S. Geological Survey Fisheries and Aquatic Resources Program, U.S. Geological Survey Quick Response Program, and U.S. Fish and Wildlife Service.

Table 2. Descriptions of side-channel chutes included in this study.
[km, kilometer; mi, mile]

Chute	River Miles	Description
Hamburg Bend	552-556	Habitat Mitigation Program site, engineered side-channel chute. Completed 1996. Hydraulic control structures upstream and downstream; some channel training structures. Length: 4.5 km (2.8 mi).
Cranberry Bend	280.5 - 282	“Natural” side-channel chute. No hydraulic control structures; partly affected by wing dike at upstream end. Length: 1.3 km (0.8 mi).
Lisbon Bottom	214 - 218	Opportunistic side-channel chute formed by series of floods 1993 – 1996. Stabilized with upstream hydraulic structure, notched revetment 1996. Length: 3.5 km (2.2 mi).
North Overton Bottoms	185.5 - 188	Habitat Mitigation Program site, Engineered side-channel chute constructed in 1999. Original length: 3 km (1.9 mi).

Acknowledgments

This project was cooperatively funded through the U.S. Fish and Wildlife Service, the U.S. Geological Survey Fisheries and Aquatic Resources Program, and the U.S. Geological Survey Quick Response Program. The authors acknowledge logistical support and contributions of data from the Big Muddy National Fish and Wildlife Refuge, the U.S. Army Corps of Engineers Kansas City and Omaha Districts, and the Nebraska Game and Parks Commission.

Approaches and Methods

Approaches used in this research varied due to questions that were specific to particular chutes, logistical constraints, and timing of hydrologic conditions. In general, understanding of physical aquatic habitat in dynamic river corridors requires quantification of three components: hydrology, geomorphology, and hydraulic habitat. The following methods were used to some extent at each site. Additional detail in methods is provided in site-specific sections of the report.

Hydrology

The physical habitat performance of side-channel chutes is fundamentally controlled by hydrology and geomorphology. Hydrology determines the magnitude, frequency, and timing of water in the corridor, as determined by hydroclimatology, runoff, and upstream reservoir management. Geomorphology determines how the water and sediment are distributed between the main channel and the chute.

We characterized the hydrology of the river corridor by developing an understanding of long-term flow frequency at the nearest streamflow-gaging station. Hydrologic data include historical, long-term daily mean discharges, divided into records before and after reservoir regulation, and a dataset consisting of daily mean discharges simulated by the U.S. Army Corps of Engineers in their Daily Routing Model (DRM, U.S. Army Corps of Engineers, 1998a). DRM flows are synthesized from historical data on tributary inflows, calculations of streamflow depletions due to evapotranspiration and consumptive use of water, and modifications of outflows according to water-control rule scenarios. The model reproduces how reservoirs would be managed under a set of water control rules, given the actual range of variability of historical inflow data. Historical inflow data are available, or have been estimated, for the period 1898-1998. The DRM uses these data and water-control rules to generate 100 years of daily flows for each of 14 sites on the mainstem Missouri River for management alternatives. The 14 sites consist of nine streamflow-gaging stations on the Lower Missouri River and five streamflow-gaging sites in inter-reservoir river segments. Model runs show the result of highly variable streamflow routed through the reservoir system according to water-control rules of varying complexity. Because storage in the Missouri River reservoir system is finite and because many tributary inflows are not regulated by reservoirs, the natural variability of the historical inputs is reflected in variability in the output discharge. The focus in this report is comparing a representation of the operating plan that has been used throughout the late 20th century (Current Water Control Plan, CWCP), a simulation of the natural hydrograph, or run-of-the-river model (ROR), and examples of environmental flow alternatives. Additional management scenarios are compared in Jacobson and Heuser (2002).

Discharge data for the alternatives were obtained from the Corps of Engineers. The data were reformatted and converted to watershed data management (WDM) format using the IOWDM program (Flynn and others, 1994; available at: http://water.usgs.gov/software/iowdm.html). The data were then analyzed for flow frequency using the program SWSTAT (Flynn and others, 1994; http://water.usgs.gov/software/swstat.html). The duration hydrograph routine of SWSTAT calculates cumulative flow frequency for every day of the year for the period of record. Output from this program consists of flow exceedance percentiles (for example, 90th percentile, 50th percentile) and the corresponding flow for each day of the year. Typically, these data – or habitat derivations from the hydrologic data – are plotted as shaded bands by day of the year to illustrate variations in flow during the year and variation over the 100 years of modeled record. Vertical variation in the graphs is a measure of variation among years and horizontal variation is a measure of seasonal variation.

The physical controls at each of the four study chutes are different, resulting in different amounts of water that can flow into the side-channel chutes. The amount of water that can flow into a side-channel chute from upstream depends on the geometry of the entrance structure. Designed chutes typically have a notched control geometry that controls discharge into the chute, with increasing percentage of flow allowed to enter as discharge increases. Natural, or non-engineered side-channel chutes (for example, Cranberry Bend) lack such control structures, but may be affected by revetments or wing dikes that work in part to control discharge. Because side-channel chutes typically cut across river bends, they tend to have steeper slopes than the main channel. As a result, the main-channel water surface typically acts as a downstream control on flow in the chute. In cases where there is a lip at the upstream entrance to the chute, water may back into the dry chute from downstream before it enters the chute from the top. Chutes at Hamburg Bend and Overton Bottoms have additional downstream hydraulic structures that control flow in both directions; Cranberry Bend and Lisbon Bottom chutes lack hydraulic control structures at their outlets.

A fundamental descriptor of hydrology at individual sites is a measure of how often water flows into and out of the side-channel chutes. We established stage-discharge relations at Cranberry Bend, Lisbon Bottom, and Overton Bottoms chutes by surveying water-surface elevations relative to benchmarks of known elevations. The frequency of flows that reach the measured stages was established by evaluating flow frequency at the nearest streamflow-gaging station.

Geomorphology

Geomorphic measurements include descriptors of channel and sandbar geometry, and can include repeat measures to assess change. Planform geometry of side-channel chutes was established by mapping with boat-mounted and backpack differential global positioning systems (DGPS). Sandbar geometry and extents were mapped with backpack DGPS.

Boat-mounted data were georeferenced in the field by a real-time, 12-channel DGPS to sub-meter accuracy. Differential corrections were provided in real time by the Omnistar ® (Omnistar Inc., Houston, Texas)[1] satellite-based system. Satellite-based corrections were found to have positional accuracies with standard deviations of 0.6 – 1.0 m. The DGPS data were collected at 200 millisecond (ms) intervals, resulting in positions approximately every 0.3 – 3.0 m along each transect at typical boat speeds of 2 – 8 knots (1-4 meters per second, m/s) during data collection. Boat speeds were maintained at 5 knots or less most of the time. Backpack DGPS data were post-processed against base-station data to approximately the same accuracy.

Bathymetric data were collected with a survey-grade echosounder equipped with a 208 kHz, 8^{o} transducer. The echo sounder was calibrated by bar test to account for boat draft, blanking distance, and environmental conditions that could affect the speed of sound in water. The bar test is a calibration procedure based on suspending a metal plate at known depths below the transducer. Pitch and heave were not compensated; however, these corrections are thought to be minor given typical calm-water working conditions. The precision of the echosounder data is 0.03 m. Patch test results in areas of known depths indicate that, under favorable bottom conditions, the depth accuracy is approximately 0.07 m. Bathymetric data have been converted to elevations by measuring water-surface elevations with a total station relative to known benchmarks, at the upstream and downstream ends of survey areas during the survey. This sloping water surface was then used as a datum from which echosounder depths were subtracted to calculate elevations.

At Hamburg Bend chute and Cranberry Bend chute, channel planform was also mapped from ortho-rectified aerial photographs (Corps of Engineers; Hamburg Bend, 1998; Cranberry Bend, 2000). Comparison with DGPS measurements on stable reaches indicates that mapping from the ortho-rectified aerial photography achieves about the same level of sub-meter accuracy.

At Cranberry Bend and Lisbon Bottom chutes, sandbar area was assessed in the chute and adjacent navigation channel. At Cranberry Bend, the relation between discharge and sandbar area was developed by mapping sandbar area with DGPS over a range of discharges. At Lisbon Bottom, the area of sandbars was calculated by subtracting wetted area from total in-channel area, where wetted area was determined over a range of discharges by using a calibrated 1-dimensional hydraulic model. In both cases, a fundamental assumption is that channel morphology does not change over the range of discharges of interest, or if it does change as a result of erosion or deposition at higher discharges, the channel morphology readjusts to an equilibrium geometry. This assumption is yet to be tested with high-density, long-term monitoring of sandbar morphology. However, in a study of channel morphology at Hermann, Missouri, Jacobson and others (2002) documented that sandbars associated with wing dikes changed little with discharges up to approximately ½ bankfull.

Hydraulics

Current velocity and water depth are fundamental hydraulic characteristics that determine how habitats are used by fishes. Current velocities and depths are dependent on the discharge on a particular day, and one of the great challenges in quantifying habitats is to account for varying discharge. In the best-case scenario, depths and velocities would be measured over their entire ranges at intervals fine enough that intermediate values could be interpolated with confidence. Usually, this approach is not feasible. Another generally accepted approach for accounting for discharge variability is to develop hydraulic models to simulate depths and velocities for a range of calibrated flows. For many types of habitat assessments, 2-dimensional finite element hydraulic models are the accepted tool. While multi-dimensional modeling is beyond the scope of this report, some 1-dimensional hydraulic modeling results are presented for analysis of side-channel chute performance at Lisbon Bottom.

Another approach to dealing with variable discharge is to measure velocities and depths at an index discharge, or a discharge that is selected for having particular ecological significance. For example, the U.S. Fish and Wildlife Service Biological Opinion (U.S. Fish and Wildlife Service, 2000) emphasizes that shallow water habitat should be evaluated at the median August flow. Although it is practically impossible to measure hydraulic conditions exactly at a predetermined discharge, design flows can be

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[1] Trade names are used for information purposes only and do not constitute an endorsement by the U.S. Geological Survey

targeted. This approach was used at Hamburg Bend where we targeted a normal, navigation-season flow of about 37,000 cfs.

A final approach to dealing with variable discharge is to focus on the spatial differences in depth and velocity between the side-channel chute and the navigation channel. While this approach does not negate the importance of understanding the range of hydraulic conditions that can exist at a site, it provides a useful measure of the contribution of the side-channel chute to habitat availability compared to the navigation channel regardless of discharge.

Depths were collected using the echosounder methods discussed in the previous section. Velocity data were collected with a Workhorse Rio Grande Model ® 600 kHz acoustic Doppler current profiler (ADCP), and logged in WinRiver ® software (RD Instruments, San Diego, California). These data also were georeferenced with DGPS data, but were collected on a separate laptop computer running the WinRiver ADCP acquisition program. The ADCP was set up to collect 3-dimensional water velocity data in 0.35-m deep bins from the surface to the bottom following generally accepted setup and operation procedures (Morlock, 1996). A column of bins (called an ensemble) was collected nominally every 2.5 seconds. Boat speeds were maintained below 5 knots, resulting in a maximum ensemble spacing of about 3.8 m. The ADCP was internally calibrated for measured water temperature and compensates automatically for pitch and roll.

Hydrology, geomorphology, and hydraulic data were processed in various ways for analysis. Velocity and depth data were compiled as individual points to make maps, compiled as histograms to illustrate differences, and used to calculate discharges in the chute and adjacent navigation channel. Bathymetric maps at Cranberry Bend and Lisbon Bottom were created to evaluate sandbar and shallow-water habitat area. Data processing steps for editing, interpolating, and constructing continuous surface maps are detailed in Jacobson and others (2002).

Results

Hamburg Bend Chute

Hamburg Bend chute was constructed in 1996 and designed to provide additional off-channel habitat not found in the adjacent Missouri River. Historical maps (1879) indicate that the Hamburg Bend area previously had much greater geomorphic diversity, including numerous side-channel chutes, islands, and sandbars compared to current (1998) conditions (fig. 2). Our data collection at Hamburg Bend Chute was restricted to hydraulic information relating depths and velocities in the main channel to depths and velocities in the chute. Survey data also were useful in evaluating geomorphic evolution of the chute as measured by bank movement.

The hydrology of the Hamburg Bend Chute can be assessed by using the nearby streamflow-gaging station 10 km upstream at Nebraska City, Nebraska (U.S. Geological Survey streamflow-gaging station 06807000, fig. 1). This streamgage was included in the U.S. Army Corps of Engineers daily routing model (U.S. Army Corps of Engineers, 1998a; Jacobson and Heuser, 2002) so modeled daily discharges are available for the gage for 100 years of record under unregulated and regulated flow conditions (fig. 3). Regulation of the Missouri River at this location has resulted in a substantial decrease in spring flood discharges and increases in summer-fall discharges, July – November.

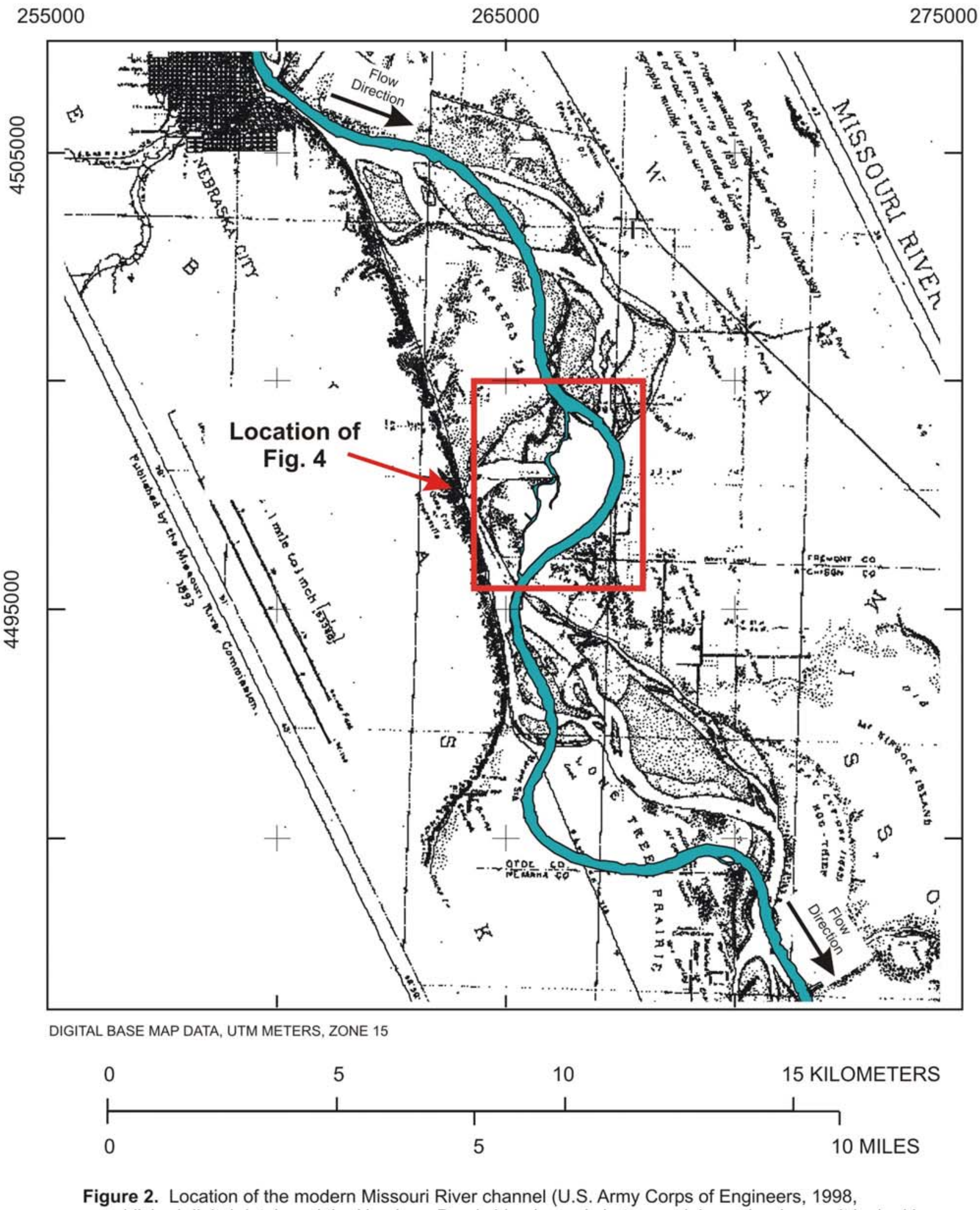


Figure 2. Location of the modern Missouri River channel (U.S. Army Corps of Engineers, 1998, unpublished digital data), and the Hamburg Bend side-channel chute, overlain on the river as it looked in 1879 (Missouri River Commission, 1893). The late 19th century Missouri River was characterized by many side-channel chutes around sandbars and islands.

Although the survey was not intended primarily to evaluate geomorphic change in the chute, our channel mapping in 2001 showed considerable movement of the channel from the position mapped from aerial photography in 1998 (fig. 4). Bank erosion of 20-40 m was common in bends in this time period. Most of the change was in the lower one-half of the chute where bends have moved laterally and slightly downstream by a channel width or more in three years (1998-2001).

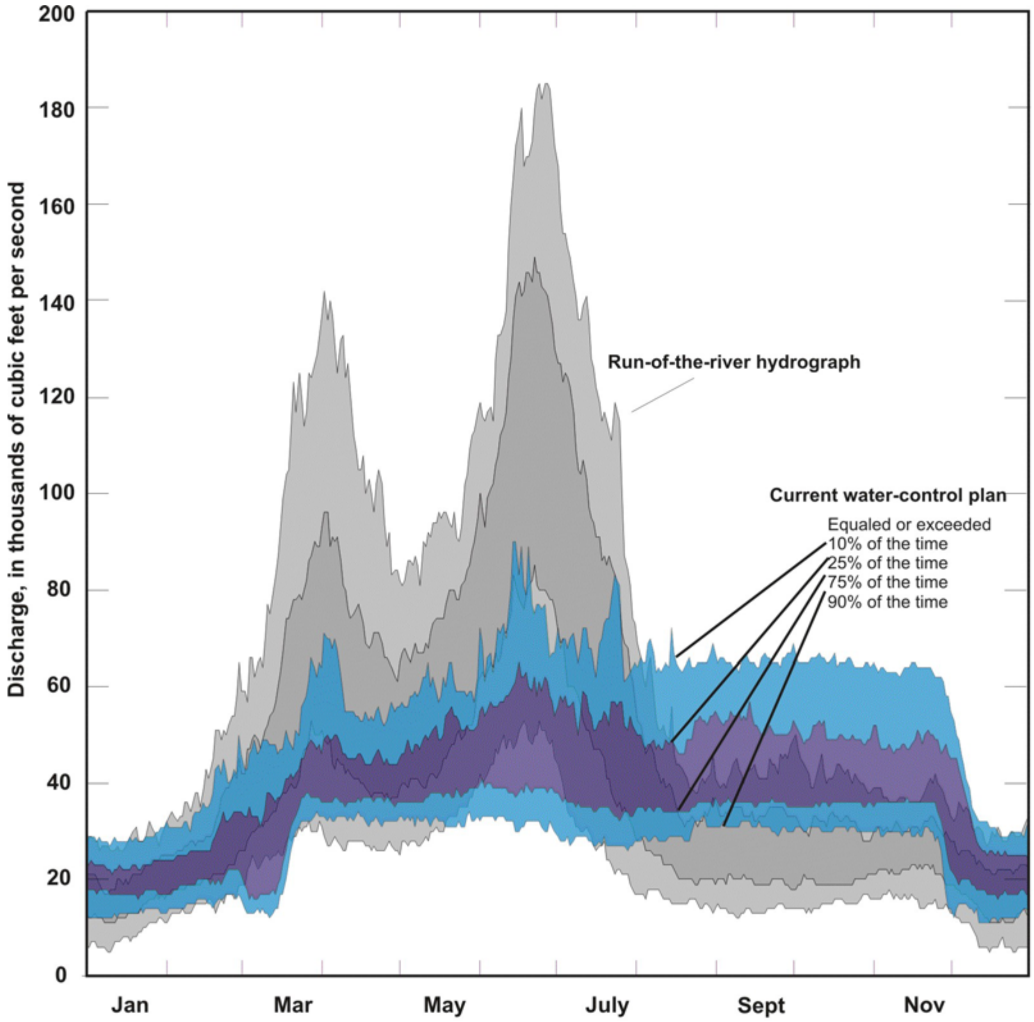


Figure 3. Duration hydrographs constructed using 100 years of simulated daily flows for the Missouri River at Nebraska City, Nebraska, approximately 10 km upstream of Hamburg Bend chute. Methods are documented in Jacobson and Heuser (2002). Gray shades depict the natural hydrograph estimated by a run-of-the-river model. Blue shades depict the regulated hydrograph simulated under the current water control plan (CWCP). Regulation has resulted in substantial decreases in spring flows and increases in late-summer, autumn flows.

Hydraulic characteristics were measured in the chute at 37,000 cfs, a flow equaled or exceeded 63% of the time over the entire year and about 75% of the time during the navigation season. This was considered a representative flow for evaluating habitat conditions in the chute. A total of 148 transects was measured for depth and velocity within the chute, and 33 transects were measured for comparison in the adjacent navigation channel (fig. 4). The percentage of flow in the chute was 9.3% of the total flow under these conditions.

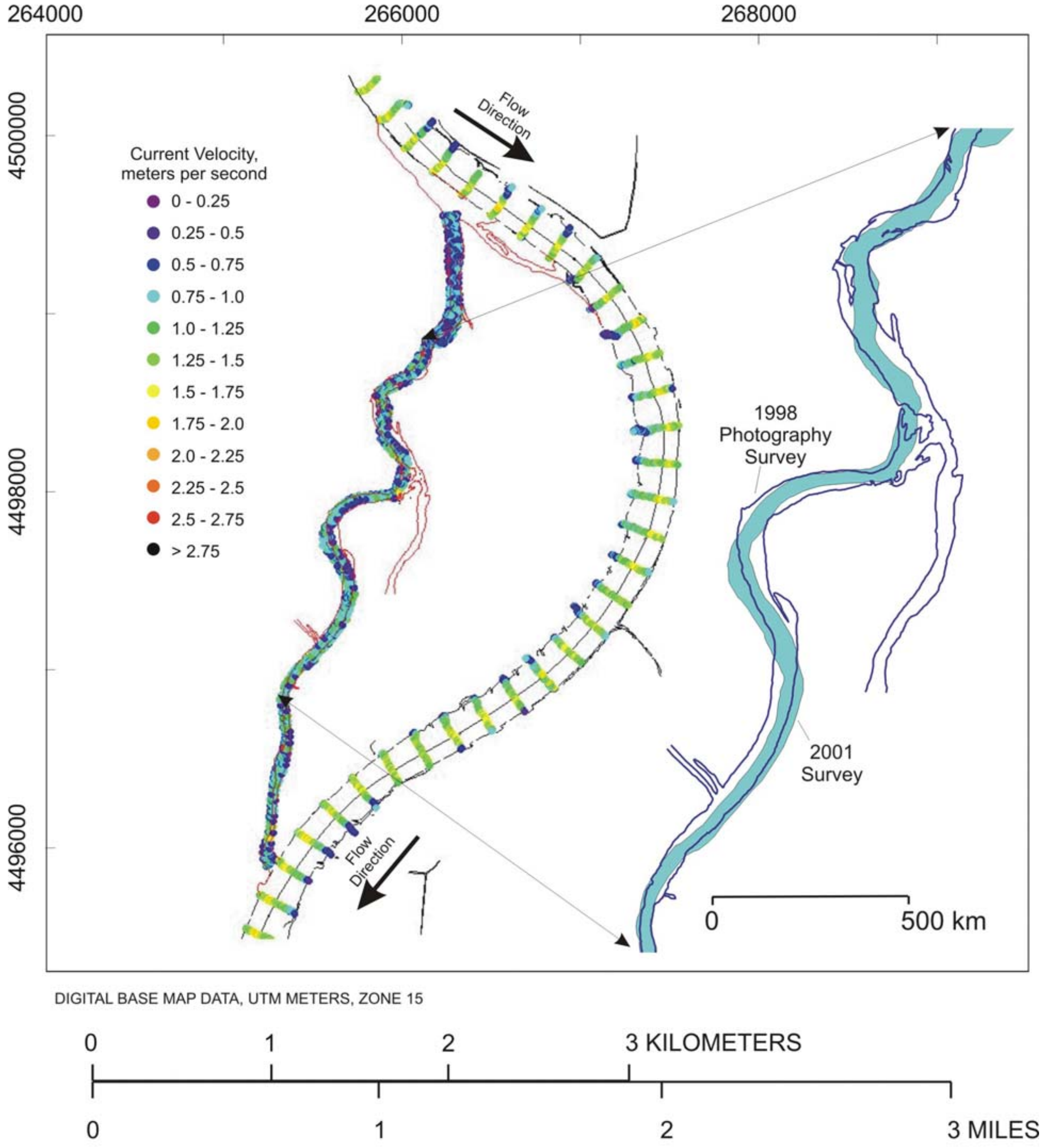


Figure 4. Flow velocities in the Hamburg Bend side-channel chute and in the adjacent navigation channel, at 37,000 cfs, or about 63 percent flow exceedance.

Histograms of depths and velocities were developed to characterize the distributions of these variables in the chute and navigation channel (fig. 5). The histograms are shown as percent of total area of the navigation channel and chute. For both depth and velocity, the navigation channel provides a much wider range of values than the chute, and the range includes all of the values present in the chute. Although most of the navigation channel is relatively fast and deep, areas of shallower, slower water exist on the margins and in association with wing dikes. For comparison, the shaded area in figure 5 shows the mean plus or minus (±) one standard deviation of the velocity used by pallid sturgeon on the upper Missouri and Yellowstone rivers (Bramblett and White, 2001). Another measure for comparison is the definition of shallow-water habitat (SWH) identified by the Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2000) as lacking in the Lower Missouri River. SWH was defined as less than 5 ft (1.5 m) deep and less than 2.5 ft/s (1.5 m/s) current velocity. At 37,000 cfs, the Hamburg Bend chute provides additional areas of SWH, and most of the velocities provided are coincident with those used by pallid sturgeon.

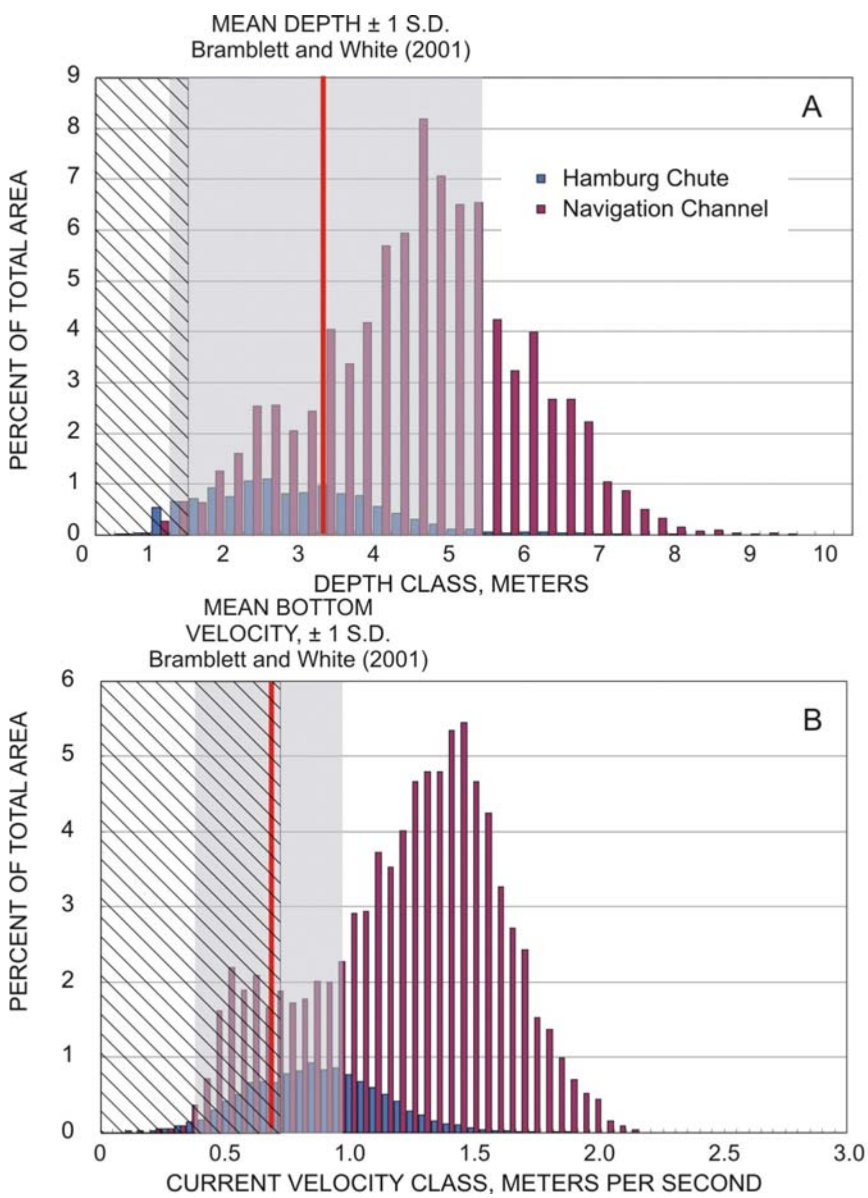


Figure 5. Histograms of depths and velocities measured in the Hamburg Chute and adjacent navigation channel at 37,000 cfs, approximately 63% exceedance. A. Depths. For comparison, mean depth (red line) and standard deviation (S.D., gray box) of pallid sturgeon locations recorded by Bramblett and White (2001) in the upper Missouri River. Depth range of the shallow-water habitat class defined by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2000) is shown for comparison in the cross-hatched box. B. Depth-averaged velocities. For comparison, mean bottom velocity (red line) and standard deviation (S.D., gray box) of pallid sturgeon locations recorded by Bramblett and White (2001) in the upper Missouri River. Velocity range of the shallow-water habitat class defined by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2000) is shown for comparison in the cross-hatched box.

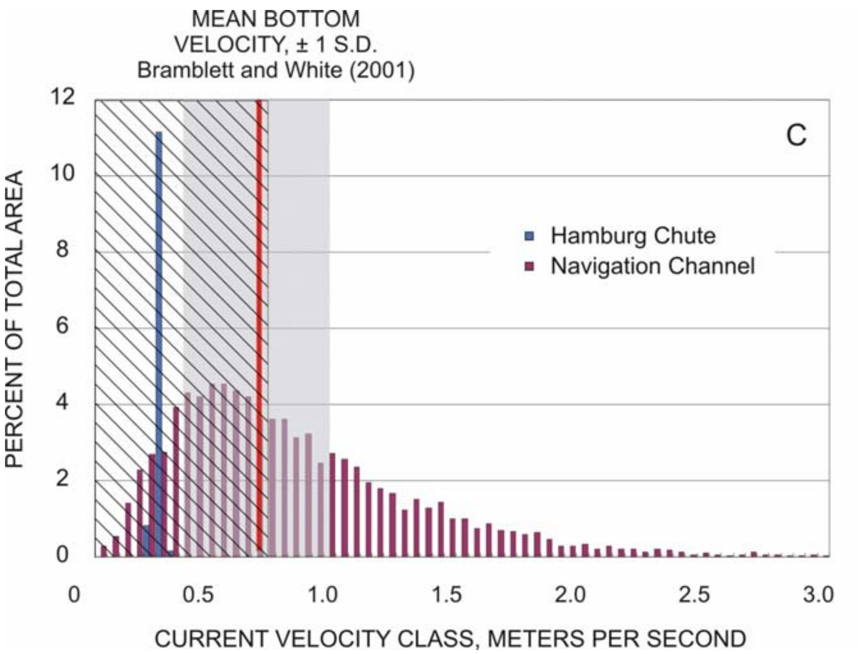


Figure 5 (cont). Histograms of depths and velocities measured in the Hamburg Chute and adjacent navigation channel at 37,000 cfs, approximately 63% exceedance. C. Bottom velocities recorded at approximately same elevation above bottom as Bramblett and White (2001).

Cranberry Bend Chute

The Cranberry Bend side-channel chute is a remnant, more-or-less natural side-channel chute that has not changed much in location and extent since at least 1954. In historical maps from 1879 and 1920, similar chutes and islands existed on the bend, however, the bend itself migrated approximately 3 mi downstream 1879 – 1954 (fig. 6).

The hydrology of Cranberry Bend chute can be characterized by the historical record at the streamflow-gaging station at Waverly, Missouri, 15 mi upstream (fig. 1). The Waverly gage was not included in the U.S. Army Corps of Engineers daily routing model, but insight into long-term and alternative flow scenarios can be obtained from the Kansas City (upstream, U.S. Geological Survey streamflow-gaging station 06893000) and Boonville, Missouri (downstream, U.S. Geological Survey streamflow-gaging station 06909000) streamgages (fig. 7). The effect of regulation is not as pronounced as it is at Hamburg Bend, but is evident in lower high flows in spring and higher flows in the summer and fall months.

The chute is stabilized at the inlet with two wing dikes. The downstream-most wing dike connects a small island to the right bank; 1994 navigation charts show the wing dike extending completely across the chute, but by 2000, aerial photography showed that about half of that wing dike had eroded or had been removed (fig. 8).

Emphasis at Cranberry Bend was on characterization of sandbar habitat availability for shorebirds. Sandbar areas were assessed using DGPS mapping of the sandbar margins over a range of discharges to determine a discharge – area relation that could be tied to the long-term discharge record at Waverly, Missouri (U.S. Geological Survey streamflow-gaging station 06895500, fig. 1). Water-surface elevations, bathymetric survey, and discharge surveys also were used to characterize habitats in the chute.

Few hydraulic measurements were completed in Cranberry Bend chute because of low water during the study. Discharge was measured on three dates (table 3).

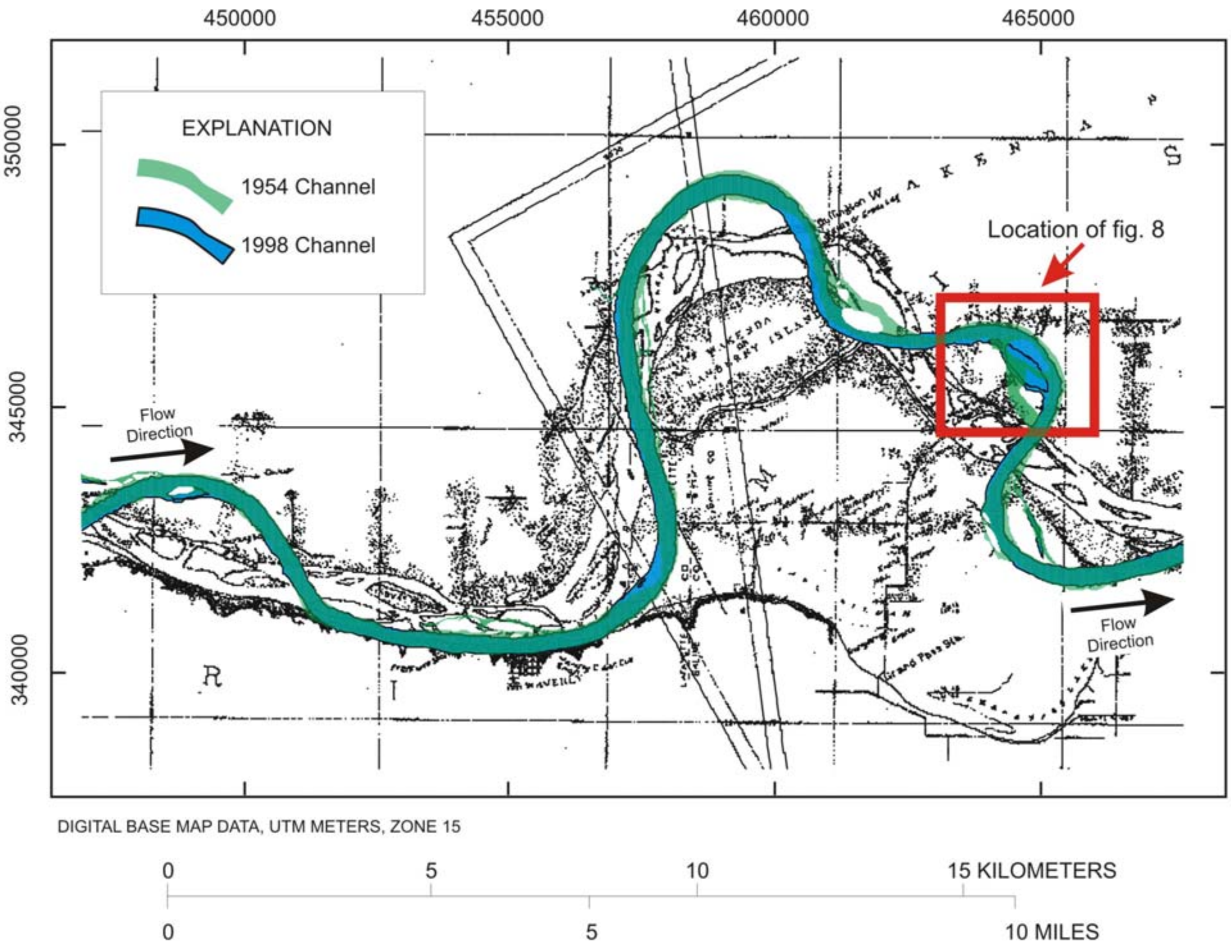


Figure 6. Location of the modern Missouri River channel (1998), and the Cranberry Bend side-channel chute, overlain on the river as it looked in 1879 (Missouri River Commission, 1893).

Table 3. Discharge data from Cranberry Chute.
[cfs, cubic feet per second]

Date	Discharge at Waverly, Missouri, cfs	Flow Exceedance, percent	Discharge in Cranberry Chute, cfs	Percent Flow in Chute
9/7/2001	39,700	76	2,600	6.5%
9/28/2001	55,900	46	3,700	6.6%
5/14/2002	92,500	13	12,000	13.0%

Most of the effort for understanding habitat dynamics in Cranberry Bend chute was focused on quantifying the relation between discharge and sandbar area for application to coordinated waterfowl/shorebird studies. The area of sandbars at Cranberry Bend was mapped five times at discharges (measured at Waverly, Missouri) ranging from 22,800 to 76,800 cfs (fig. 8). The relation between discharge and sandbar area is shown in fig. 9. At about 80,000 cfs nearly all sand bars are inundated at Cranberry Bend. Based on measured areas, the Cranberry Bend chute provides 13-43% of the total sandbar area in the river reach. The percentage increases with decreasing discharge (fig. 9).

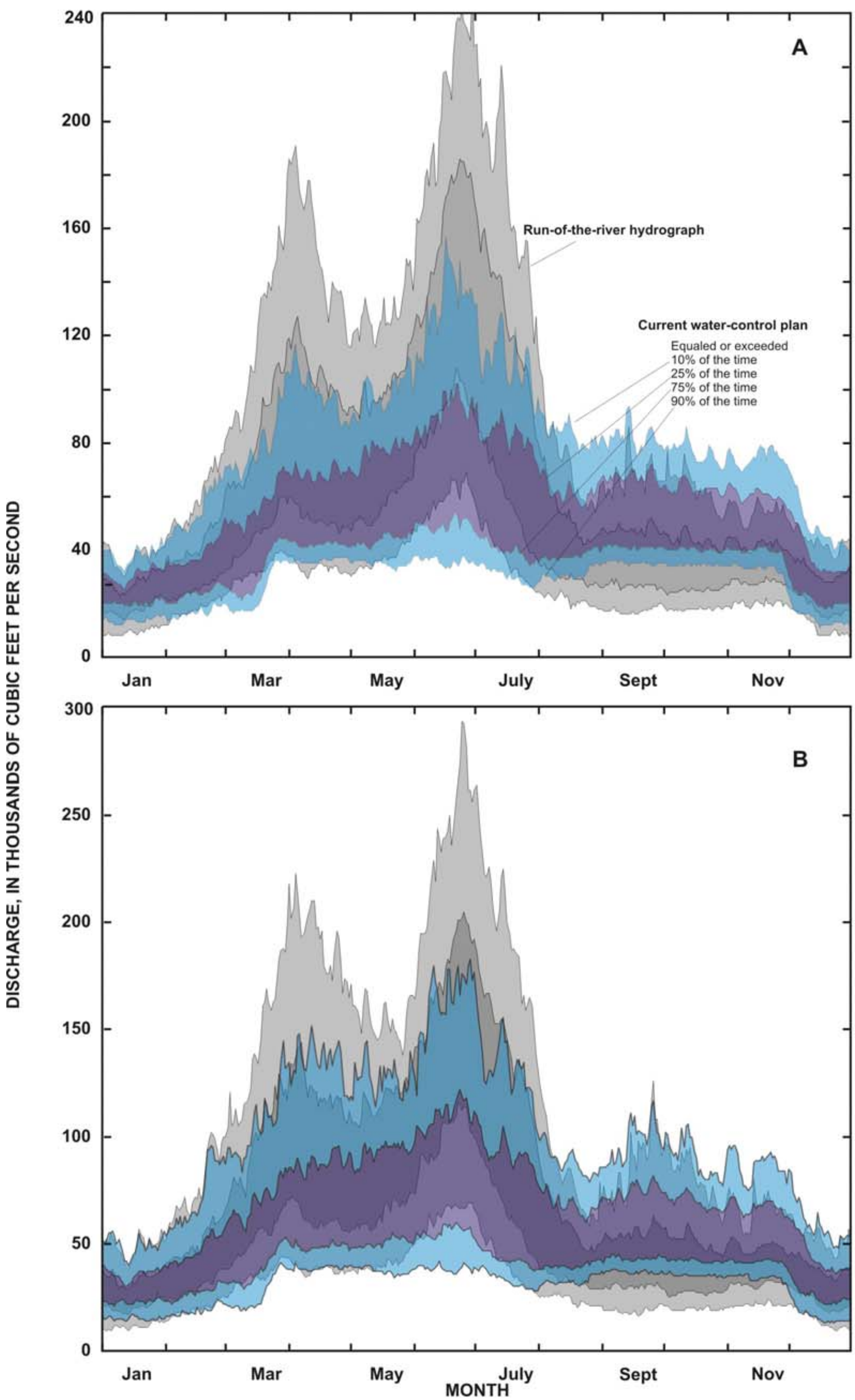
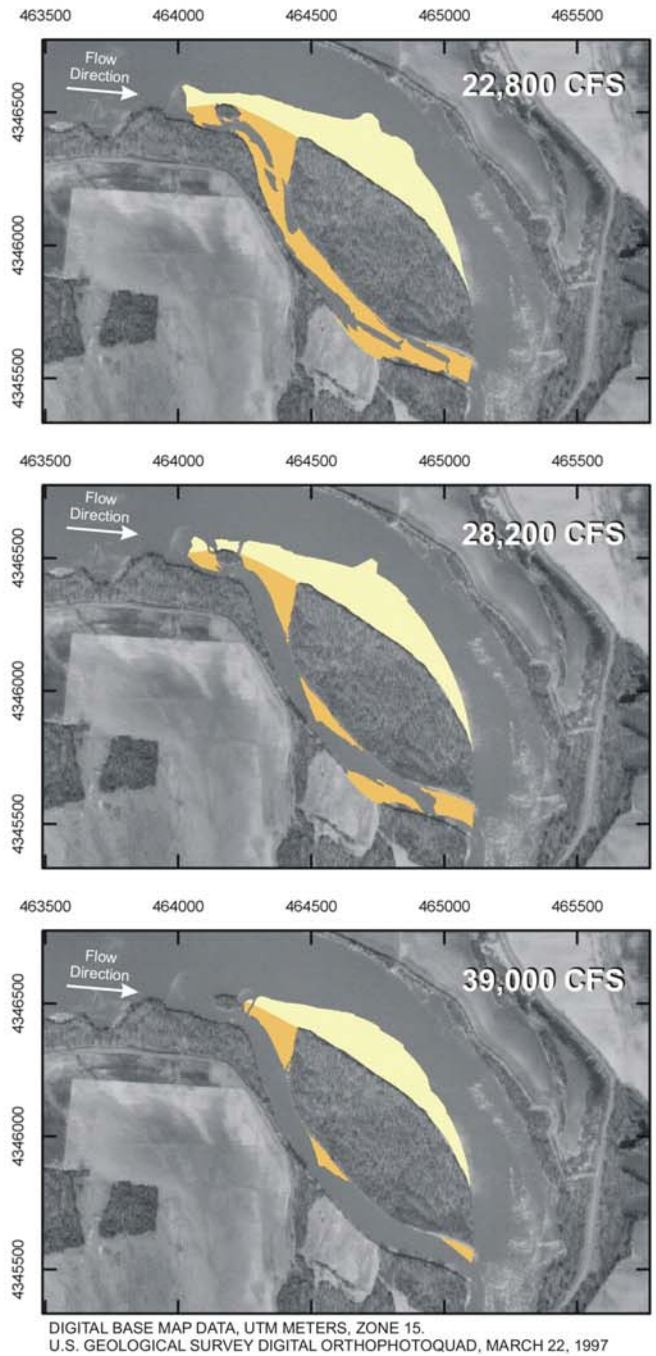


Figure 7. Duration hydrographs constructed using 100 years of simulated daily flows for the Missouri River at A. Kansas City, Missouri, and B. Boonville, Missouri. Gray shades depict the natural hydrograph estimated by a run-of-the-river model. Blue shades depict the regulated hydrograph simulated under the current water control plan (CWCP).



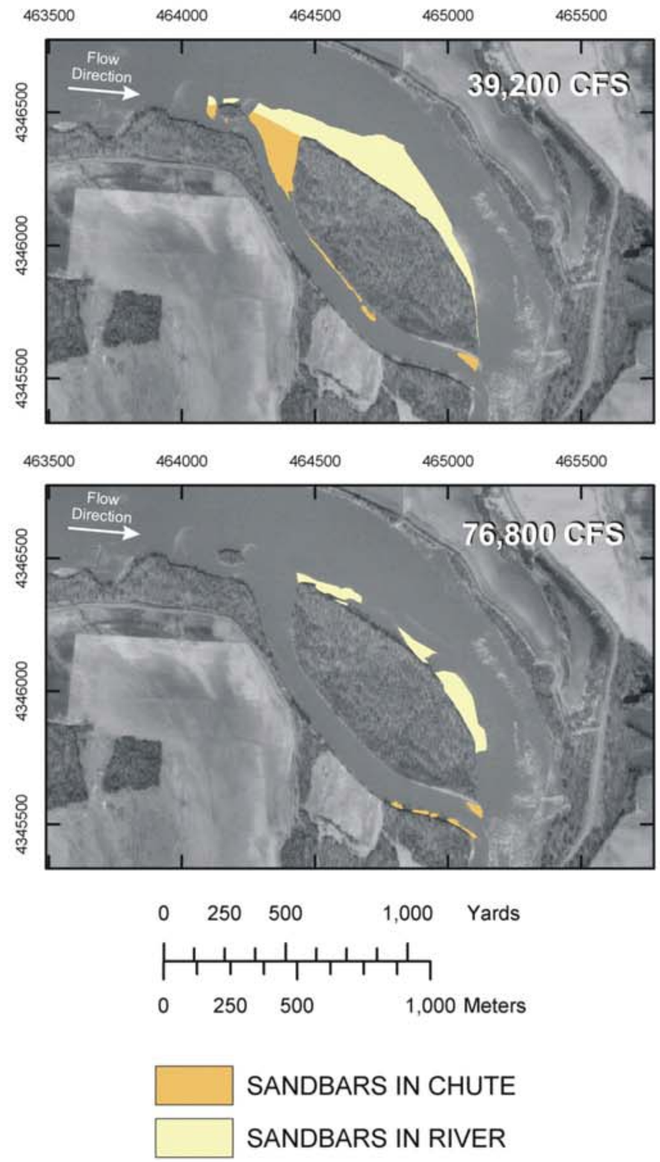
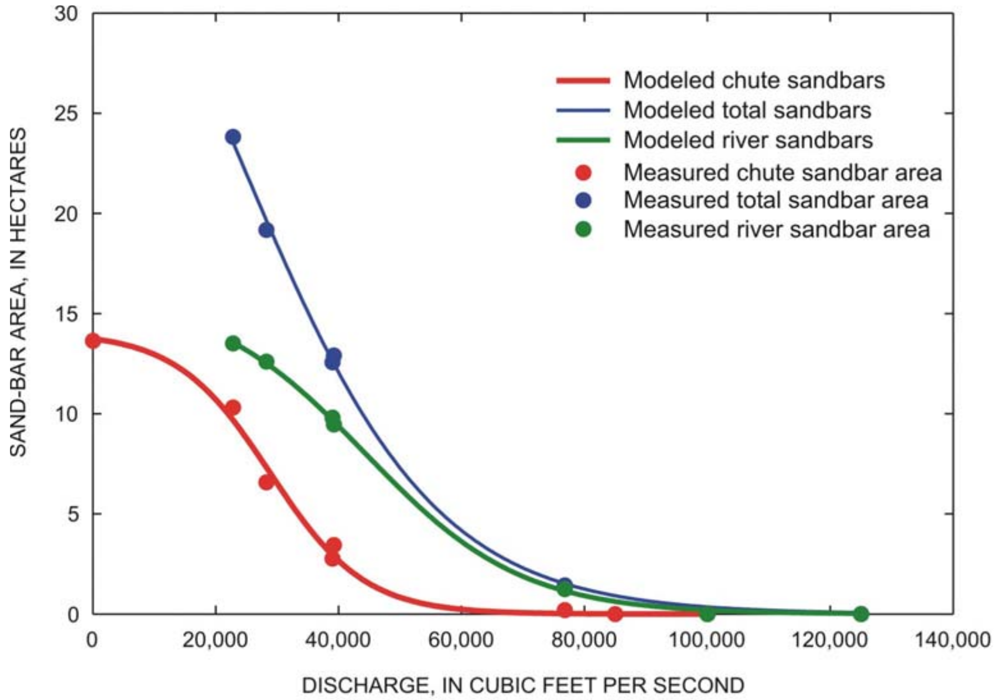


Figure 8. Maps of sandbar areas in the Cranberry Bend side-channel chute and in the adjacent navigation channel, for discharges 22,800 - 76,800 cubic feet per second. At 85,000 cfs there are no sandbars exposed in the chute and at 100,000 cfs there are no sandbars exposed in the navigation channel. CFS, cubic feet per second.



$$\text{Chute Sandbar Area} = \frac{14.1}{\left(1+e^{\left(-\frac{(Q_{wv}-28897)}{-7634.4}\right)}\right)},\ r^2 = 0.99$$

$$\text{River Sandbar Area} = \frac{16.0}{\left(1+e^{\left(-\frac{(Q_{wv}-44329)}{-12704}\right)}\right)},\ r^2 = 0.99$$

$$\text{Total Sandbar Area} = \frac{45.2}{\left(1+e^{\left(-\frac{(Q_{wv}-24159)}{-15681}\right)}\right)},\ r^2 = 0.99$$

Figure 9. Relations between sandbar area and discharge at Cranberry Bend. Separate curves and equations are given for sandbars in the chute, in the main river channel, and total. Sandbar area was fit to sigmoidal functions of discharge. Area is in hectares; Q_{wv}, discharge in cubic feet per second at Waverly, Missouri; e, base constant of natural logarithms; r^2, correlation coefficient.

By fitting the discharge – area relation for sandbar area in the chute to a sigmoidal model (fig. 9), the relation can be used for calculating sandbar availability for any day of the year and for any frequency of flow, assuming static channel morphology (fig.10). This analysis uses the historical, post-regulation record at Waverly, which may be biased toward high values compared to the U.S. Army Corps of Engineers daily routing model because it does not include drought years of the 1930's. The same analysis using pre-regulation historical data 1928 – 1954 is shown for reference. The difference in pre- and post-regulation sandbar durations is substantial. Sandbar area is very sensitive to discharges below about 50,000 cfs. Because regulation of the Lower Missouri River for navigation tends to maintain flows greater than 40,000 cfs in the summer and fall (figs. 7A, B), sandbar area is substantially less than under a natural flow regime.

A full bathymetric and velocity survey of the chute was completed on May 14, 2002 at a discharge of 95,000 cfs, or 13% flow exceedance. These conditions were favorable for boat access to all parts of the chute. Because this flow is relatively rare, the hydraulic conditions shouldn't be considered representative; nevertheless, histograms of depth and depth-averaged velocity are shown with a map of velocities in figure 11.

The bathymetric map (fig. 12) indicates the features that control the hydrology of the chute. Scour around the remnant wing dikes and island at the inlet maintain a channel that allows water to enter the chute over a broad range of discharges. The upstream 400 m of the chute is flanked by a large sandbar on the left, after which the chute narrows and shallows considerably. A scour maintains depth on the right bank at about 600 m downstream of the inlet. The thalweg again narrows and shallows to a minimum depth (nearly 0 at 95,000 cfs total discharge) about 1100 m downstream from the inlet. A short deep area at the downstream end provides a deep, slow area of off-channel habitat over a broad range of discharges.

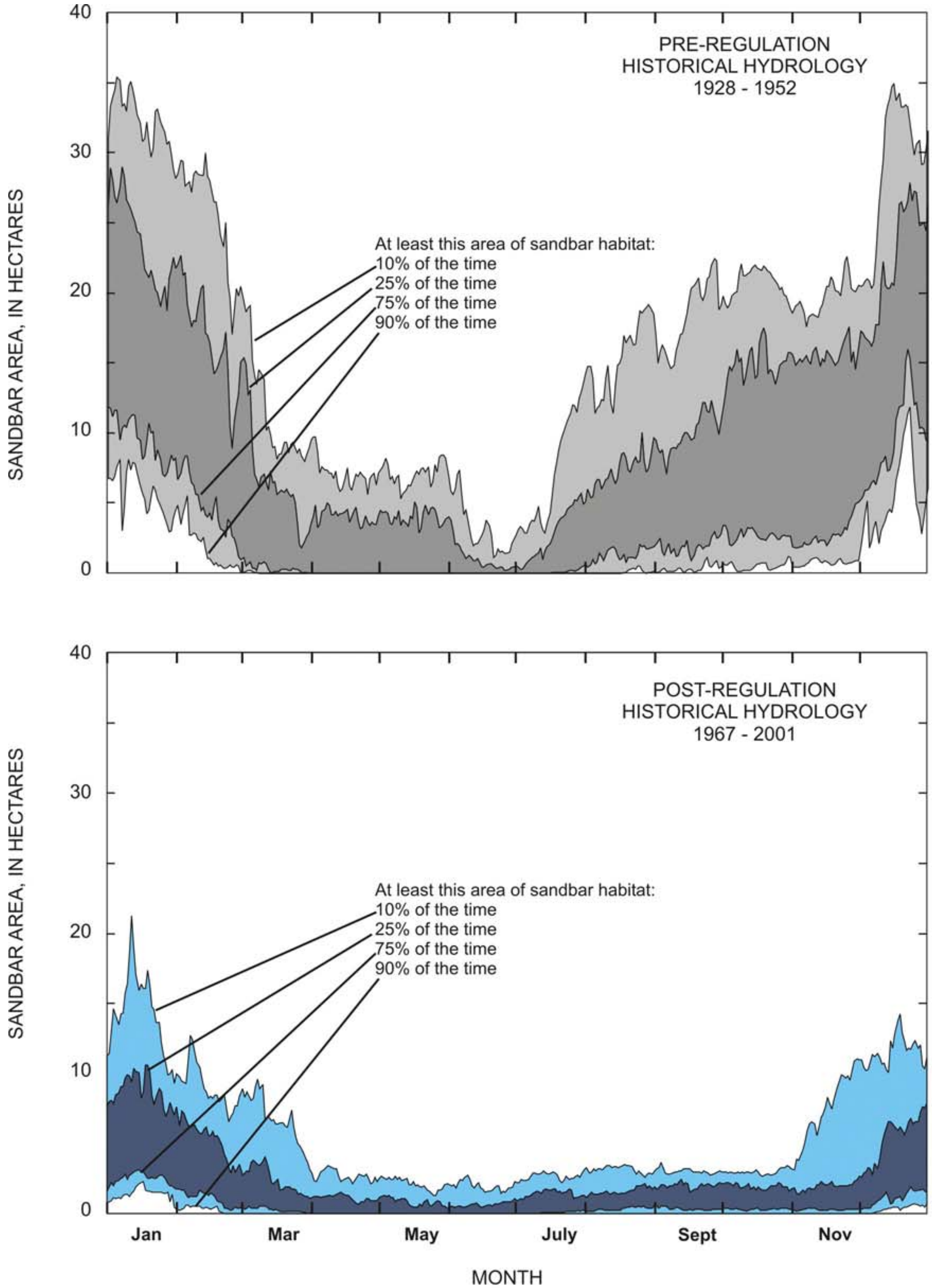


Figure 10. Sandbar area durations for the Cranberry Bend side-channel chute for historical pre- and post-regulation time periods. The graphs depict sandbar areas resulting from discharges that are equaled or exceeded 90, 70, 25, and 10% of the time for each day of the year.

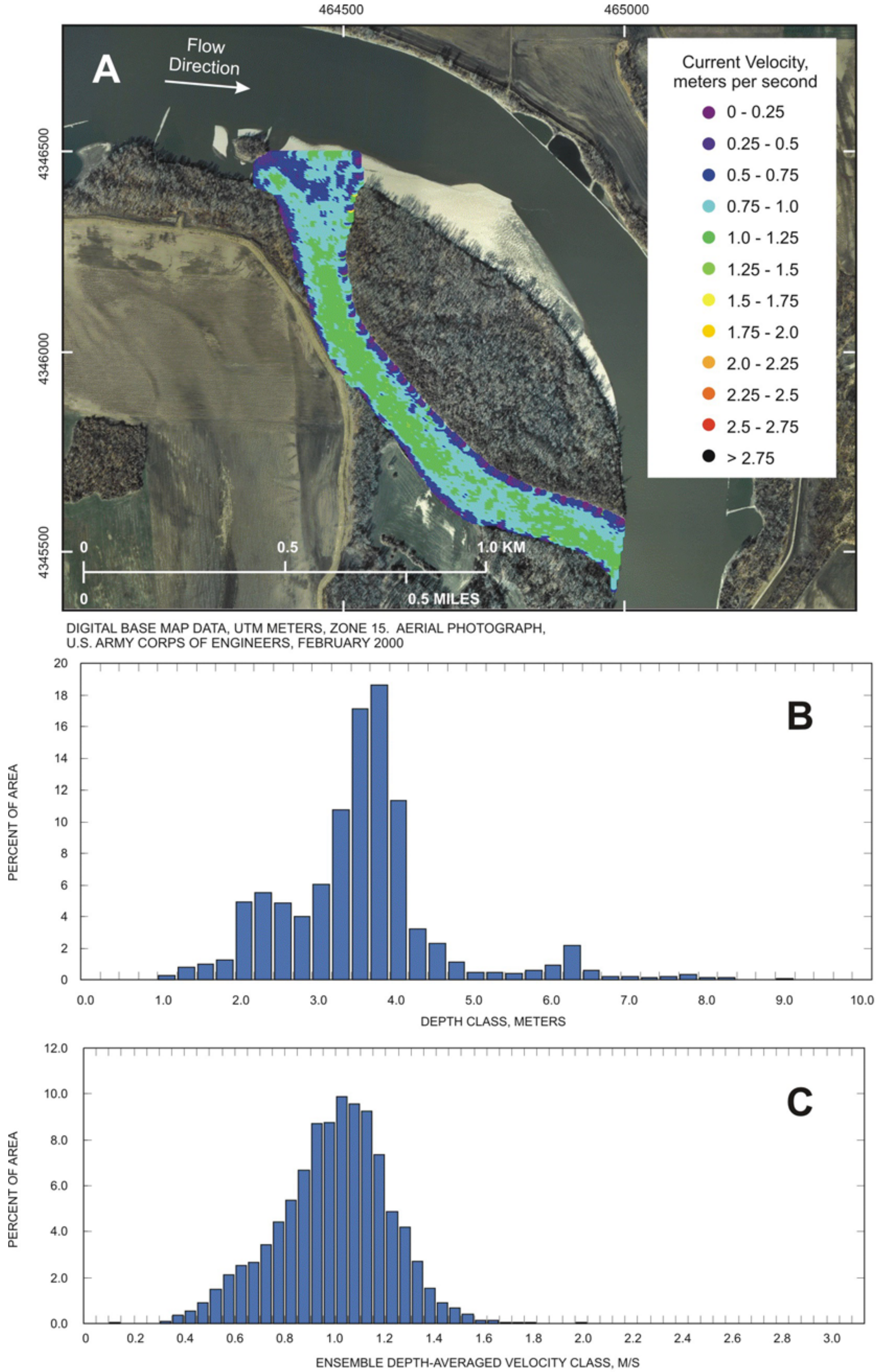


Figure11. Depth and velocity data from Cranberry Bend chute, measured May 14, 2002. The discharge in the main channel on this date was 95,000 cfs, and approximately 12,000 cfs was flowing through the chute. Aerial photo base is from February 27, 2000, discharge = 39,000 cfs. A. Map of depth-averaged velocity from acoustic Doppler profiler data. B. Histogram of depths in the chute. C. Histogram of velocities in the chute.

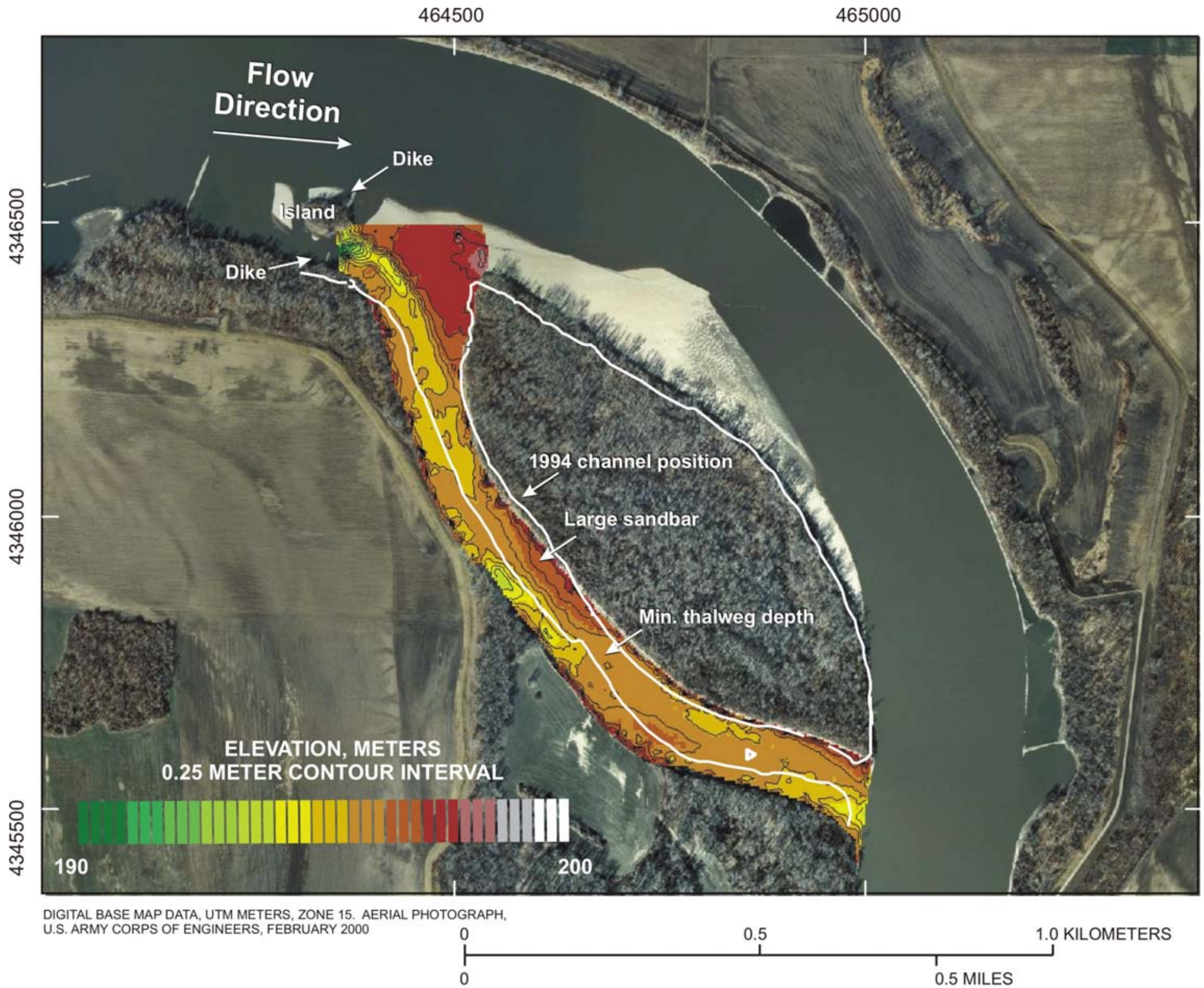


Figure 12. Map of Cranberry Bend side-channel chute showing bottom elevation contours and position of chute from 1994 navigation charts (white line, U.S. Army Corps of Engineers, 1994, unpublished digital data). Black contour lines have 0.2 m contour interval.

Lisbon Bottom Chute

Lisbon Bottom chute has received the most intensive data collection and analysis among the study sites. Hydrologic, geomorphic, and hydraulic data have all been collected and are presented here. The history of Lisbon Bottom chute is summarized in Jacobson and others (2001) and the hydrology of Lisbon Bottom is described in Jacobson and Kelly (2002).

Lisbon Bottom is in a narrow segment of the Missouri River where tight bends extend from bluff to bluff (fig. 13). Side-channel chutes occurred historically in this segment, presumably as a result of channel avulsion when bends were cutoff during floods.

The Lisbon Chute was formed as a result of levee breaks during the 1993 flood and subsequent high flows 1993-1996. During 1993-1999 there was minimal engineering influence on the chute, apart from repeated attempts to limit flow by repairing the revetment at the upstream end (fig. 14). During this time, as much as 20% of the total Missouri River flow was through the chute. In June 1999, in consultation with the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers installed a grade-control structure across the chute approximately 450 m upstream from the downstream end (fig. 14). The design for the grade-control structure called for rocks to be keyed into the banks and emplaced into a trench in the channel bed, so it would not affect flow or impede boat and fish passage (U.S. Army Corps of Engineers, 1998b). Beginning in autumn 1999 and extending through May 2000, a notched hydraulic control structure was constructed approximately 270 m downstream from the revetment at the upstream end of the chute (fig. 14). This structure and the revetment were designed with notches to allow flow through the structure 95% of the time, and to allow an increasing percentage of total flow with increasing discharge.

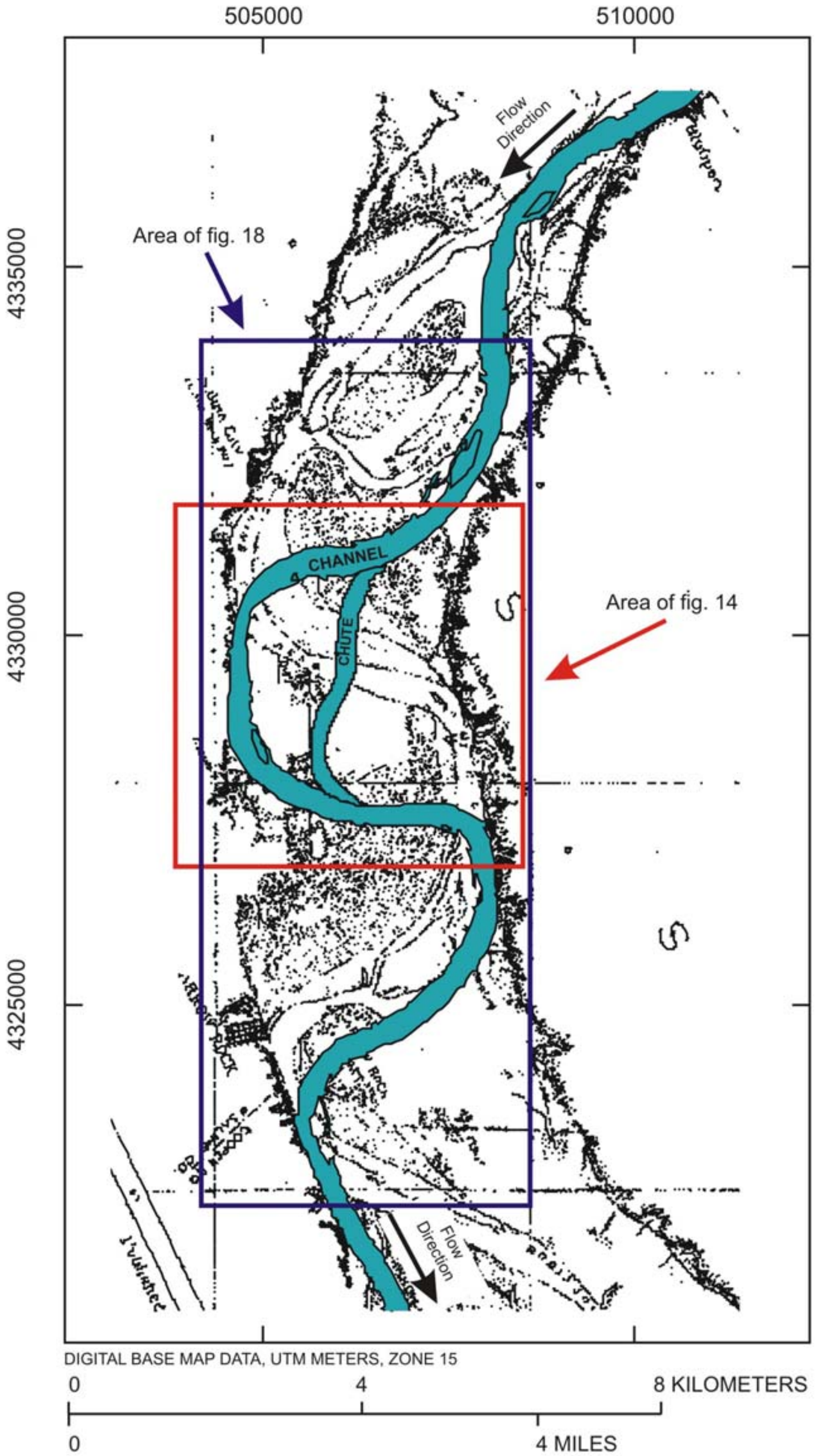


Figure 13. Location of the modern Missouri River channel (1998), and the Lisbon Bottom side-channel chute, overlain on the river as it looked in 1879 (Missouri River Commission, 1893).

The chute widened rapidly 1996 – 1997, followed by a smaller rate of change 1998 - 2002 and achievement of an apparent equilibrium width (fig. 15). During this time the chute developed a planform dominated by a braided channel appearance in the upstream one half and a meandering planform in the downstream one half.

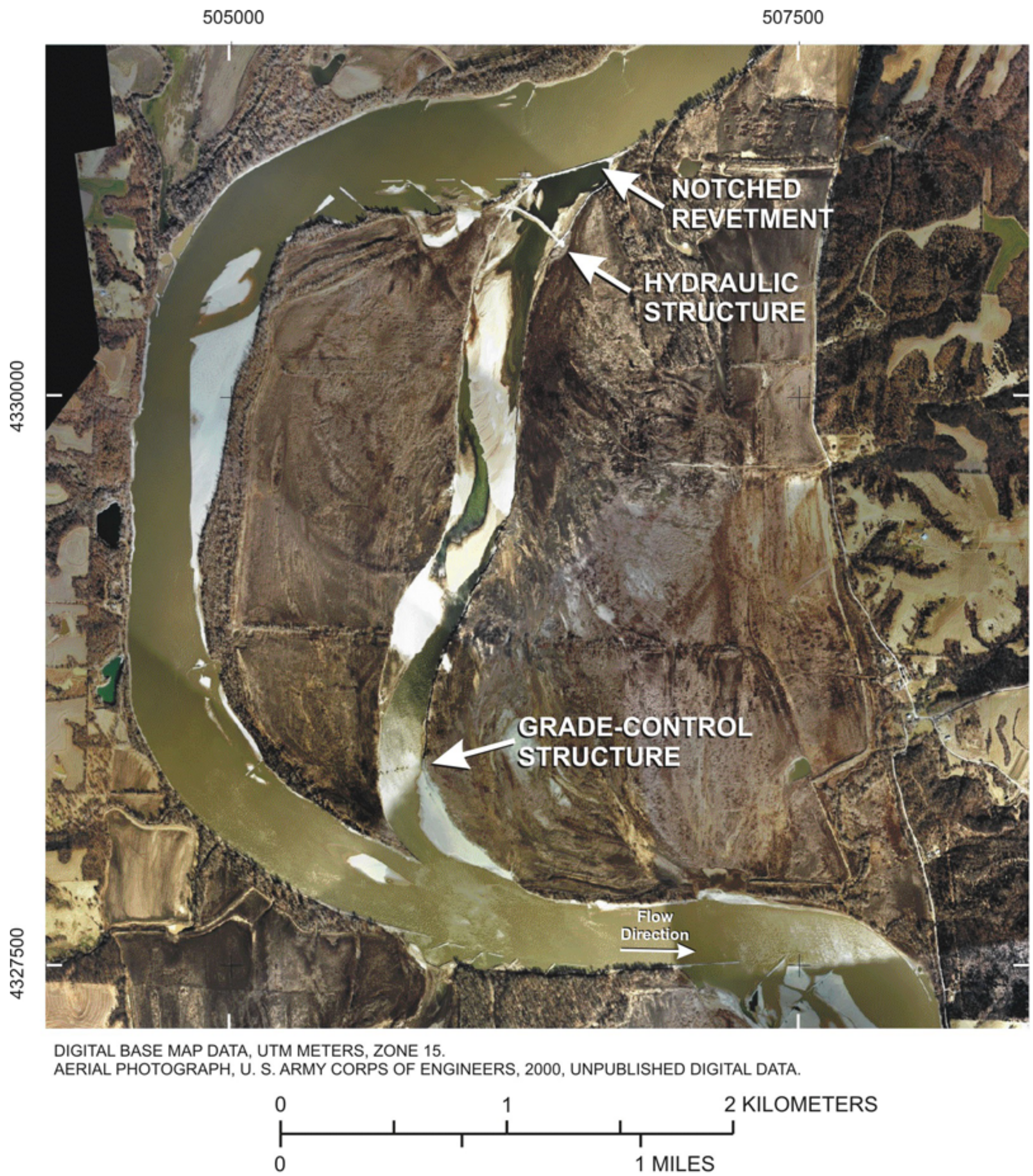


Figure 14. Aerial photograph of Lisbon Bottom side-channel chute, 2000, showing extensive sand bars in chute, and locations of the engineered structures.

The hydrology of Lisbon Bottom can be characterized by the hydrologic record measured 20 miles downstream at Boonville, Missouri. Between Lisbon and Boonville, the Missouri River receives flow from the Lamine River, but with a drainage area of 0.5% of that of the Missouri River, the influence on the hydrograph is usually negligible. Figure 7B shows U.S. Army Corps of Engineers daily routing model data for the current water control plan and the natural hydrograph simulation at Boonville. Compared to the natural hydrograph, the CWCP has less inter-annual variability but maintains the seasonal form of the natural hydrograph. The greatest departures from the natural hydrograph in the 10-90% exceedance range are in decreased magnitude of the March-July flood peaks and increased flows during the August-November low-flow period.

The hydrology of the chute is controlled by the hydrology of the main channel and the elevations and geometries of the upstream and downstream entrances. The notches in the upstream revetment and control structure were surveyed at 178.87 m on December 10, 2002; evidence of erosion in these notches indicates that these elevations have probably not been static since construction in 2002. Zero flow into the chute from upstream was independently determined by a survey when the elevation of water in the main channel was 179.24 m (24,600 cfs at the Boonville gage, U.S. Geological streamflow-gaging station 06909000); at this water-surface elevation there was a very slight flow of water from the chute back into the main channel. The elevation of the downstream entrance to the chute (outlet, in the center of the thalweg as of April 2002) was determined from bathymetric survey to be about 177.2 m .

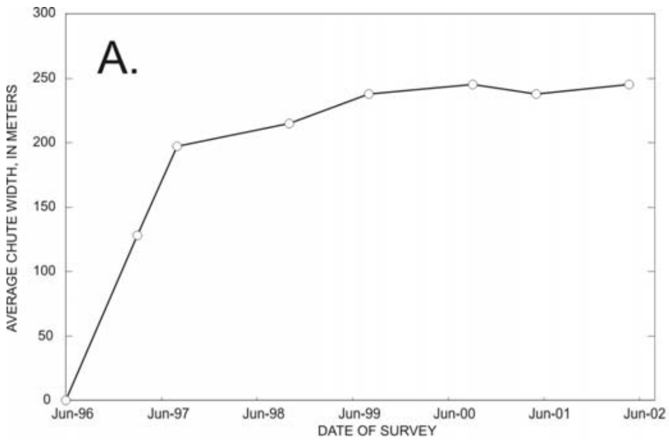


Figure 15. A. Graph of average width of the Lisbon Bottom side-channel chute, 1996-2002. B. Oblique aerial photograph of the chute in 1999 showing widened, braided portion in the upper one half.

The hydrology can be characterized by the frequency with which flow enters the chute. Stage-discharge relations for the upstream and downstream ends of the chute are shown in figure 16. By characterizing the flow frequency as the percent of time the flow is equaled or exceeded at Boonville, the frequency with which water flows into the inlet and outlet can be calculated (fig. 17). Zero flow into the chute at about 24,600 cfs is equaled or exceeded about 97% of the time. Based on the water-surface elevation at the downstream end of the chute, a surface-water connection (whether or not there is any flux of water) is estimated to occur down to a discharge of about 18,000 cfs, effectively 100% exceedance. The stage-discharge relation at the downstream end of the chute is based on fewer measured points and requires an extrapolation to the limiting elevation.

Discharge measurements in the chute, since closure of the upstream structures in spring 2000, show an increase in the percentage of flow in the chute as discharge increases in the main channel (fig. 18). The discharge – percent flow relation can be modeled and used to evaluate how alternative hydrologic scenarios would affect flow in the chute. For the purposes of this report, we compare the present-day hydrology (represented by the current water control plan, CWCP), the natural hydrograph (represented by the run-of-the-river model, ROR), and an environmental alternative management scenario that incorporates a 20,000 cfs spring rise and a 21,000 cfs low-flow from Gavins Point Dam (GP2021). The comparison between the CWCP and the GP2021 scenario is intended to illustrate the sensitivity of discharge in the chute to an environmental flow alternative that was being discussed by Missouri River management agencies 2000 – 2002 (U.S. Fish and Wildlife Service, 2000). The CWCP and GP2021 have very similar effects on discharge in the chute: the CWCP has somewhat lower peak percentages in the early spring, and higher percentages in mid-July to August (fig. 19). Flows under the GP2021 scenario are somewhat larger in the late fall and provide more water in the chute because of the need to evacuate greater volumes from the reservoirs in many years.

Depths and velocities were measured in the chute (25 transects) and the adjacent navigation channel (22 transects) at 112,000 cfs (December 1997) and 68,800 cfs (May 1998). The distributions of depths and velocities, calculated as percent of total area (navigation channel plus chute), show how much habitat is provided by the chute compared to the navigation channel (fig. 20). Similar to the situation in the

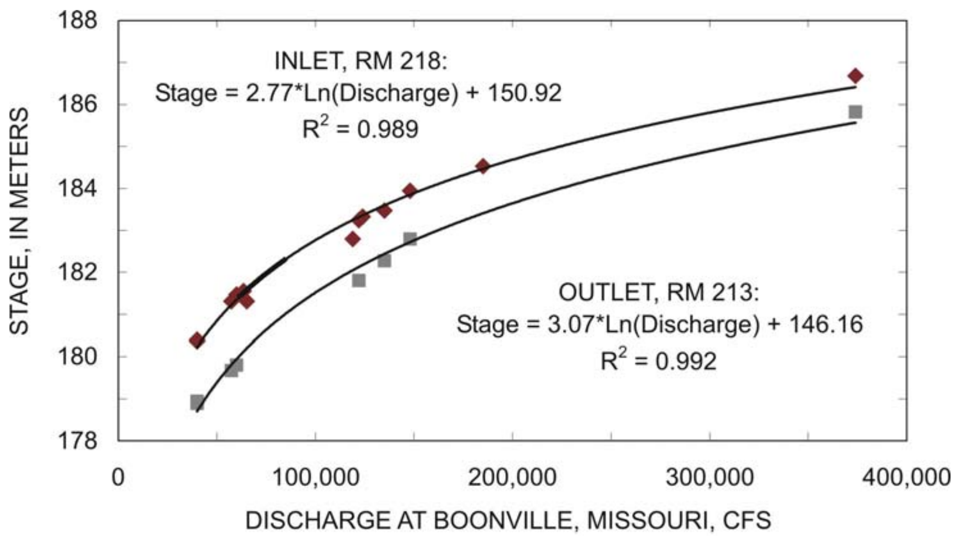


Figure 16. Stage-discharge relations at upstream inlet and downstream outlet of the Lisbon Bottom side-channel chute. Units in equations: stage in meters, discharge in cubic feet per second. RM, river mile.

Hamburg Bend side-channel chute, the navigation channel has a wide range of depth and velocity and virtually all of the variability in the chute fits within the variability of the navigation channel at both discharges. High variation within the navigation channel results from large areas of slow, shallow habitat, mainly in wing-dike fields. Hence, the chute does not contribute *unique* habitat (measured as depth and velocity) but it does contribute a substantial quantity of slow, shallow habitat. The contribution of the chute to slow, shallow habitat is greater at lower discharges.

Additional aspects of habitat availability in the Lisbon Chute and adjacent channel were explored using a 1-dimensional hydraulic model for the reach of the river RM 209 – 220 (fig. 21). The model was developed in HEC-RAS (U.S. Army Corps of Engineers, 2002), using the Arcview® GeoRas extension. Input topographic data came from three sources.

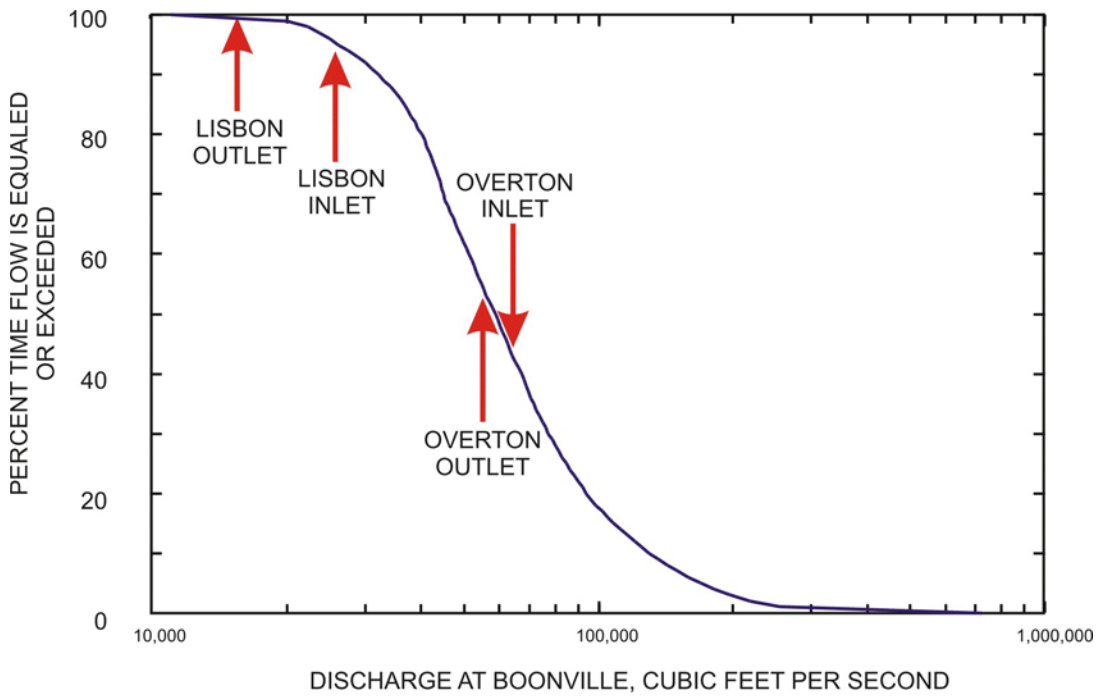


Figure 17. Flow duration of the Missouri River at Boonville and discharges at which flow enters the inlet and outlet of the Lisbon Bottom and Overton Bottoms side-channel chutes.

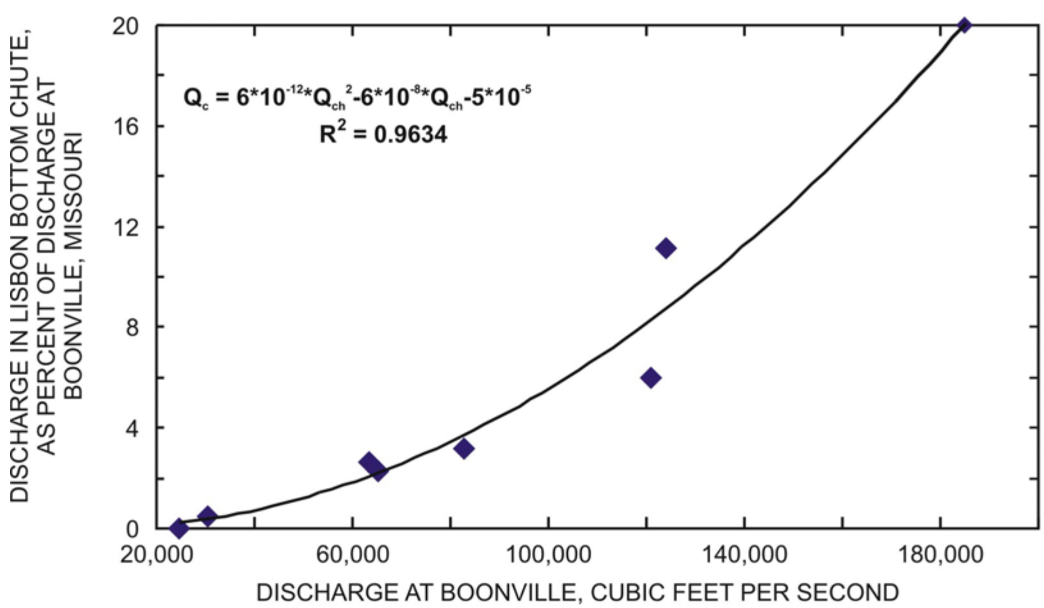


Figure 18. Percent flow in Lisbon Bottom side-channel chute compared to discharge in main channel as measured at Boonville, Missouri. Q_c, discharge in chute; Q_{ch}, discharge in main channel at Boonville, Missouri.

1. The flood-plain topography was a 5-m-cell digital elevation model developed by the U.S. Geological Survey after the 1993 flood.
2. The main-channel topography was a 5-m-cell digital elevation model gridded from 1999 bathymetric survey data collected by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1999a).
3. Lisbon chute topography was gridded from a U.S. Geological Survey high-resolution bathymetric survey in May 2001.

The three gridded datasets were merged together in the order given above to sequentially replace older data with new data where they overlapped. The resulting topographic dataset (digital elevation model, DEM) was used to create channel cross sections for input to HEC-RAS hydraulic modeling software. Forty-five cross sections were defined in the main channel and 16 in the chute; the average spacing was approximately 350 m. Flood-plain hydraulic roughness was estimated using unpublished maps of landcover from 1996 (Raymond Arvidson, Washington University of St. Louis, personal communication, 2001). The model was calibrated under existing conditions by varying roughness values, using independently developed stage-discharge relations (24,000 – 374,000 cfs) surveyed at RM 218 (Lisbon Chute inlet) and at RM 213 (main channel).

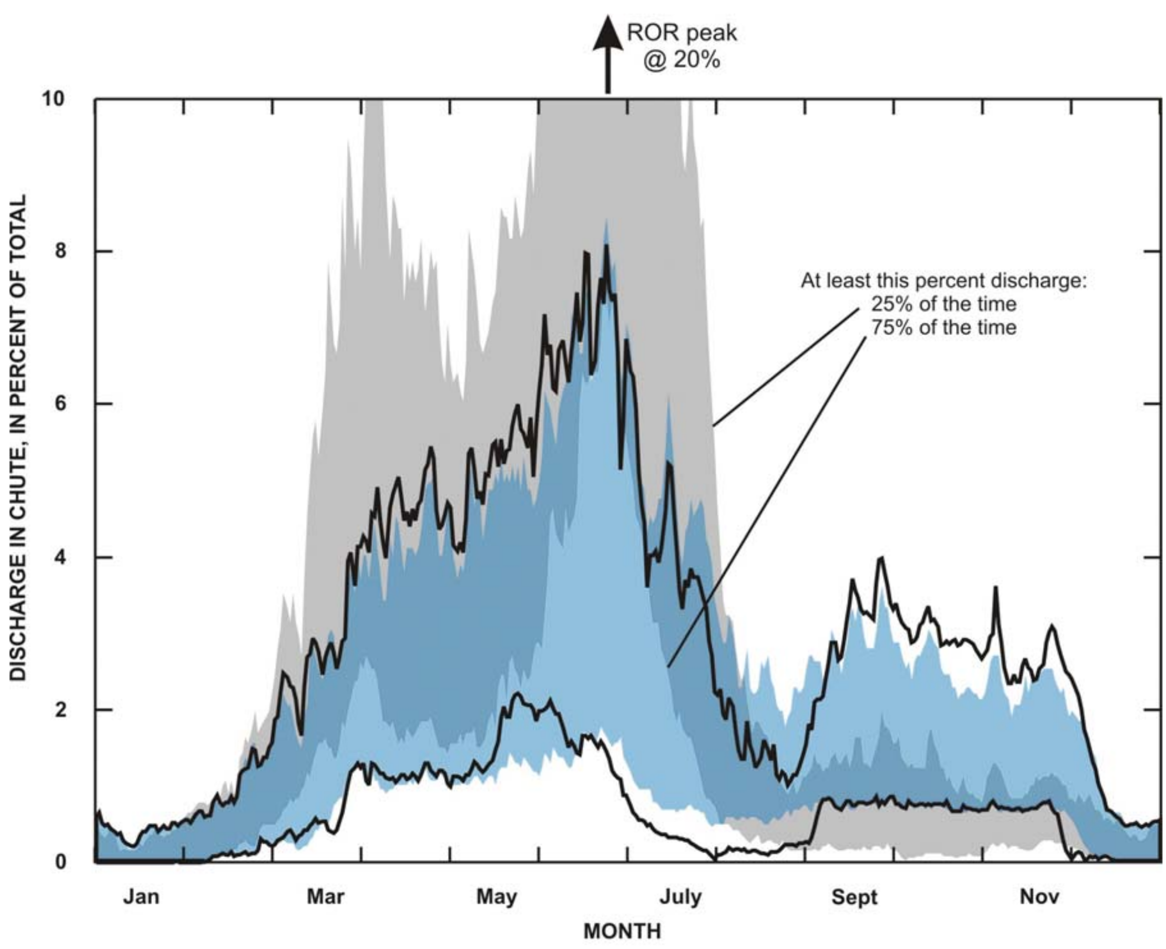


Figure 19. Duration hydrographs for percentage flow in the Lisbon Bottom side-channel chute. The gray shaded background is the 25-75% exceedance flows for the natural (ROR) hydrograph; the dark black lines depict the 25-75% exceedances of the GP2021 alternative, and the blue shaded areas depict the 25-75% exceedances of the current water control plan.

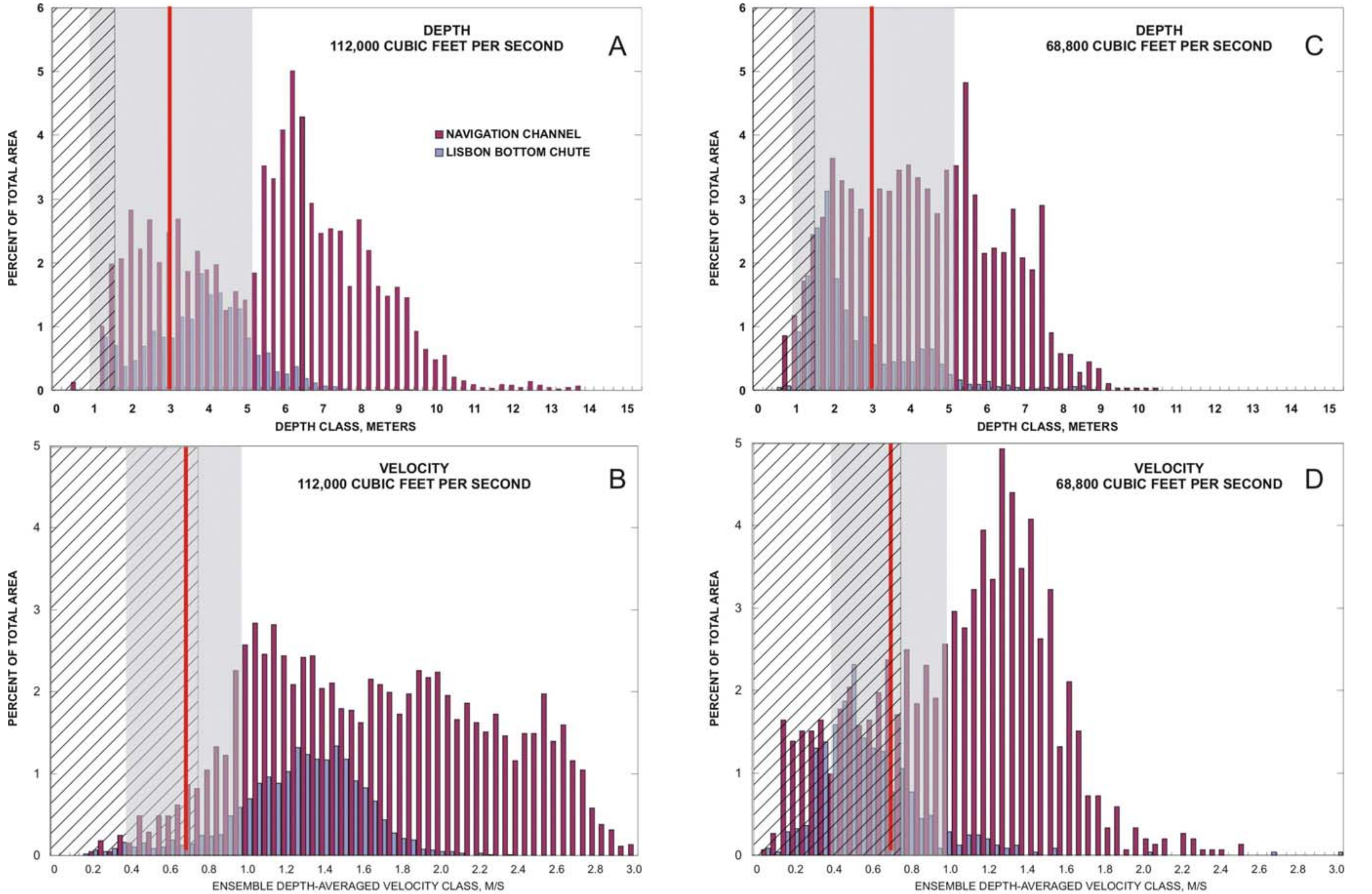


Figure 20. Distributions of depth and velocities at Lisbon Bottom side-channel chute, and adjacent navigation channel. Sample size ranges 463-3,662 measurements in velocity data and 4,101-14,251 measurements in depth data. The red line is the mean habitat selected by pallid sturgeon and the gray area shows plus/minus one standard deviation (from Bramblett and White, 2001). The cross-hatched area depicts the shallow-water habitat class defined by the Fish and Wildlife Service (U. S. Fish and Wildlife Service, 2000). A. Depth distributions at 112,000 cfs. B. Velocity distributions at 112,000 cfs. C. Depth distributions at 68,800 cfs. D. Velocity distributions at 68,800 cfs.

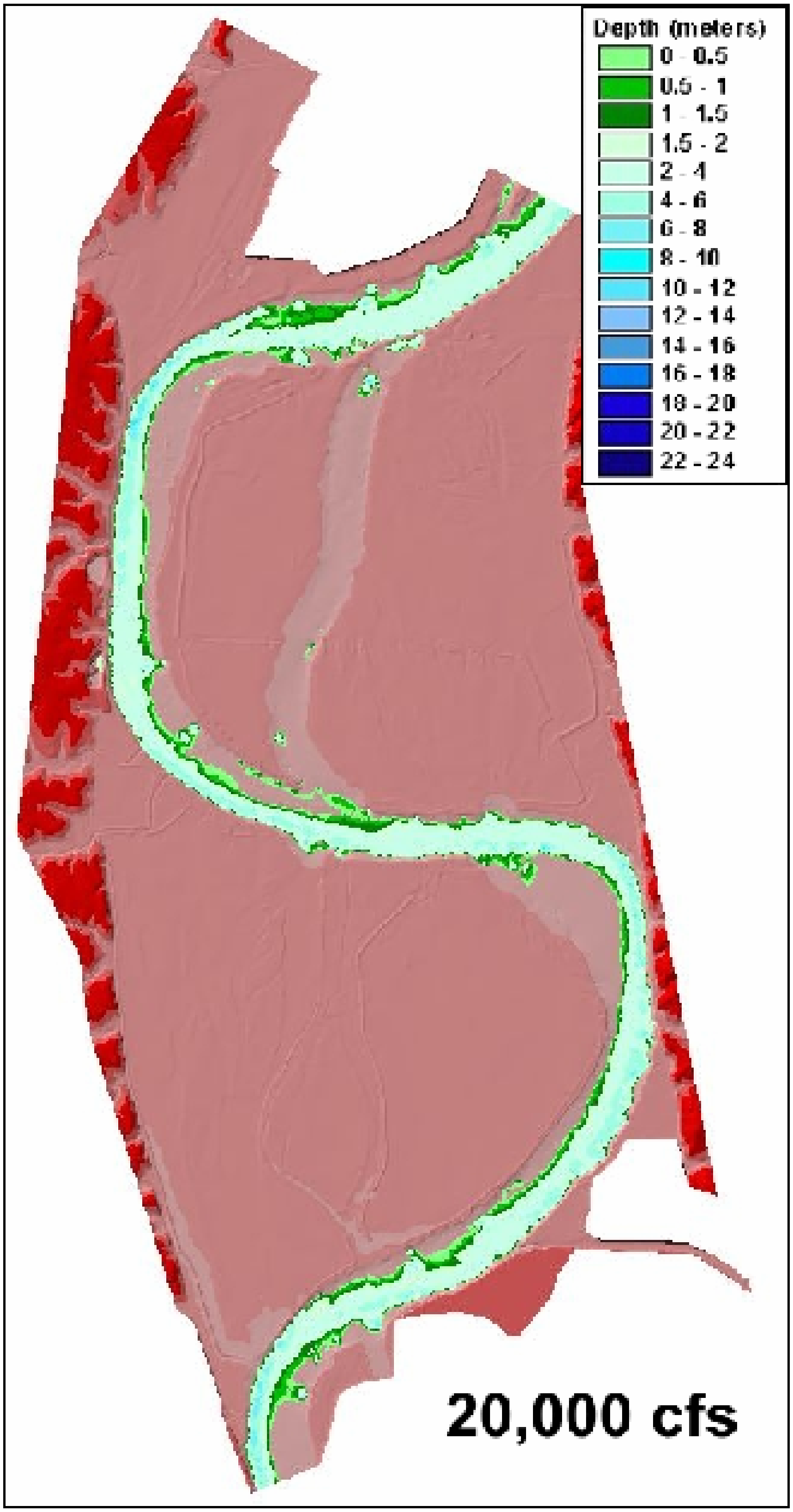


Figure 21. Animation of flooding 20,000 – 450,000 cubic feet per second in Lisbon-Jameson reach. Inundation is calculated from a 1-dimensional hydraulic model. Depths are color coded to indicate shallow-water habitat

Habitat availability in the Lisbon Chute and adjacent channel was evaluated as the area of shallow-water predicted by the 1-dimensional model. The amount of shallow water was calculated by intersecting the water surfaces generated by the model for each discharge with the DEM.

The Missouri River Biological Opinion (U.S. Fish and Wildlife Service, 2000) identified water less than 5 feet (1.5 m) deep and less than 2 feet/sec (0.75 m/s) current velocity as an important habitat for rearing of juvenile fishes. The results of the 1-dimensional model can be analyzed to determine areas of depths corresponding to SWH, although the model does not give accurate representation of velocities and so cannot be used to evaluate the velocity component of SWH.

Modeled SWH within the chute increases with increasing discharge 20,000 – 70.000 cfs, and then declines 70,000 – 100,000 cfs (fig. 22A). From 100,000 to 240,000 cfs, modeled SWH increases as flood-plain surfaces adjacent to the chute are inundated; the magnitude of the chute contribution to SWH at these discharges is in part a function of the arbitrary delineation of area accounted to the chute. Discharges of 240,000 – 260,000 generally overflow the entire Lisbon Bottom and are considered equivalent to bankfull discharge (Jacobson and Kelly, 2002). At discharges greater than about 260,000 cfs, the area of SWH in and adjacent to the chute decreases.

River discharge management issues typically address low flows that are considerably less than bankfull. At modeled discharges 20,000 – 140,000 cfs, well within the chute banks, the chute contributes substantial areas to the total SWH in the modeled reach (fig. 22B). While flows 20,000 – 50,000 cfs provide SWH area outside the chute as patches marginal to the main channel, the chute doubles available SWH near 70,000 cfs, and provides substantial additional SWH 50,000 – 140,000 cfs when the main channel contribution diminishes. The chute therefore increases the range of discharges that provides SWH in this reach.

Distribution of SWH during the year varies with hydrograph characteristics and whether the entire modeled reach or just the chute is considered (fig. 23). For the entire area (fig. 23A), all the regulated discharge scenarios provide more SWH (measured as median daily area from 100 years of modeled discharges) than the natural hydrograph (ROR) March – mid June. The spike of SWH contributed by the ROR scenario in June is inundated area outside the chute as flows go overbank. For the area within the chute, the natural hydrograph (ROR) provides about one third of the SWH area provided by regulated hydrographs in June because the natural spring rise would tend to deepen the chute greater than 1.5 m. Flow-modification scenarios have been proposed to increase SWH during late summer by decreasing discharge in late July and August (GP1528, GP2021, fig. 23B). Because flow scenarios with low July-August discharges would tend to produce July-August flows less than 70,000 cfs (peak of the chute SWH habitat availability curve), these scenarios would provide less SWH in the chute than the CWCP (fig. 23B). The CWCP hydrograph provides the most SWH in the chute in late July because the median flow is approximately 70,000 cfs, and attains the maximum of the SWH – discharge relation (fig. 22). However, because the main channel adds in SWH at lower flow (with a peak about 40,000 cfs), SWH availability in the chute and the main channel are compensatory, resulting in little overall variation in SWH availability among engineered flow alternatives in the Lisbon Bottom reach (fig 23A).

Exposed, unvegetated sandbars also are considered valuable physical habitat in the Lower Missouri River, primarily for shorebirds and turtles. Sandbar-area also can be calculated from the 1-dimensional model by subtracting wetted area from the total area between the high banks. Unlike SWH, sandbars decrease monotonically in area with increasing discharge (fig. 24). The Lisbon Bottom side-channel chute provides 31 – 47% of the total sandbar area at discharges 20,000 – 90,000 cfs, indicating that the chute increases the persistence of sandbars over a wider range of discharges compared to the river without the chute.

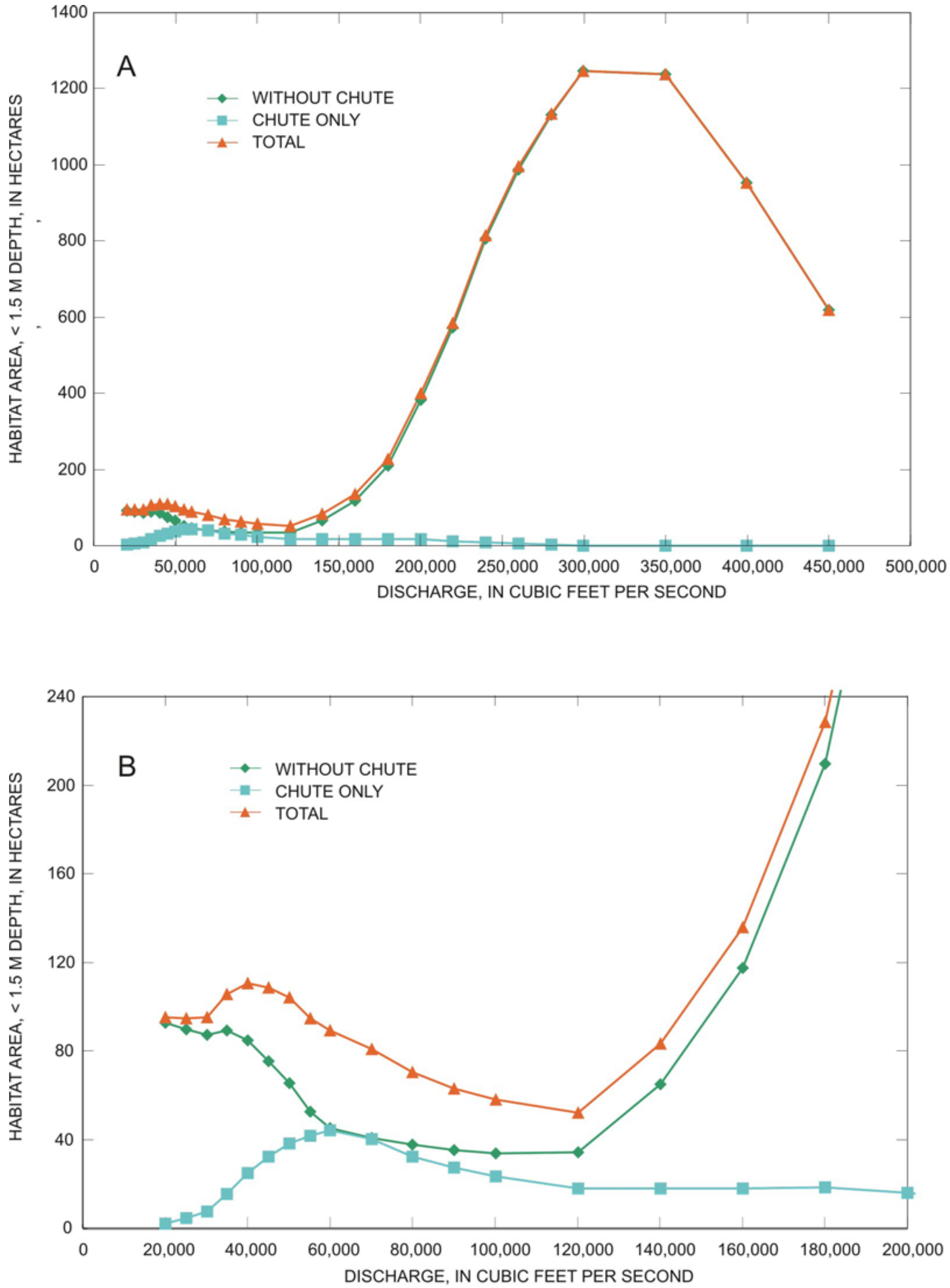


Figure 22. Shallow-water habitat availability and discharge, Lisbon Bottom side-channel chute and adjacent area, estimated using 1-dimensional hydraulic model. A. All discharges, 20,000 - 450,000 cfs. B. Detailed view of discharges 20,000 - 200,000 cfs showing shallow-water habitat added within banks of the chute.

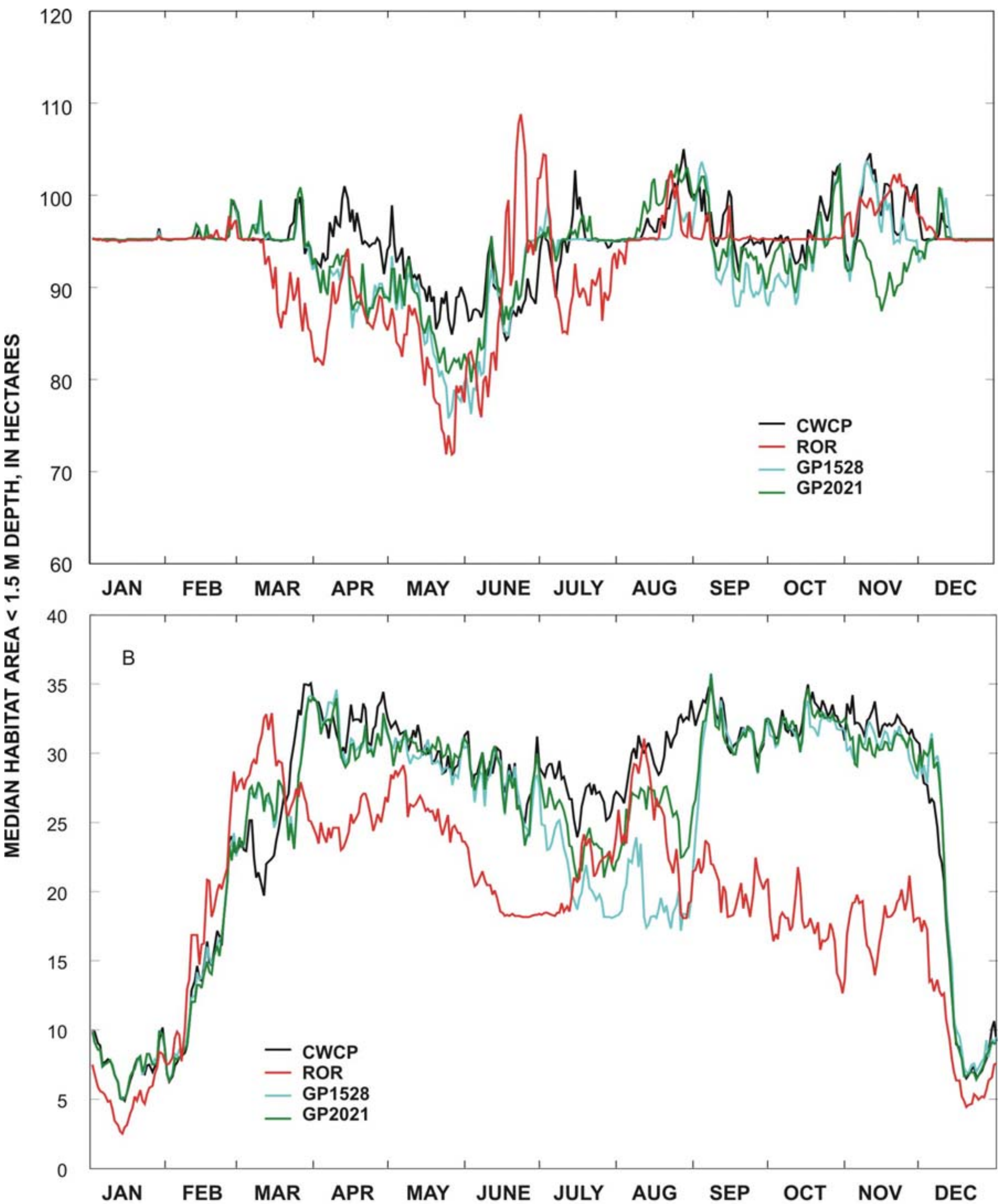


Figure 23. Shallow-water habitat (SWH, < 1.5 m deep) availability at Lisbon Bottom side-channel chute by time of year and by discharge scenario. Areas were calculated using a 1-dimensional hydraulic model for the Lisbon - Jameson Island reach. A. Median of 100 years of daily SWH availability for entire modeled area. B. Median of 100 years of daily SWH availability within the banks of the chute. CWCP, current water-control plan; ROR, run of the river model; GP1528, flow scenario with 15,000 cfs spring rise and 28,000 cfs summer low flow; GP2021, flow scenario with 20,000 cfs spring rise and 21,000 cfs summer low flow.

Median sandbar area in the chute and in total for Lisbon Bottom and adjacent areas is shown by day of the year and by flow scenario in figure 25. The median area is calculated from 100 years of daily modeled flow values and the sandbar-area relations shown in figure 24. The chute and total sandbar area graphs have the same general shape: decreasing sandbar area March-June, and increasing sandbar area June – December. The ROR hydrograph would produce substantially less sandbar area in March-July because high flows would inundate all bars. The managed flow scenarios produce more sandbar area during this time. The ROR scenario produces greater sandbar area August – January because low flows would uncover large areas of bars. The managed flows have substantially less sandbar area August – November because of higher discharges maintained for navigation. The exception is the GP2021 scenario, which attains sandbar areas comparable to the ROR flow in July – August during a managed low-flow period.

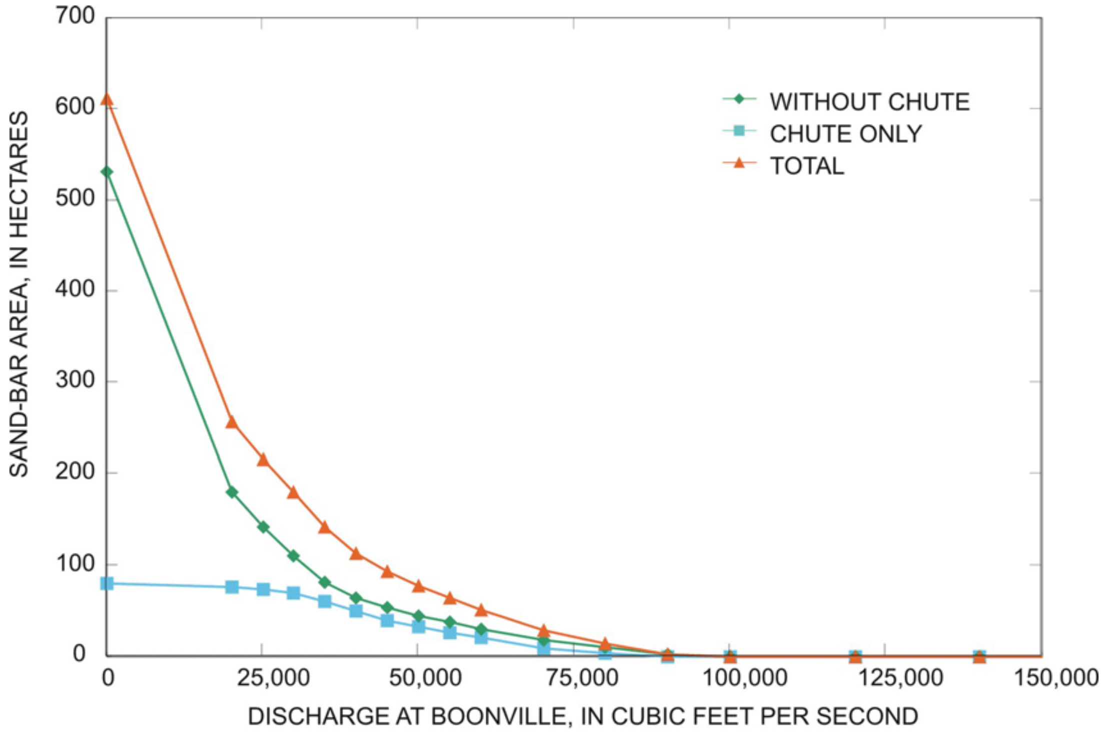


Figure 24. Sand-bar area and discharge, Lisbon Bottom side-channel chute and adjacent area. Calculated from 1-dimensional hydraulic model of the Lisbon-Jameson reach.

In addition to hydrologic variation of habitat availability, geomorphic characteristics of the Lisbon Bottom side-channel chute have evolved since 1996, changing channel geometry and how habitats are expressed for a given discharge in the chute. Early evolution of the chute is documented in Jacobson and others (2001). The most dramatic change measured during 1996 – 2003 has been widening of the chute, followed by a period of little change in width (fig. 15). Even after the chute appeared to have reached an equilibrium, the channel continued to erode its banks and migrate laterally (Jacobson and others, 2001).

Three bathymetric resurveys provide information for assessing whether the bed of the chute is continuing to change through erosion or deposition (fig. 26). Surveys in June 2000, May 2001, and April 2002 were gridded to develop continuous surfaces of elevation. Changes in elevation were assessed by subtracting grids. The elevation maps document persistence of the main features of the Lisbon Bottom side-channel chute: the shallow, braided nature of the upstream one half, and the meandering, well-developed thalweg of the lower one half. Change maps document deepening of the large scour just downstream of the inlet structure by as much as 9 m, during 2000 – 2001. In this same time period, there was moderate (one meter or less) aggradation of the central sandbar. The greatest aggradation during 2000 – 2001 occurred in the thalweg in the downstream one third where net deposition was as much as 3 m. (fig. 26D). The April 2002 bathymetric survey was incomplete because of low water, but for the parts that were coincident with the May 2001 survey, some trends were evident. The scour hole just downstream of the inlet structure aggraded by as much as 1-3 m during 2001 – 2002. Also, the surveyed portion of the central upstream bar showed no appreciable change; and some small areas of moderate deepening (-1 to –2 m) were evident (fig. 26E).

Geomorphic changes to the Lisbon Bottom side-channel chute during 2000 – 2002 were dominated by changes in bed elevations, with minor, ongoing lateral erosion of banks. While width trends support the concept that the chute is approaching or has attained a dynamic equilibrium, the three annual surveys of bed elevations document measurable aggradation. It is not clear from this short record whether aggradation is a persistent phenomenon or if it might be reversed over time as the chute adjusts to a more representative series of flows.

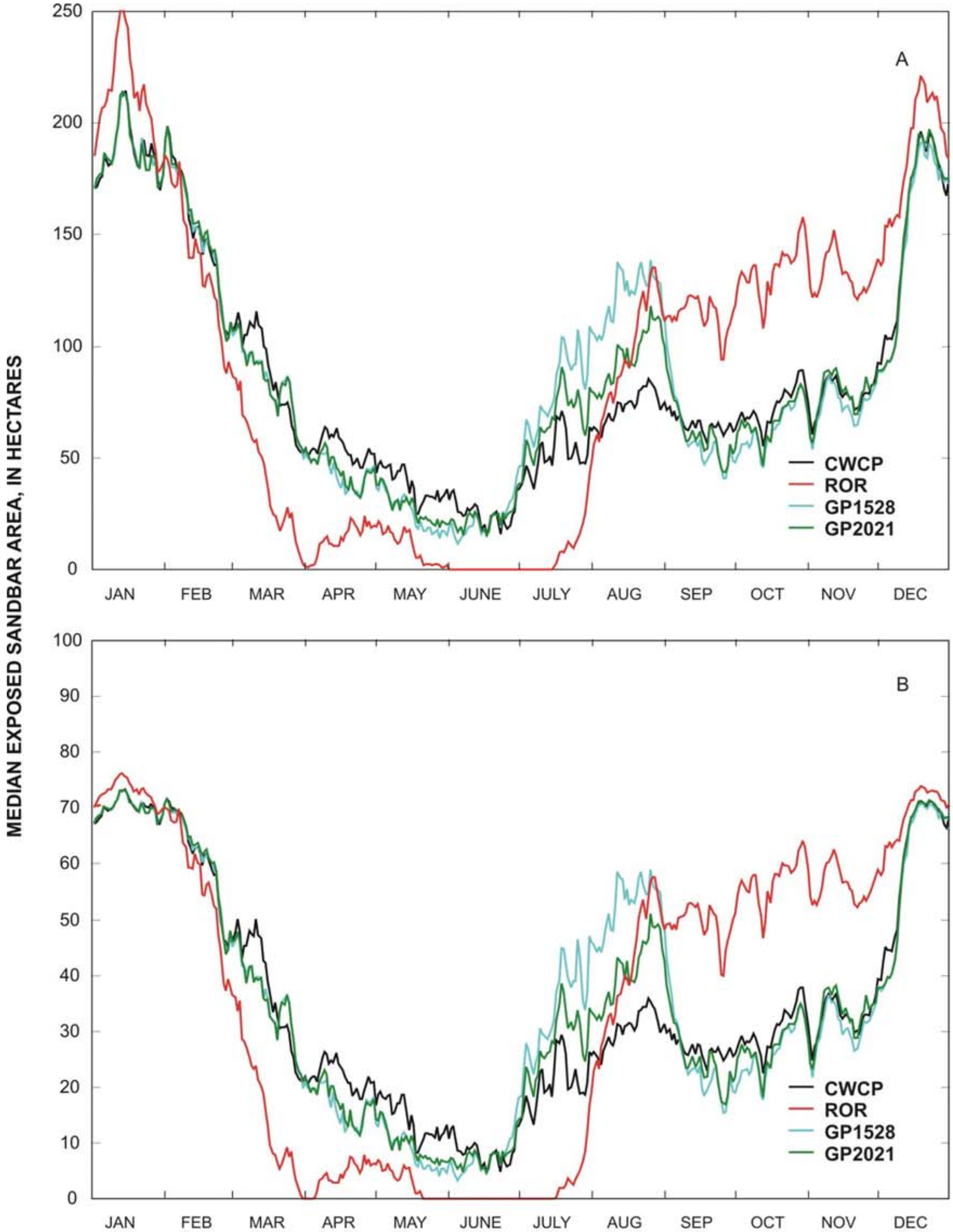


Figure 25. Exposed sandbar availability at Lisbon Bottom side-channel chute, calculated from 1-dimensional hydraulic model, by time of year and by discharge scenario. A. Median of 100 years of daily sandbar availability for entire modeled area. B. Median of 100 years of daily sandbar availability within the banks of the chute. CWCP, current water-control plan; ROR, run of the river model; GP1528, flow scenario with 15,000 cfs spring rise and 28,000 cfs summer low flow; GP2021, flow scenario with 20,000 cfs spring rise and 21,000 cfs summer low flow.

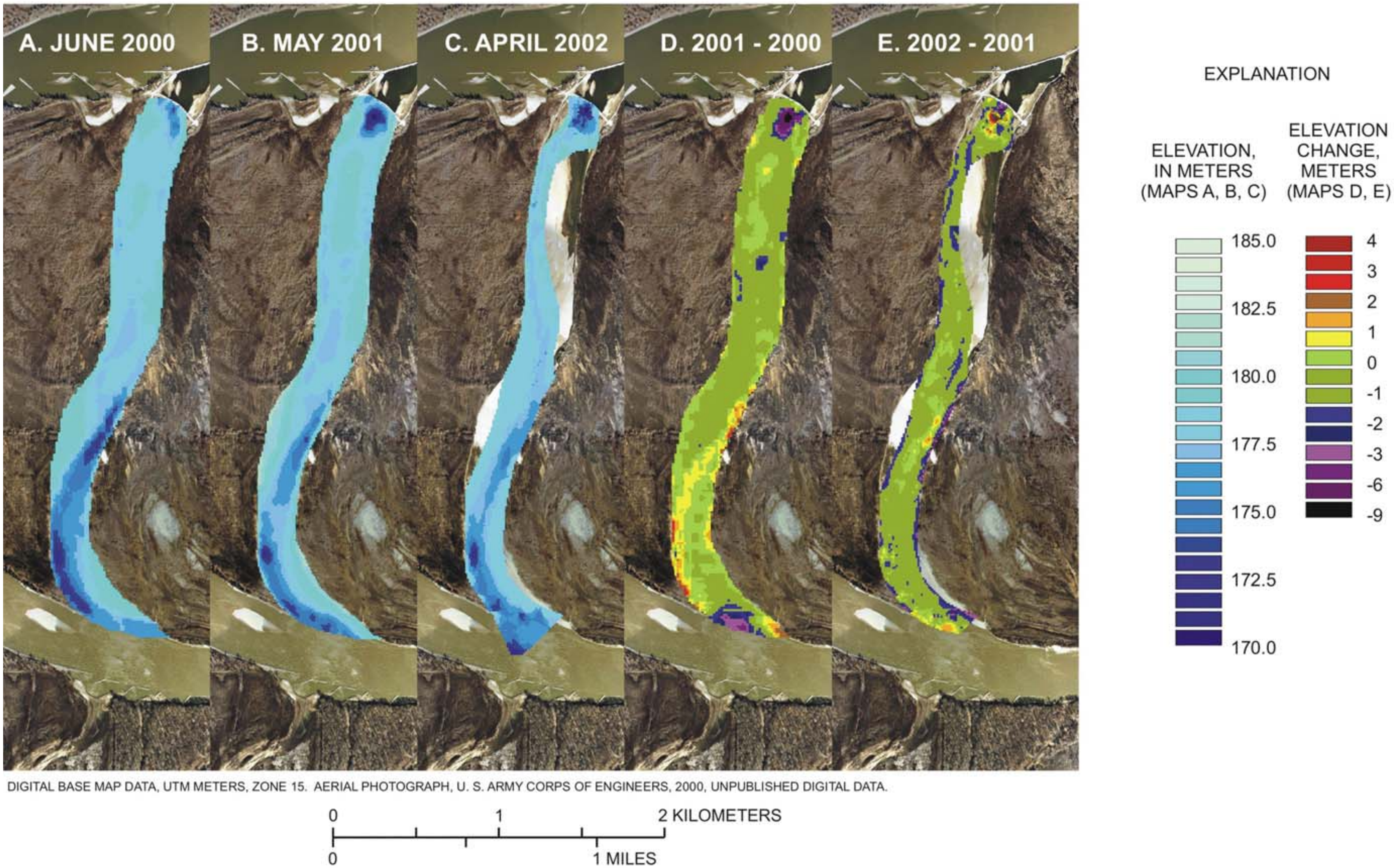


Figure 26. Elevation maps of Lisbon Bottom side-channel chute (A-C), and elevation change maps (D, E). The April 2002 survey of the chute was not able to cover the entire area of the chute because of insufficient depth.

North Overton Bottoms Chute

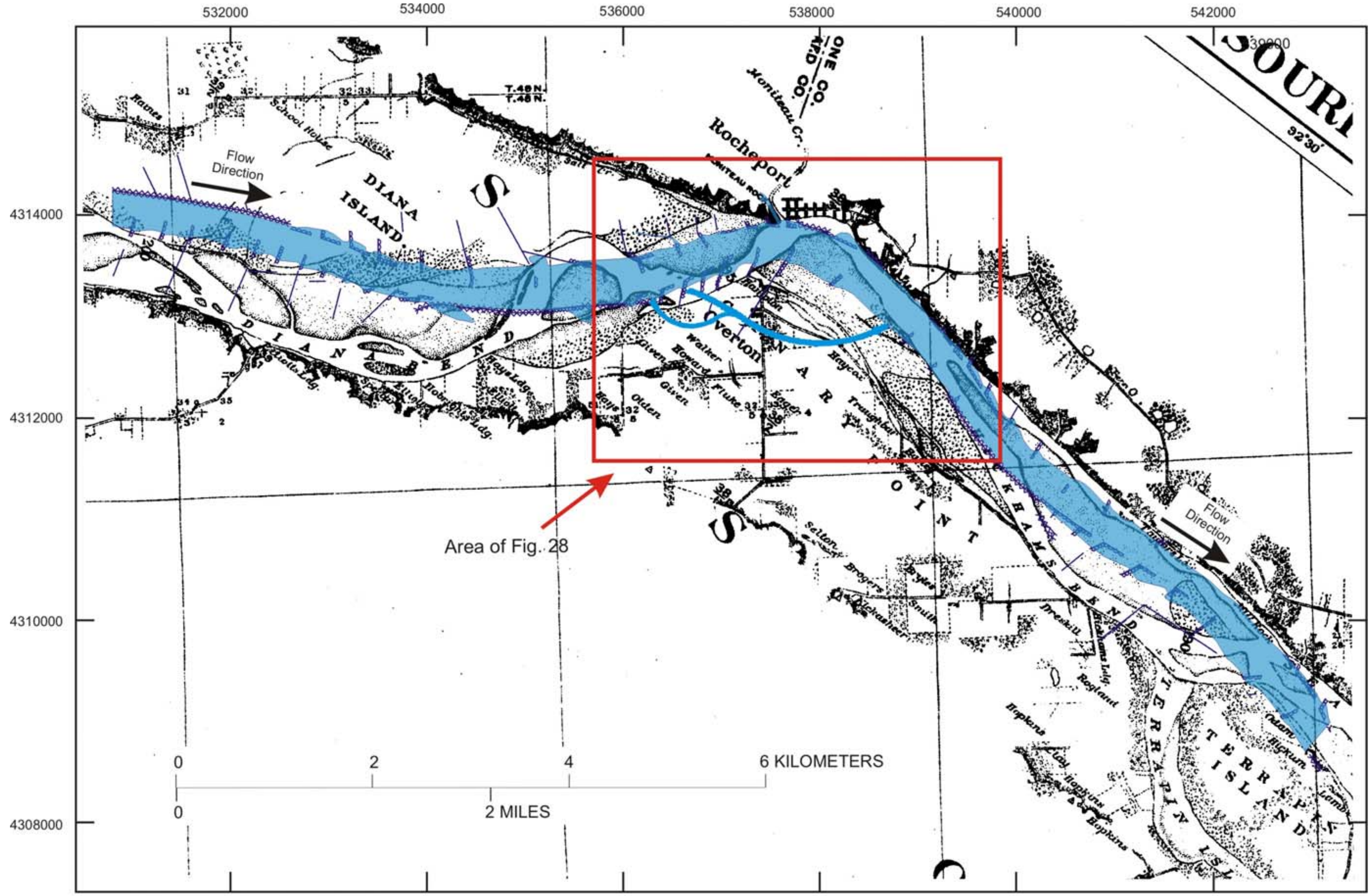
The North Overton Bottoms chute was constructed as part of the Missouri River Bank Stabilization and Navigation Project Fish and Wildlife Habitat Mitigation Project in 2000 (figs 27, 28). The chute was originally designed and constructed as a shallow, narrow pilot ditch intended to erode to achieve a more natural shape (U.S. Army Corps of Engineers, 1999b; fig.29). Originally, the length was about 3,000 m, the top width was nominally 12 m, and bank slopes were 1 on 1.5 (66% or about 34^{o}). The slope of the chute was designed to be nominally 0.00022. The design set inlet and outlet elevations to allow water to flow through the chute 50% of the time during April – September. In addition, a sill was constructed on the adjacent tie-back levee and was designed to pass water at approximately the 2-year flood (fig. 28).

Hydrologic performance of the chute was determined by developing stage-discharge relations at the inlets and outlets, and by evaluating as-built survey data. Discharge duration for flow in the inlet and outlet were calculated in the design documents (U.S. Army Corps of Engineers, 1999b) using flows at Boonville, Missouri, during “navigation season”, March - September, 1970-1996. It is not clear why the navigation season was stipulated for calculation of flow duration, nor why the months March – September were used instead of the conventional Missouri River navigation season, April – November. The March – September period has higher average discharge, so the design elevations were slightly higher than they would have been if the conventional definition had been used. For the duration analysis presented here, flow duration will be calculated using the historical 1967 – 2003 flow data from the Boonville, Missouri, streamflow-gaging station and the entire year.

The design inlet elevation of 174.0 m would have allowed water in the inlet at about 75,000 cfs, a flow equaled or exceeded only 30% of the time (figs. 17, 30). As-built surveys, however indicated that the actual inlet sill elevation was approximately 173.5 m, an elevation that would allow water to flow in at about 65,000 cfs, or 42% of the time. The design outlet elevation was 172.8 m, and would have allowed water to flow in the upstream direction through the outlet at about 56,000 cfs, or about 53% of the time. The as-built survey indicated that the actual elevation was very close at 172.7 m. In early spring 2002, the outlet (and a short area upstream in the chute) was adaptively deepened approximately 1.4 m to 171.4 m, a stage that should be equaled or exceeded 90% of the time.

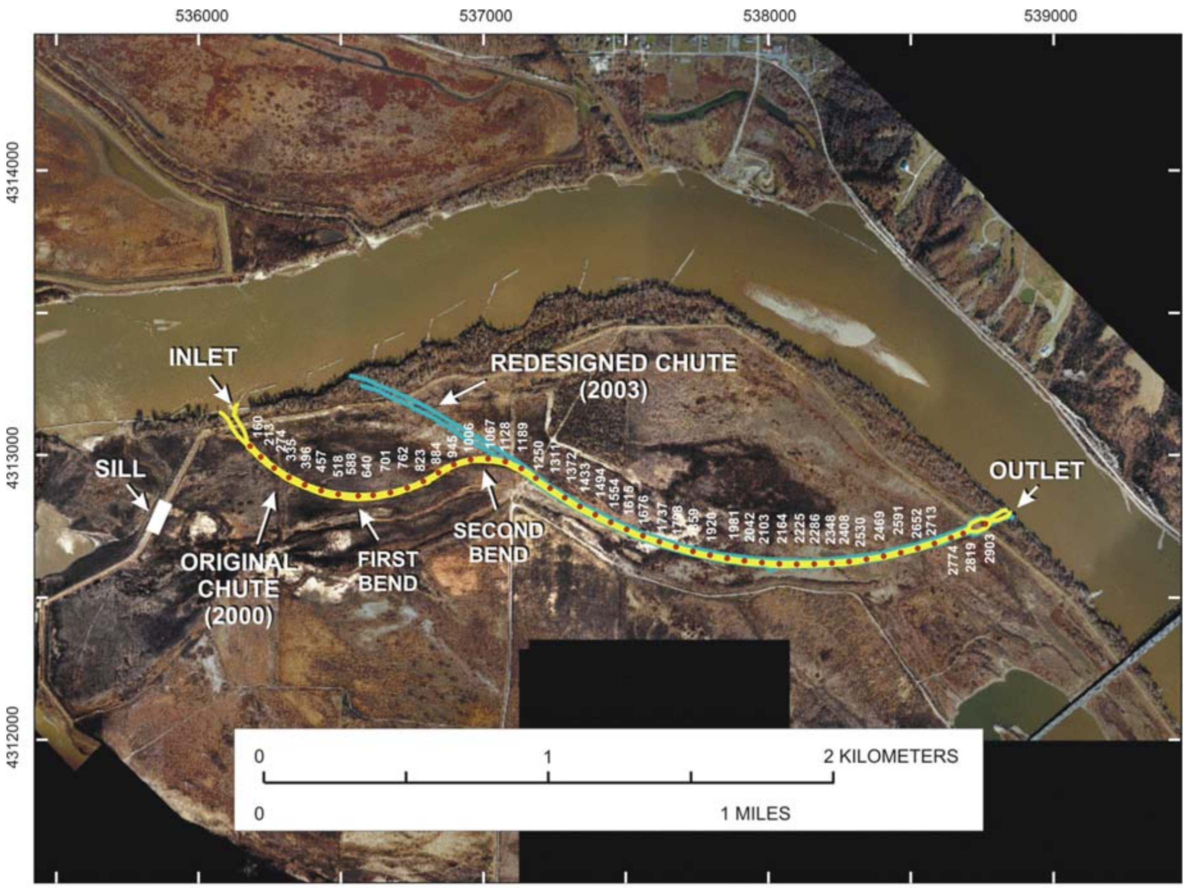
Twenty cross sections were surveyed in October 2001 to compare with the October 2000 as-built survey. Because the as-built survey used different methods and geographic datum, exact replication was not possible. The as-built cross sections were located relative to the U.S. Geological Survey cross sections by estimating position based on stationing along the chute construction reference line. The nearest U.S. Geological Survey cross section was then matched with the as-built by aligning the centers of the cross sections; these cross sections are estimated to be no more than 15 m in longitudinal distance from the as-built sections. In addition, 94 cross sections were measured by echosounder survey during high flow in May 2002. Some of the bathymetric cross sections can be matched to as-built cross sections and some can be matched to the October 2001 survey. Locations of all cross sections are shown in figure 28 and data from 35 cross sections with matched, replicate surveys are shown in figure 31. A longitudinal profile developed from as-built and October 2001 cross sections is shown in figure 32.

The chute was remarkably stable during this time period despite being subjected to several large floods (fig. 33). In addition to aggradation of 0.5 – 1.0 m on the downstream one-half of the chute (fig. 32), the chute widened slightly in places, especially in the upper one-third of the cross sections (fig. 31). Widening at the top of the banks indicates that erosion was primarily from small topples or slumps in the sandy-silt sediment that comprised the top 1 meter of sediment. In addition, field observations indicated that widening was associated with bank erosion due to subsurface piping – concentrations of groundwater through-flow – in sandy sediment below the cohesive layer. Piping apparently led to undermining of the cohesive layer and subsequent collapse. The combined effect was to create discrete embayments or scallops along the chute bank where piping and bank collapse led to incipient gullies 2-4 m long oriented perpendicular to the chute axis. Because the gullies were discrete features no more than 4 m wide, it was unlikely that surveyed cross sections would record widening associated with these processes.



DIGITAL BASE MAP DATA, UTM METERS, ZONE 15

Figure 27. Location of the modern Missouri River channel (1998), and the North Overton Bottoms side-channel chute, overlain on the river as it looked in 1879 (Missouri River Commission, 1893).



DIGITAL BASE MAP DATA, UTM METERS, ZONE 15.
AERIAL PHOTOGRAPH, U.S. ARMY CORPS OF ENGINEERS, 2000, UNPUBLISHED DIGITAL DATA.

Figure 28. Locations of the side-channel chutes and features at North Overton Bottoms. Red dot markers and numbers refer to monitored cross section stationing (see figure 31).

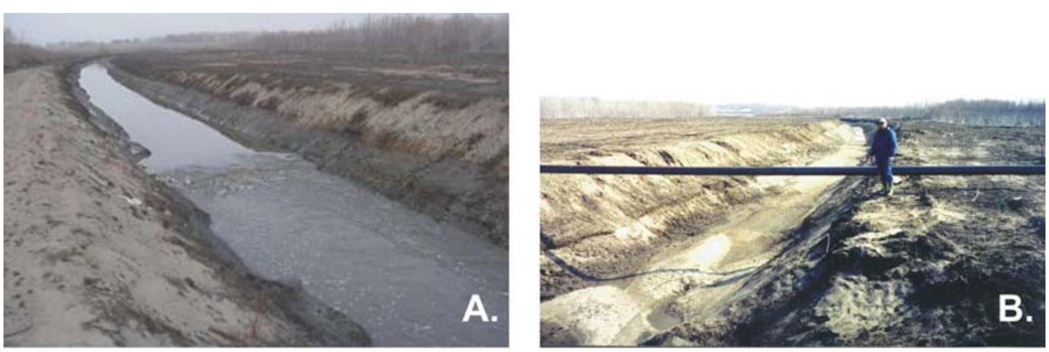


Figure 29. Photographs of the North Overton Bottoms side-channel chute during Spring 2001. A. Flow over grade-control structure; note graded bank slopes. B. After a medium flow event. Sediment in channel indicates recent deposition; shallow scallops in banks indicate some lateral erosion processes taking place.

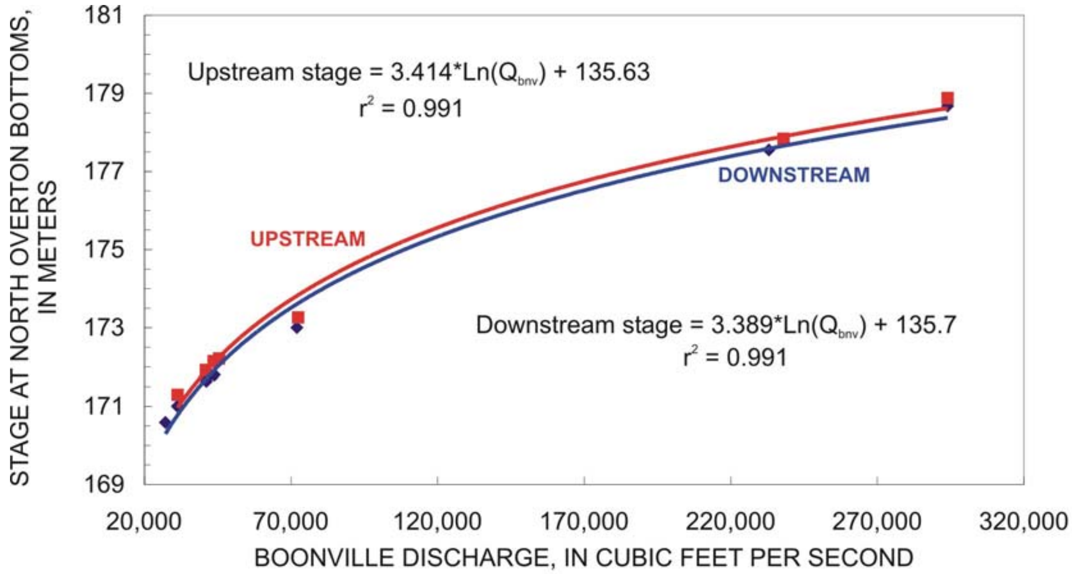


Figure 30. Stage-discharge relations surveyed for the original inlet and outlet, North Overton Bottoms side-channel chute. The relations are fitted to logarithmic functions. Stage is in meters; Q_{bnv}, discharge at Boonville, Missouri in cubic feet per second..

Another process that was evident in cross section resurveys was accumulation of large woody debris (LWD, station 160 m, Fig. 31). Unfortunately, because the as-built surveys did not extend for more than 5-20 meters beyond the top of bank, they cannot be used to evaluate much of the deposition of sediment or LWD along the chute channel. Some of the cross sections surveyed in October 2001 recorded the top of LWD and the ground surface below it. These surveys indicated as much as 1.5 m accumulation of LWD.

LWD also was evaluated using oblique aerial photography and videography collected by the Missouri Department of Conservation in waterfowl studies (Dale Humburg, Missouri Department of Conservation, personal communication, 2003). Accumulation of LWD was clearly the most dramatic geomorphic response of the Overton side-channel chute (figs. 34). LWD accumulation over time was evaluated using oblique aerial imagery. This method provides semi-quantitative assessment of how much, when, and where LWD accumulated in the chute. Aerial photography dates are shown in figure 33 and maps of LWD are shown in figure 35. Little LWD accumulated in the chute during the winter 2000-2001. In February and March, 2001, three floods overflowed the inlet, each successively larger in discharge. Photographs taken on March 3 between the second and third flood indicated initial accumulation of LWD in a jam on the second bend near station 1100 m. The third flood on March 18, 2001 was about 200,000 cfs. Photographs taken March 19 showed that the inlet was packed with LWD, the LWD on the second bend was breached, and an LWD jam had expanded on the second bend. Water continued flowing through the inlet until mid July 2001. On March 26, more LWD was apparent and the LWD distribution was little changed on April 30.

The next available photography was acquired on July 5, 2001 following two months of high flow that included a flood of 365,000 cfs on June 8, 2001 that was of sufficient stage to flow over the tie-back levee sill. This flood was estimated to be between a 5 and 10-year recurrence interval (U.S. Army Corps of Engineers, written communication, 1997). The 365,000 cfs flood mostly cleared the chute channel of large woody debris, depositing it in three prominent discrete positions: splays on the right and left banks just downstream of the inlet, splay and levee on the right bank at the tight bend, and two large splays on the right bank just upstream of the outlet. While the quality of the mapping data is not sufficient to quantify the volume of LWD, the total area of LWD remaining after the June 8, 2001 flood appears comparable to the area of LWD mapped on April 30, 2001.

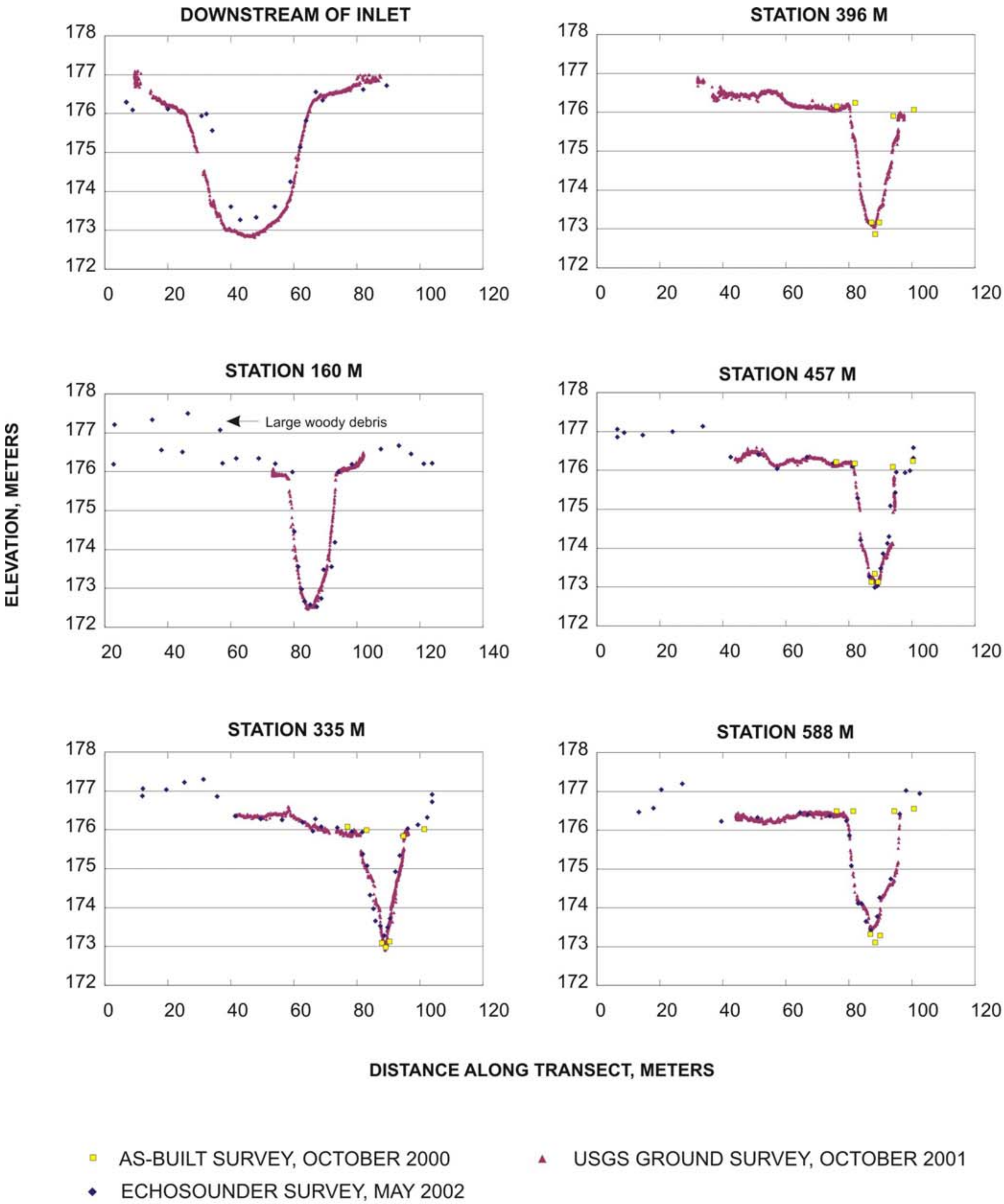


Figure 31. Monitored cross sections in North Overton Bottoms side-channel chute, surveyed October 2000, October 2001, and May 2002.

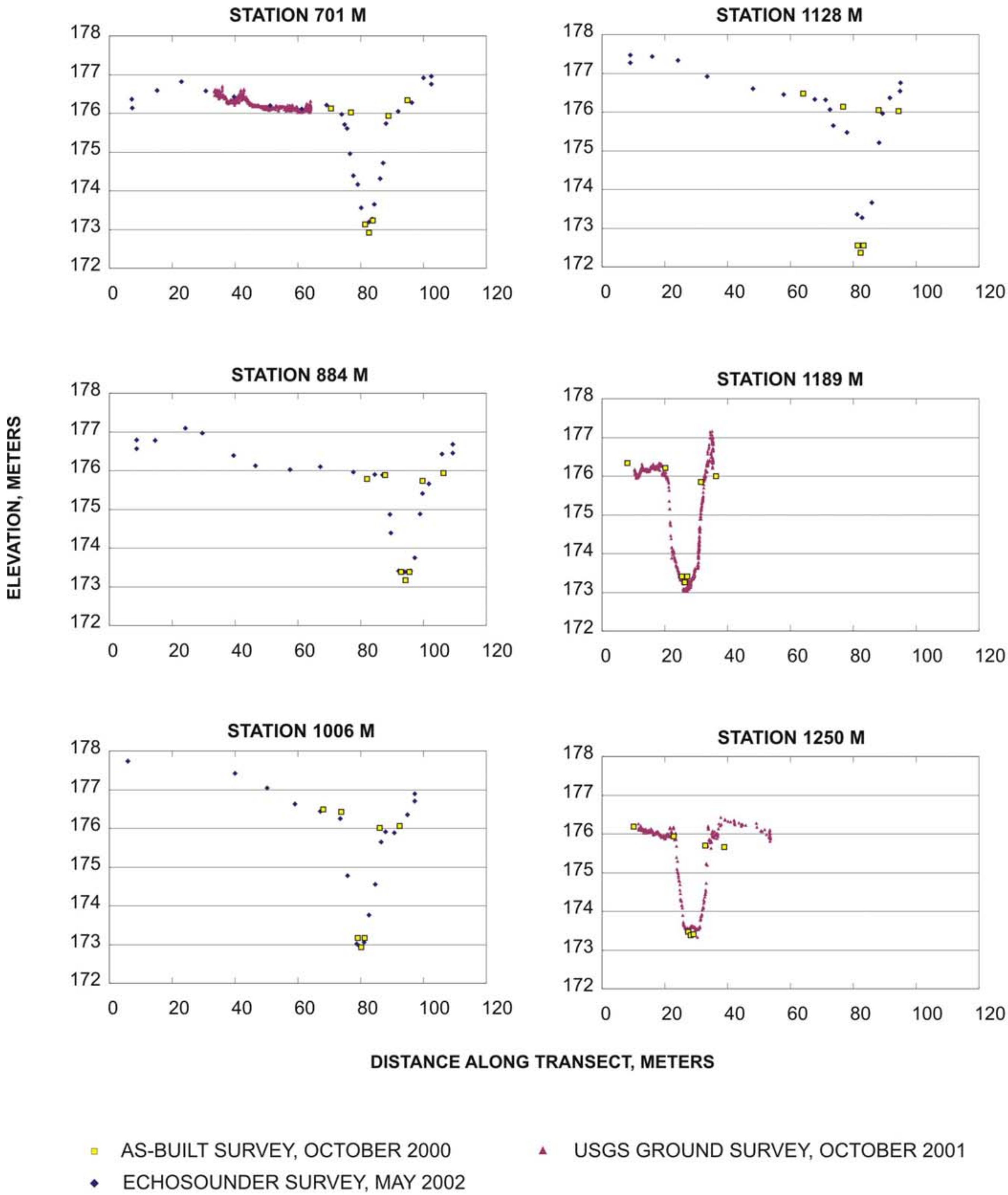


Figure 31 (cont.). Monitored cross sections in North Overton Bottoms side-channel chute, surveyed October 2000, October 2001, and May 2002.

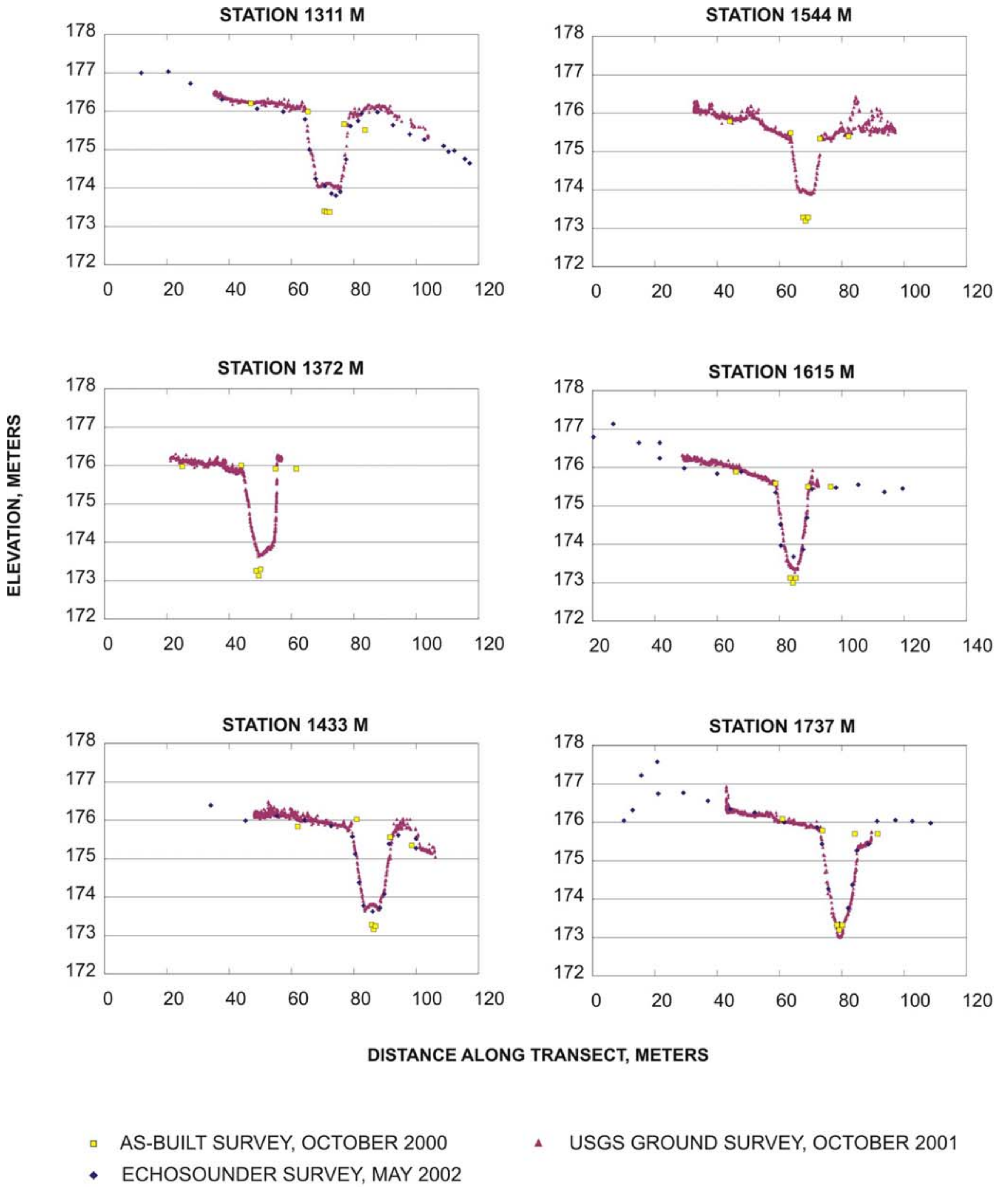


Figure 31 (cont.). Monitored cross sections in North Overton Bottoms side-channel chute, surveyed October 2000, October 2001, and May 2002.

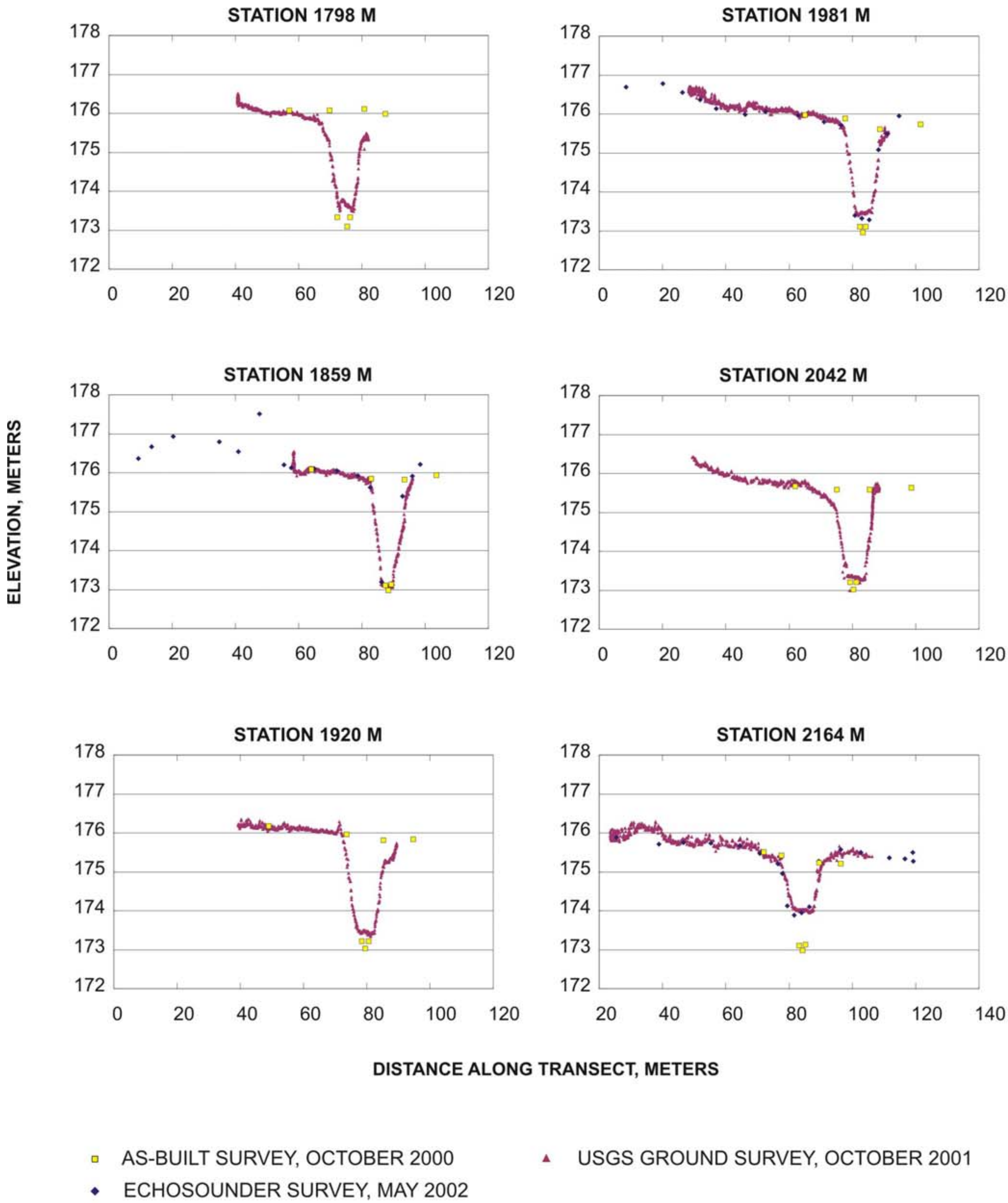


Figure 31 (cont.). Monitored cross sections in North Overton Bottoms side-channel chute, surveyed October 2000, October 2001, and May 2002.

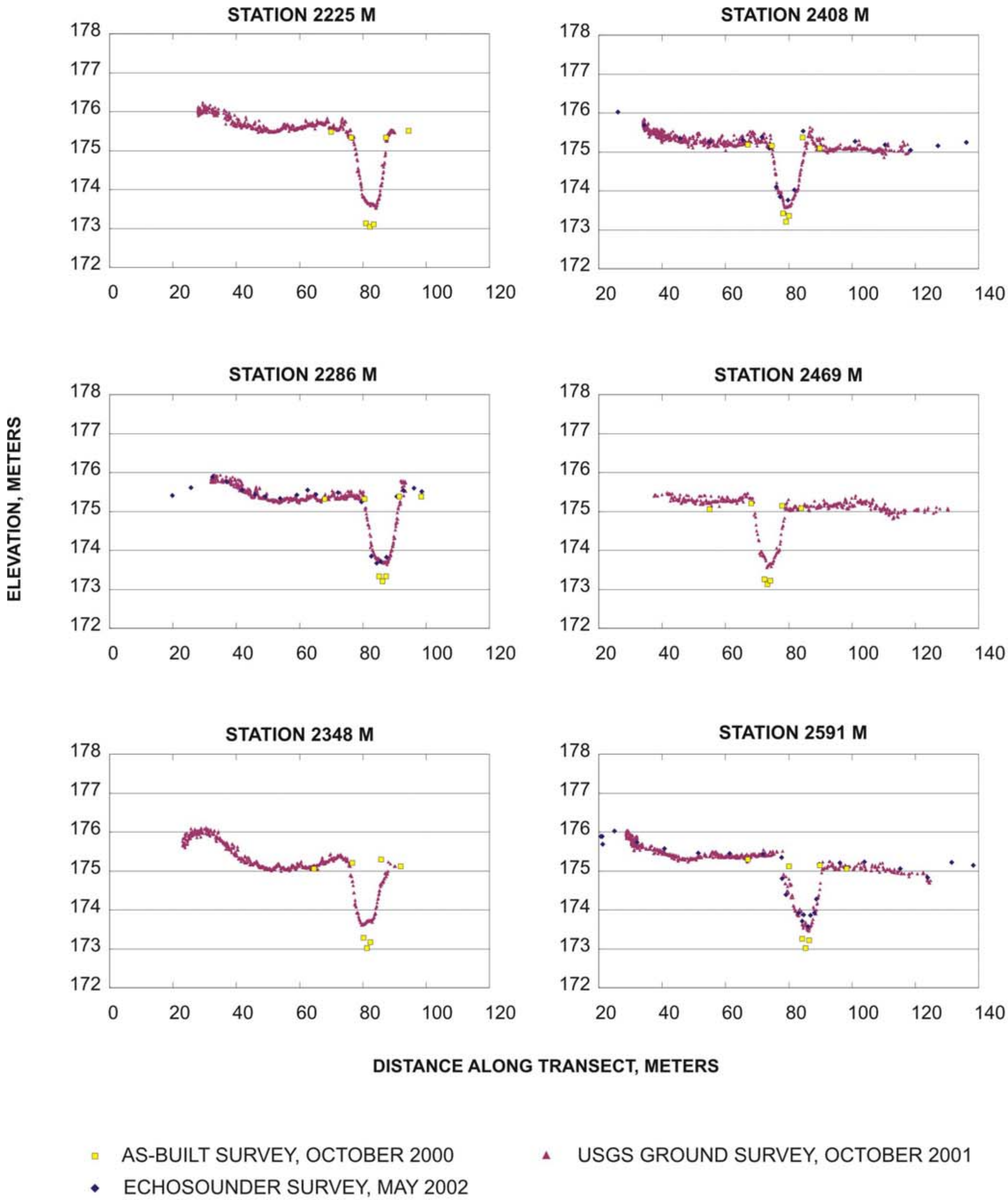


Figure 31 (cont.). Monitored cross sections in North Overton Bottoms side-channel chute, surveyed October 2000, October 2001, and May 2002.

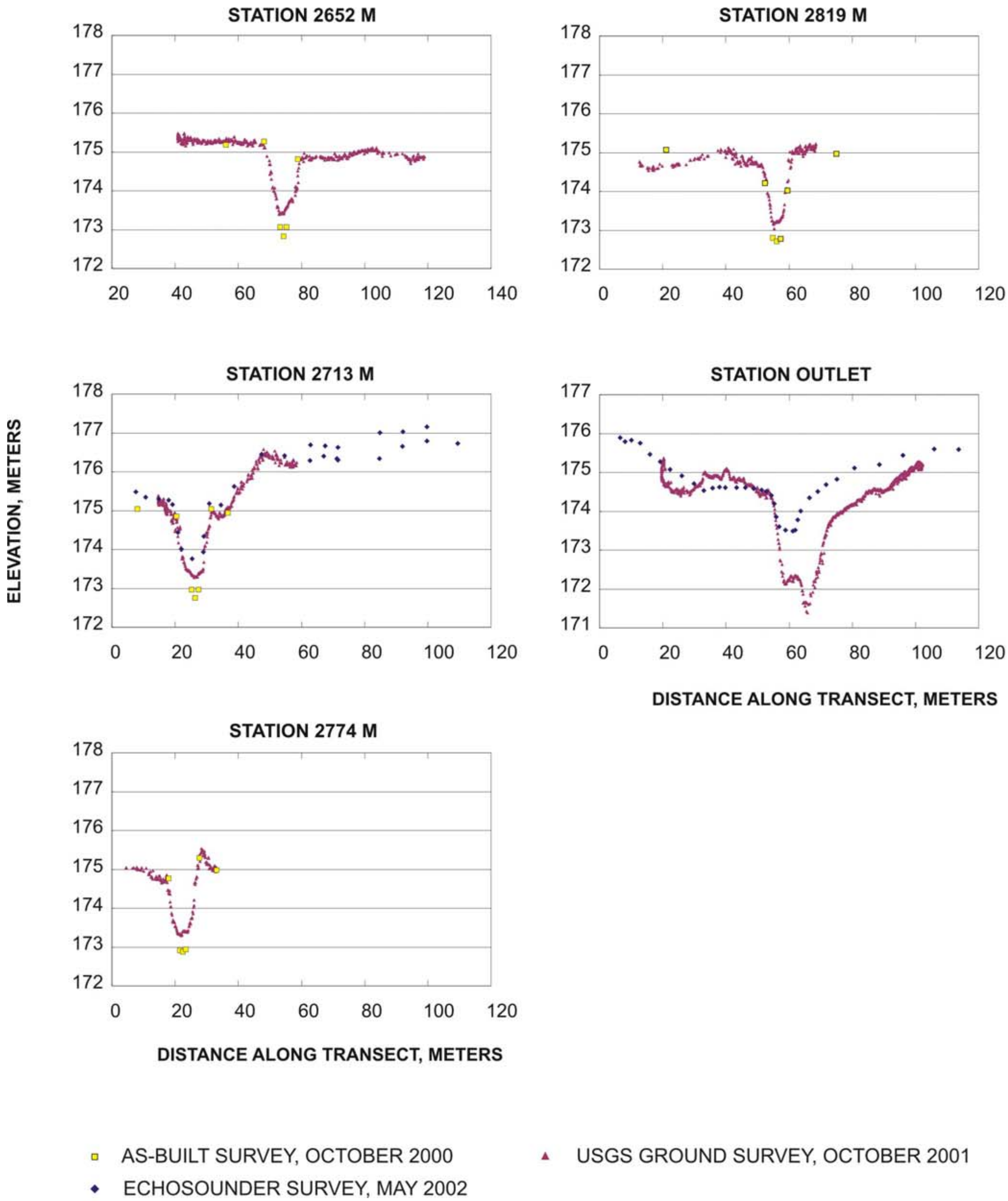


Figure 31 (cont.). Monitored cross sections in North Overton Bottoms side-channel chute, surveyed October 2000, October 2001, and May 2002.

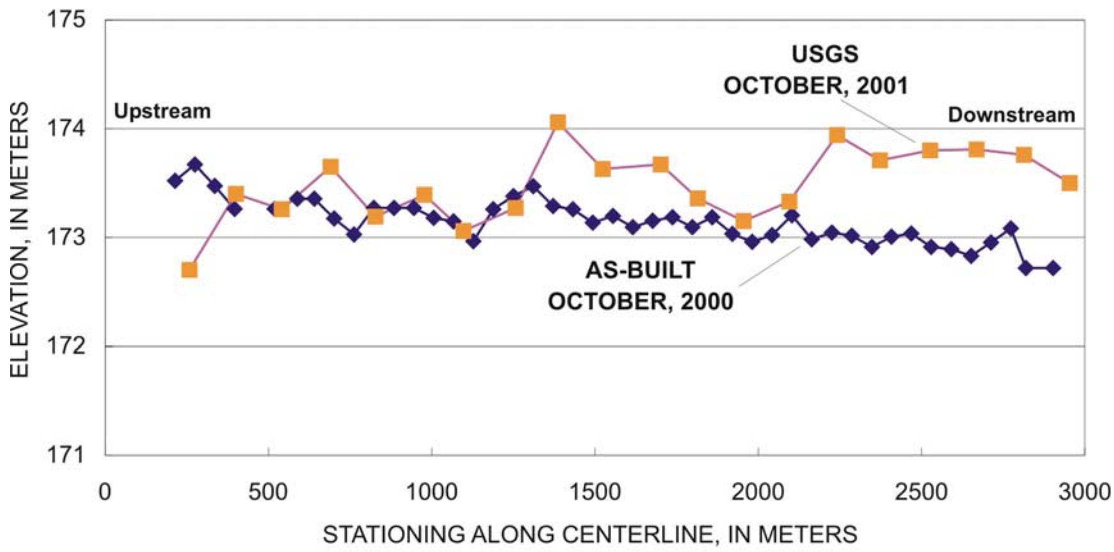


Figure 32. Long profile in North Overton Bottoms side-channel chute, surveyed October 2000 and October 2001. Substantial aggradation was measured in the downstream one half of the chute.

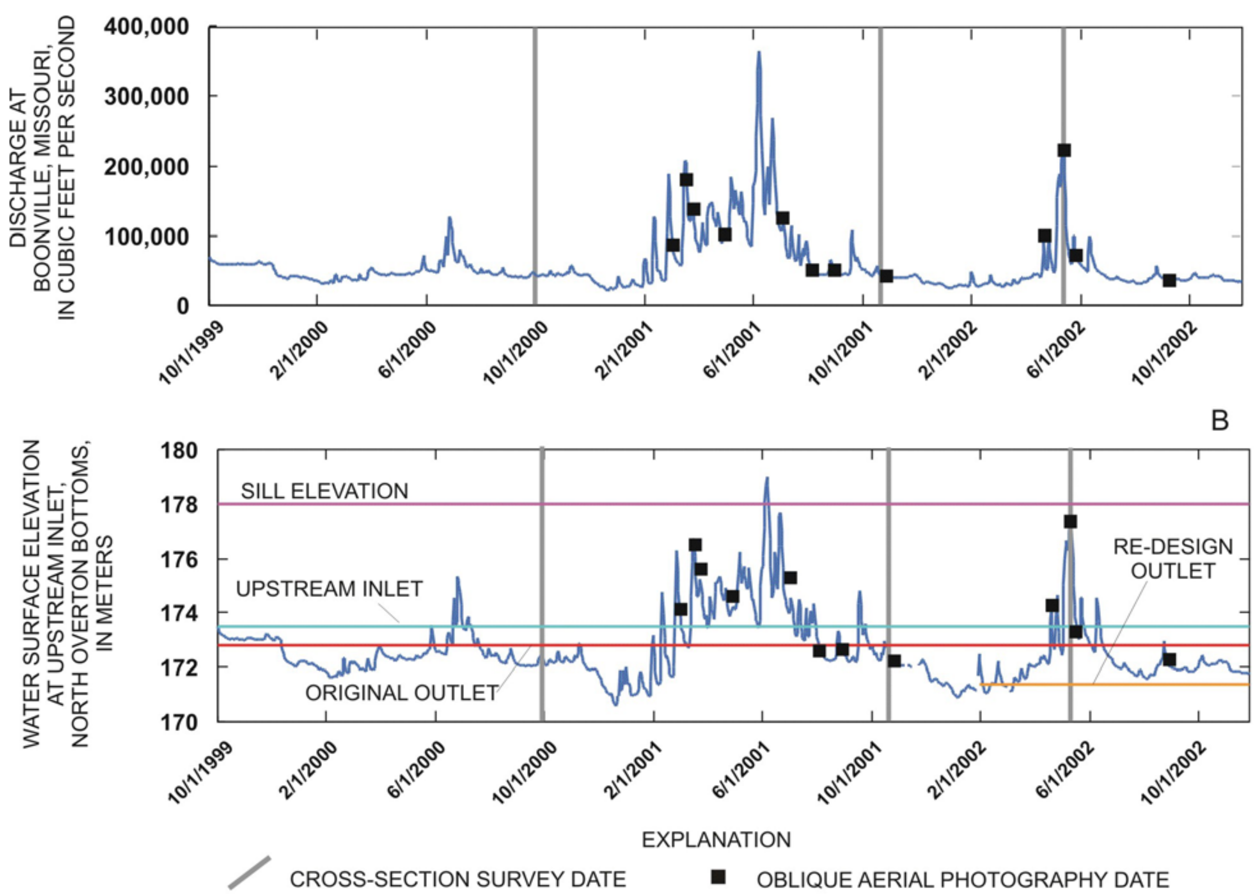


Figure 33. Hydrologic history of North Overton Bottoms side-channel chute with dates of surveys and oblique photography, October 1999 - October 2002. A. Discharge at Boonville, Missouri. B. Stage at the North Overton Bottoms inlet with minimum elevations of features along the chute.

Figure 34. Photographs of large woody debris jam in North Overton Bottoms side-channel chute. A. Inlet, looking downstream; navigation channel to left. Photo courtesy of Missouri Department of Conservation. B. Inlet from oblique aerial photograph. Photo courtesy of Missouri Department of Conservation. C. Upstream one third of chute. Photo courtesy of Missouri Department of Conservation.

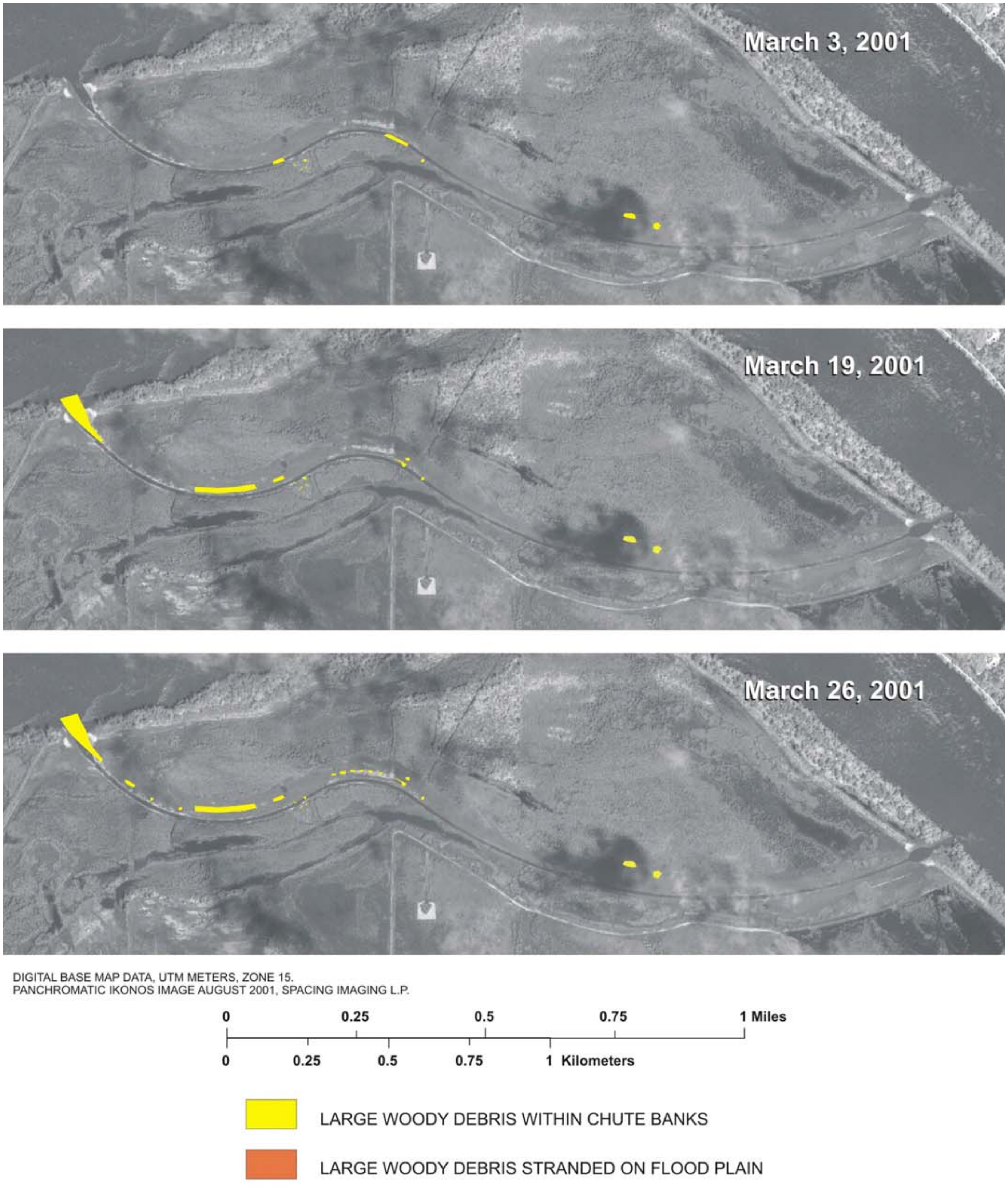


Figure 35. Maps of large woody debris accumulation at North Overton Bottoms side-channel chute, March 2001 to September 2002. Hydrologic record and map dates are shown in figure 33.

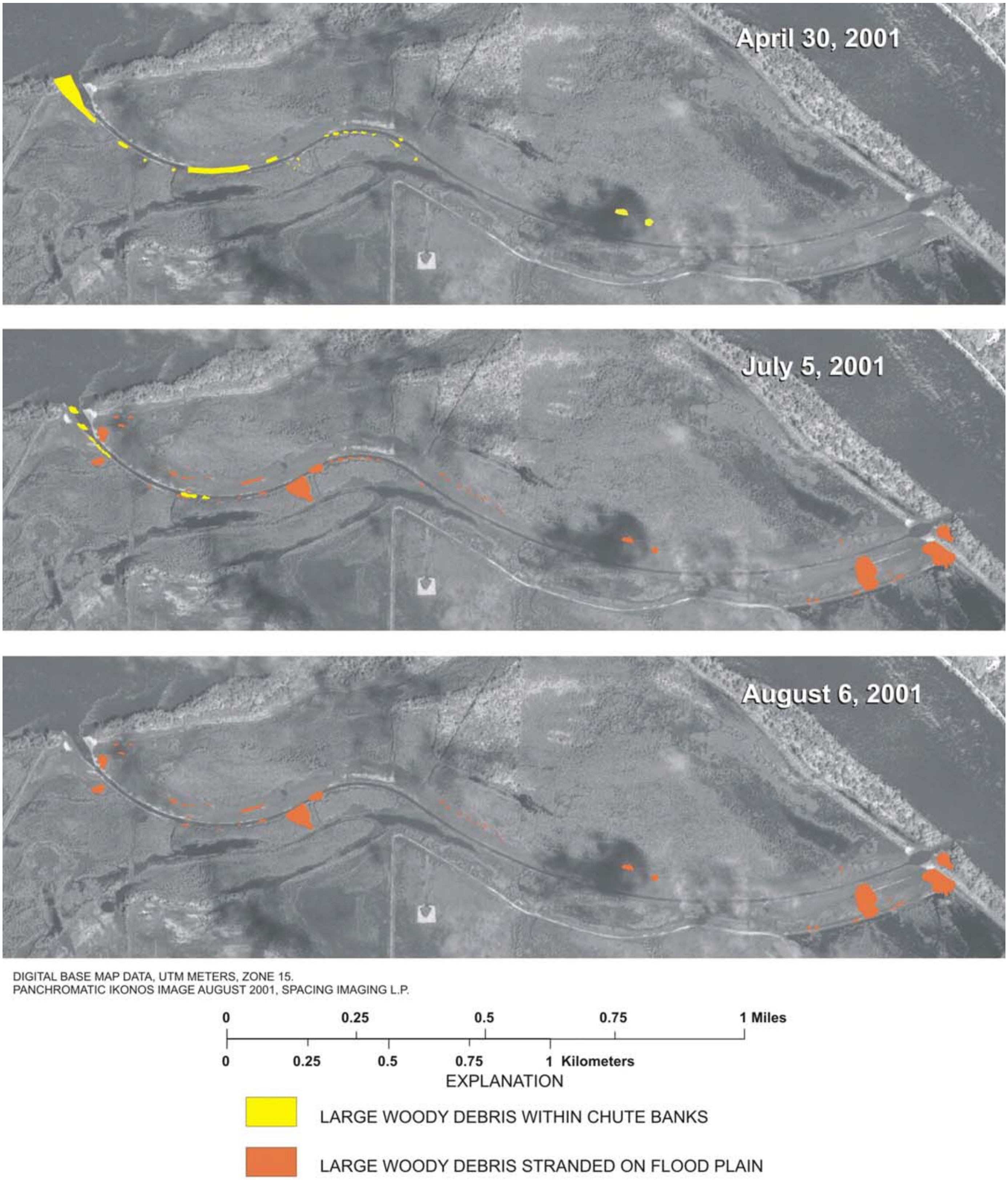


Figure 35 (cont.). Maps of large woody debris accumulation at North Overton Bottoms side-channel chute, March 2001 to September 2002. Hydrologic record and map dates are shown in figure 33.

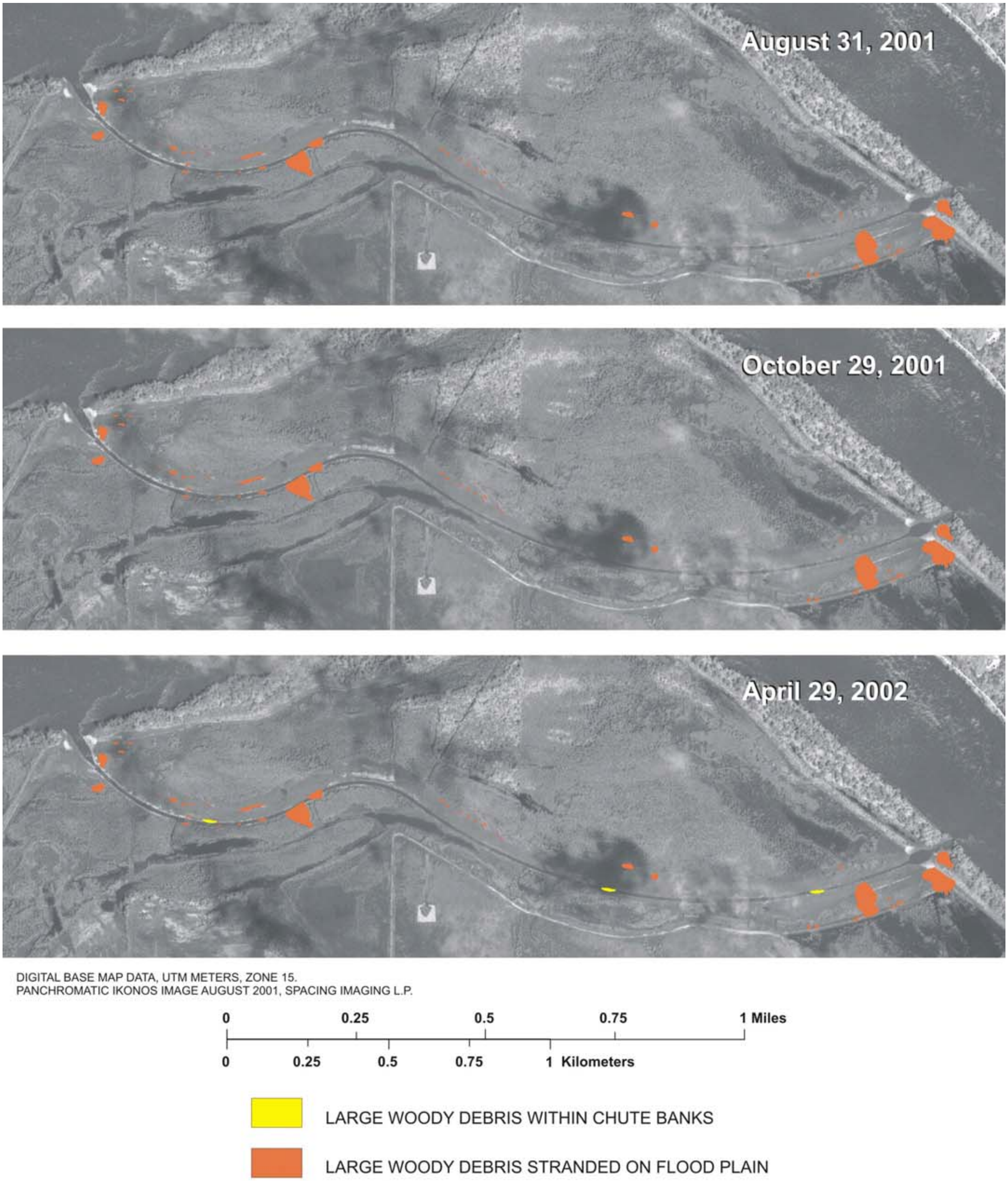


Figure 35 (cont.). Maps of large woody debris accumulation at North Overton Bottoms side-channel chute, March 2001 to September 2002. Hydrologic record and map dates are shown in figure 33.

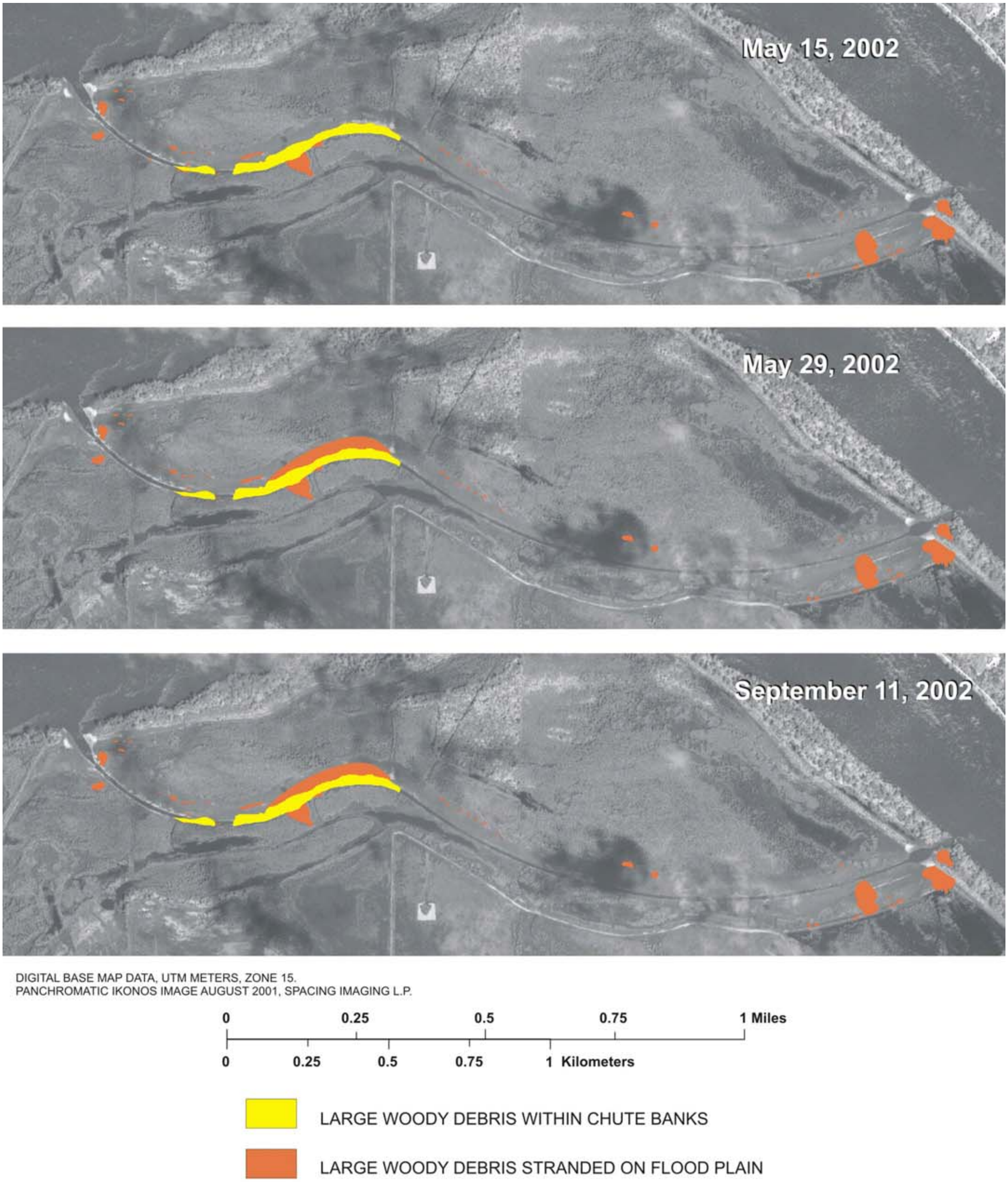


Figure 35 (cont.). Maps of large woody debris accumulation at North Overton Bottoms side-channel chute, March 2001 to September 2002. Hydrologic record and map dates are shown in figure 33.

There was no appreciable change in LWD accumulation from October 29, 2001 to April 29, 2002, a period characterized by relatively low flows. By May 15, 2002 more LWD had accumulated in the upstream one third of the chute than had been there in the spring of 2001. The rapid accumulation of LWD occurred as discharges increased from 100,000 cfs on April 29 to 222,000 cfs on May 15. This flow was well over the upstream inlet, but below the stage of the sill.

Discharges and velocities were measured in the chute during the high flow in May 2002. Measurements were made on May 15 when flow at Boonville was 222,000 cfs, a discharge between a 2 and 5-year flood (U.S. Army Corps of Engineers, written communication, 1997). This discharge was below the sill elevation but above the banks of the chute. Because flow was over the banks and we could not measure the component of overbank flow in the trees, discharges measured in the chute are a minimum estimate of flow over Overton Bottoms. Discharge measured at the upstream end of the chute was about 4,900 cfs, or 2% of the total flow in the main channel. Mean water-column velocity was 0.62 m/sec, and maximum velocity was 2.59 m/sec; highest velocities were concentrated in the center of the chute in the upstream one third (fig. 36). Velocities within the banks of the chute were commonly in excess of 1.0 m/sec whereas velocities in the overbank (grassy or unvegetated surface adjacent to the chute) were typically 0 – 0.7 m/sec. LWD accumulations interacted with flow to alter the typical distribution. Where LWD blocked flow within the chute banks, flow was diverted around the LWD resulting in overbank velocities that were appreciably higher (fig. 36 inset). Between the two LWD jams that existed on May 15, 2002, the velocity distribution was reversed, with greater velocities in the overbank and smaller velocities within the bank. These data support the idea that LWD accumulations can lead to complex flow patterns and could eventually create a complex channel pattern.

The design of the Overton Bottoms side-channel chute has been adaptively altered twice since it was constructed. In the first instance, the outlet and the downstream end were deepened about 1.4 m during the early spring of 2002. In the second instance the chute was deepened and realigned during the spring of 2003 (fig. 28). Characteristics of the redesigned chute are not within the scope of this report.

Physical Habitat Dynamics in Side-channel Chutes

The side-channel chutes studied for this project are diverse and perhaps each is unique. Studying these chutes cannot yield a statistical understanding of variation among chutes, but it can illustrate the range of chute types that exist and something about the processes that are responsible for creating and sustaining aquatic habitat.

All four of the side-channel chutes contribute shallow, slow current velocity habitat (SWH) that is in short supply, although not totally absent, in the navigation channel. At Lisbon Bottom the side-channel chute also was shown to expand the range of discharges and flow duration over which SWH occurs. At Cranberry Bend and Lisbon Bottom, the combination of deep areas related to the thalweg and shallow areas in the upstream halves of the chutes contribute to habitat diversity.

How long side-channel chutes will contribute aquatic habitat depends on whether they can sustain transport of water and sediment. Three of the chutes – Hamburg, Lisbon, and Overton – are young relative to many other channel features of the Lower Missouri River. They have been created recently and continue to evolve geomorphically, with a range of engineered controls designed to limit geomorphic change. The availability and quality of physical habitat measured currently in these chutes may be quite different from what exists in the future. A dominant idea in the field of geomorphology is the concept of dynamic equilibrium: that fluvial features will adjust to prevailing discharge and sediment supply to form a stable geometry. It is possible that these relatively young chutes have not yet reached an equilibrium form, and are still in the process of adjustment. Adjustment to substantially different geomorphic form would alter the discharge-habitat relations shown in this report. The concept of equilibrium channel geometry does not necessarily imply a static channel location, as an equilibrium channel form can exist for an actively migrating channel.

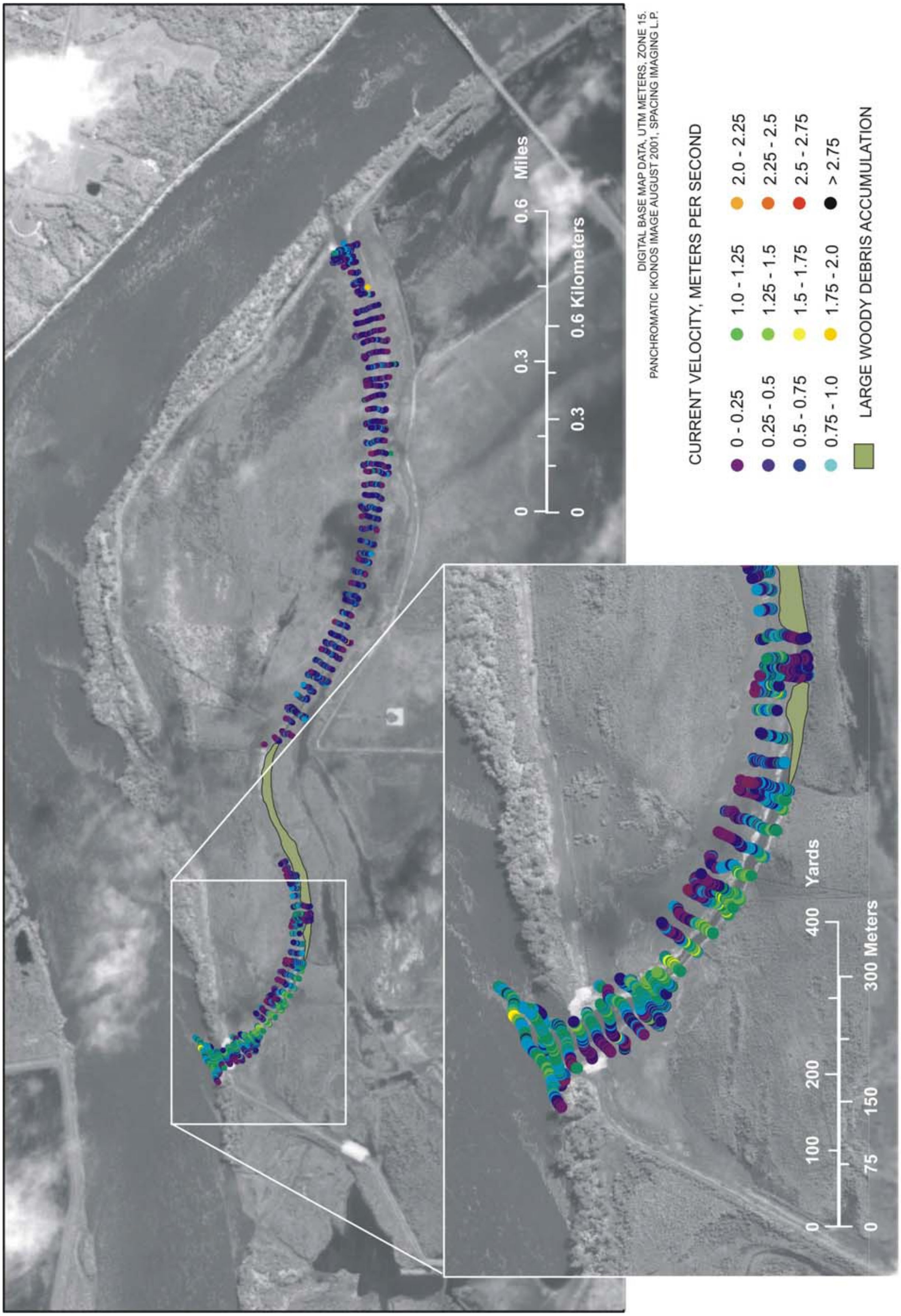


Figure 36. Maps of large woody debris and velocities in the North Overton Bottoms side-channel chute, June 2002.

Side-channel chutes are not necessarily permanent, sustainable features. As discussed by Jacobson and others (2001), the characteristics of side-channel chutes are controlled in complex ways by discharge, sediment transport, and the vertical and horizontal geometries of the inlet and outlet that control exchange of water and sediment between the main channel and the chute. Some authors argue that side-channel chutes are inherently unstable and transient features of alluvial rivers, and therefore should be expected to either fill up with sediment or capture the main channel (Schropp, 1995; Bareneveld and others, 1994). Our geomorphic measurements can shed some light on the question of inherent stability of side-channel chutes, although the relatively short time frame over which these chutes have existed prevents conclusive statements.

Limited observation of the planform evolution of the Hamburg Bend side-channel chute indicated that some bends are eroding laterally in places and constructing a new flood-plain surface at a lower elevation. The Cranberry Bend chute appears to have been in essentially the same position since 1954, but as much as 48 m of recent lateral erosion of the right bank at Cranberry Bend is evident from comparison of bank positions in our data to the bank position in 1994 navigation charts (fig. 8).

The Lisbon Bottom side-channel chute widened rapidly in the first 4 years and then reached an apparent equilibrium width (fig. 15). Similarly, the rate of lateral movement has decreased (see Jacobson and others, 2001). Combined with evidence of aggradation these facts suggest that the Lisbon Chute may be filling in. It is unlikely that the chute would ever fill completely because the notched revetment and lack of levee at the upstream end would allow flows into the chute at lower stages than other sites along the channel. Instead, if sediment continues to accumulate in the chute, it would probably evolve to a narrower channel flanked by newly constructed flood plain. Flood plain constructed by the chute would be expected to provide riparian aquatic-terrestrial habitats that would be inundated more frequently than the present flood-plain surface of Lisbon Bottom. The ultimate fate depends on details of the sediment budget for the chute, which is highly dependent on the sequence of floods, geometry of the two inlet notches, and sediment transport through the notches. Sediment transport and the fate of the chute may be altered by ongoing adaptive management of the notch geometry.

The North Overton Bottoms side-channel chute was originally designed as a pilot chute that would use the river's energy to create an equilibrium morphology, assumed to be a shallow, meandering channel with an ultimate width of 30 – 46 m (U.S. Army Corps of Engineers, 1999b, p. 9). In apparent contradiction, however, the design also called for training structures to create deep-water habitats and to assure that a sinuous channel would result (U.S. Army Corps of Engineers, 1999b, p. 11). While conceptually designed to erode an equilibrium channel, the conservative design of inlet and outlet structures that allowed flow through a relatively small percentage of the time (fig. 17) and channel side slopes specifically designed to be stable (U.S. Army Corps of Engineers, 1999b, p. 14) worked to slow the equilibration process. Our surveys indicated that the original chute was not widening as expected, except in limited areas where piping created embayments in the bank and where complex flow around large woody debris jams caused bank scalloping (fig. 31). In addition, the longitudinal profile of the chute indicated that the original configuration was leading to aggradation of the downstream end (fig. 32).

With time, the North Overton Bottoms pilot chute may have evolved to the conceptual slow, shallow, meandering channel envisioned in the design documents (U.S. Army Corps of Engineers, 1999b). However, the chute showed remarkable stability even after being subjected to floods of 2-5 and 5-10 year recurrence (fig. 33). The most dynamic geomorphic change during this period was the accumulation and flushing of LWD. LWD is considered to be an important aspect of river ecosystems (Orth and White, 1999) and is thought to be greatly diminished in the Missouri River compared to the historical condition (National Research Council, 2002). The accumulations of LWD in the chute presented substantial ecological value as they provided stable substrate for invertebrates, cover for fish species, and organic material for energy. In contrast to depth and velocity contributions of chutes, which overlap with depths and velocities provided by the main channel, LWD is a unique ecological feature of side-channel chutes. LWD is extremely scarce in the main channel of the Lower Missouri River. In addition, the limited bank erosion that was noted in the North Overton chute was associated with secondary flows around the margins of the LWD rafts, indicating that LWD could eventually contribute to development of physical habitat diversity. From an engineering perspective, however, the LWD accumulations also had the potential to cause unpredictable erosion or sedimentation. In response to the LWD accumulation, evidence of aggradation, and lower-than-expected flows in the chute, the chute was adaptively redesigned in spring 2003 to create a much wider, deeper, shorter and steeper channel that would receive more flow, more frequently through the inlets and outlets. Monitoring of this new phase of the experiment is continuing and performance will be documented in a future report.

Summary and Conclusions

Hydrologic, hydraulic, and geomorphic characteristics of four side-channel chutes in the Lower Missouri River document a wide range of physical habitat potential. The Cranberry Bend side-channel chute has existed for at least 40 years and is an example of a persistent, minimally engineered chute. The Lisbon Bottom side-channel chute was created by extreme floods during 1993 – 1996 and was allowed to evolve with minimum engineering. The Hamburg Bend and North Overton Bottoms side-channel chutes were constructed in 1996 and 2000, respectively, as part of the Missouri River Bank Stabilization and Navigation Fish and Wildlife Mitigation Project.

All of the side-channel chutes provide increased areas of shallow, slow water habitat (SWH) to the total available in the river corridor. Depths and velocities measured in side-channel chutes are also present in the main channel, but the chutes provide additional areas of SWH and they increase the range of discharges over which SWH is present. The 2.2 mile long Lisbon Bottom chute, for example, provides as much as 50% of all of the shallow water habitat that exists in the encompassing 9.6 mile reach of the river. At Cranberry Bend and Lisbon Bottom, the side-channel chutes provided 10 – 40% of the available sandbar area in the encompassing reaches, depending on discharge. Each of the side-channel chutes shows evidence of continuing erosion and deposition. The longevity of the Cranberry Bend chute attests to dynamic stability – that is, a chute that maintains form and processes while shifting in position. The Hamburg Bend chute similarly shows evidence of lateral movement and construction of flood plain to compensate for erosion. The Lisbon Bottom chute – the most intensively studied chute – appears to have achieved an equilibrium width and continues to migrate slowly; however, evidence of aggradation indicates that the chute has not reached an ultimate form, and may be continuing to adjust to altered hydrology and sediment availability. The North Overton Bottoms chute, the newest chute in the study, was originally constructed as a pilot chute that was meant to erode. However, the chute proved to be extremely stable, even while being subjected to two floods in excess of 2-year recurrence interval and after accumulating large, potentially destabilizing LWD jams. Ongoing adaptive re-engineering of the Overton chute has prevented assessment of how the chute might have adjusted its form in the absence of intervention.

While the side-channel chutes studied for this report are currently providing substantial areas of sandbar and shallow-water habitats, ongoing geomorphic adjustment of the chutes makes prediction of their ultimate habitat contribution uncertain. Continued monitoring of physical habitat and biological responses will be necessary to understand their long-term contribution to restoration and management of the Lower Missouri River.

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