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Effects of a 2006 High-Flow Release from Tiber Dam on Channel Morphology at Selected Sites on the Marias River, Montana

By Gregor T. Auble and Zachary H. Bowen

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
	Hydraulic gradient	
meter per kilometer (m/km)	5.27983	foot per mile (ft/mi)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Vertical coordinate data was determined relative to the North American Vertical Datum of 88 (NAVD88). Horizontal coordinate data was determined relative to the North American Datum of 83(99) (NAD83[99]).

Effects of a 2006 High-Flow Release from Tiber Dam on Channel Morphology at Selected Sites on the Marias River, Montana

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Executive Summary

In June 2006, an opportunistic high-flow release was made from Tiber Dam on the Marias River in Mont., to investigate possible alternatives for partially restoring the river's natural flow pattern and variability. At two sites along the river, we measured channel geometry before and after the high-flow release to evaluate channel change and alteration of physical habitat.

Streamflow downstream from Tiber Dam has been stabilized by reduction of high flows and augmentation of low flows. This has produced flood-control benefits as well as some possible adverse environmental effects downstream from the dam. The 2006 high-flow release resulted in a downstream hydrograph with high flows of above-average magnitude in the post-dam flow regime of the Marias River. Timing of the peak and the declining limb of the release hydrograph were very similar to a historical, unregulated hydrograph of the Marias River. Furthermore, the high flow produced many of the qualitative elements of ecologically important physical processes that can be diminished or lost due to flow stabilization downstream from a dam. Typically dry back channels were occupied by flowing water. Islands were inundated, resulting in vegetation removal and sediment accretion that produced new disturbance patches of bare, moist substrate. Cut banks were eroded, and large woody debris was added to the river and redistributed. Flood-plain surfaces were inundated, producing substantial increases in wetted perimeter and spatially distinctive patterns of deposition associated with natural levee formation.

The scale of the 2006 high flow—in terms of peak magnitude and the lateral extent of bottomland influenced by inundation or lateral channel movement—was roughly an order of magnitude smaller than the scale of an infrequent high flow in the pre-dam regime. Overall extent and composition of riparian vegetation will continue to change under a scaled-down, post-dam flow regime. For example, the importance of the non-native Russian-olive (*Elaeagnus angustifolia*) will likely increase. Reestablishing a more natural pattern of flows, however, should promote the increase of native cottonwood and willow (*Salix* spp.) in the new—albeit smaller—post-dam riparian ecosystem. A more natural flow regime will also likely provide improved habitat for native fish in the Marias River. Response of fish communities to such flows is the subject of current fisheries studies being conducted in cooperation with Bureau of Reclamation.

Introduction

Dams affect downstream riverine ecosystems through a complex and interacting set of changes. Flood control is one of the central purposes of dam construction. At the same time, there has been increasing interest in mitigating the adverse effects of dams on downstream biological resources and ecosystems that depend on historical flooding patterns. In recognition of the multiple components that compose natural (pre-dam) flow regimes that contributed to the natural functioning of riverine ecosystems, mitigation of dam effects is evolving from minimum-flow constraints or single-flow specifications to considerations of flow variability (Poff and Ward, 1989; Petts, 1996; Poff and others, 1997; Sparks and others, 1998). On a number of rivers, changes in dam operations, including prescribed high flows, are being explored to regain some characteristics of their natural flow regimes and benefit downstream biological resources (Michener and Haeuber, 1998; Richter and others, 2006).

Tiber Dam was constructed on the Marias River in the mid-1950s for purposes of flood control and water supply. Construction of Tiber Dam and storage of water upstream in Lake Elwell have substantially altered the flow regime of the Marias River downstream to its confluence with the Missouri River near Loma, Mont., and have influenced flows on the Missouri River between the confluence and the downstream Fort Peck Reservoir (Rood and Mahoney, 1995; Bovee and Scott, 2002). Changes in the downstream environment include reduced sediment supply (Rood and Mahoney, 1995), modified water temperature and quality (Stober, 1962, 1963), attenuation of high flows, and augmentation of low flows (Rood and Mahoney, 1995).

Tiber Dam has achieved flood control, most notably in the floods of 1964 when it substantially reduced downstream flooding and flood damage (Boner and Stermitz, 1967). Concern over biological effects in the downstream riverine environment has focused on two areas: (1) changes in riparian vegetation and (2) effects on the endangered pallid sturgeon (*Scaphirhynchus albus*) and other native fish species. Riparian vegetation has been changing under the more-stabilized flow regime: disturbance-dependent native cottonwood (dominantly *Populus deltoides* and *P. angustifolia*) and willow (*Salix* spp.) have been declining, whereas the non-native Russian-olive (*Elaeagnus angustifolia*) has been increasing (Rood and Mahoney, 1995; Lesica and Miles, 1999, 2001). Although multiple factors are influencing these changes, including beaver (*Castor canadensis*) herbivory on cottonwood and anthropogenic introduction of Russian-olive, the basic mechanisms are well understood. Cottonwood and willow generally depend on bare, moist sites for effective regeneration from seed. Under the stabilized flow regime, flooding and channel movement are diminished; thus, creation of these sites in the bottomland is much reduced.

The endangered pallid sturgeon was once widespread in the Missouri and Mississippi Rivers. Currently (2007), there is a small population in Mont. upstream from Fort Peck Dam on the main-stem Missouri River; however, it is not clear whether this population is self-sustaining. Information gaps in the pallid sturgeon's life history and habitat requirements have precluded scientists from determining why the pallid sturgeon is declining (Dryer and Sandvol, 1993). Among the suspected causes, however, are anthropogenically driven habitat changes, barriers to migration and dispersal, and reduced food resources (Dryer and Sandvol, 1993). Historically, flooding likely played a crucial role in the species' life cycle by prompting spawning migrations and creating suitable sturgeon spawning and brood-rearing habitats; flooding also created suitable habitat for sturgeon prey, including macroinvertebrates and fish (Carlson and others, 1985).

A high-flow release was made from Tiber Dam in June 2006, as an experiment to reestablish some of the variability that characterized the natural (pre-dam) flow regime. Several studies were conducted to evaluate environmental responses to this release, the primary focus of which was direct measurements of fish responses. The work reported here entailed measurements of water surfaces and channel geometry before and after the prescribed high flow to examine both the expansion of aquatic habitat during a managed high flow and the extent of channel change produced by the high flow.

Marias River Site Description

Setting

The Marias River begins at the confluence of Cut Bank Creek and Two Medicine River in north-central Mont. (fig. 1). With headwaters east of the Continental Divide, the Marias River flows generally northwest to southeast through gently rolling prairie and eventually discharges to the Missouri River near Loma, Mont.. The soils and geology of the area downstream from Tiber Dam were extensively influenced by Pleistocene glaciation. Loam and clay-loam topsoils of the upland plains overlie 30–80 m of glacial till (Garvin and Botz, 1975). The Marias River meanders through a 1- to 2-km-wide bottomland flanked by steep buttes up to 60 m high (Gardner and Berg, 1983). Multiple cut-fill cycles have produced terraces in the valley-bottom alluvium, and only in deeper sections has the channel cut through glacial deposits to expose bedrock (Smith and others, 1959).

The semiarid, continental climate of the study area is characterized by 25–30 cm of annual precipitation, frigid winters, warm to hot summers, and a growing season of 110–130 days (Jones, 2003). Upland vegetation is shrub-steppe or mixed-grass prairie (Lesica and Miles, 2001). Dominant upland species are big sagebrush (*Artemisia tridentata*) and perennial grasses, including needle and thread (*Hesperostipa comata*), western wheatgrass (*Pascopyrum smithii*), and blue grama (*Bouteloua gracilis*). In the river valley, high terraces are dominated by silver sagebrush (*Artemisia cana*), western wheatgrass, green needlegrass (*Nassella viridula*), Kentucky bluegrass (*Poa pratensis*), and smooth brome (*Bromis inermis*). Lower bottomland surfaces support cottonwood (dominantly *Populus deltoides* along with some *P. angustifolia* and hybrids between them downstream from Tiber Dam), willow (*Salix exigua*, *S. lutea*, *S. amygdaloides*), Russian-olive (*Elaeagnus angustifolia*), silver buffaloberry (*Sheperdia argentea)*, box elder (*Acer negundo*), redosier dogwood (*Cornus sericea*), chokecherry (*Prunus virginiana*), western snowberry (*Symphoricarpos occidentalis*), and Woods' rose (*Rosa woodsii*), as well as hydrophytic grasses, sedges, and bulrushes (Lesica and Miles, 1999, 2001; Jones, 2003).

Hydrology

Tiber Dam and the 37-km-long reservoir (Lake Elwell) impounded by the dam separate the Marias River into its upper and lower reaches (fig. 1). Including Lake Elwell, the upper reach is about 137 km long and the lower reach is about 135 km. Elevations along the river drop from about 1,005 m at the Cut Bank Creek–Two Medicine River confluence to about 865 m downstream from the dam and about 790 m at the river's confluence with the Missouri River. This represents an average gradient of less than 1.0 m/km (0. 104–0.85 m/km; Stober, 1963). Tiber Dam, completed in 1956 for flood control and to provide irrigation water for the region east of the dam (Smith and others, 1959; U.S. Bureau of Reclamation, 2007), is 60 m high and has an outlet works design capacity of 165.5 m^3/s. In the early 1960s, Lake Elwell had a

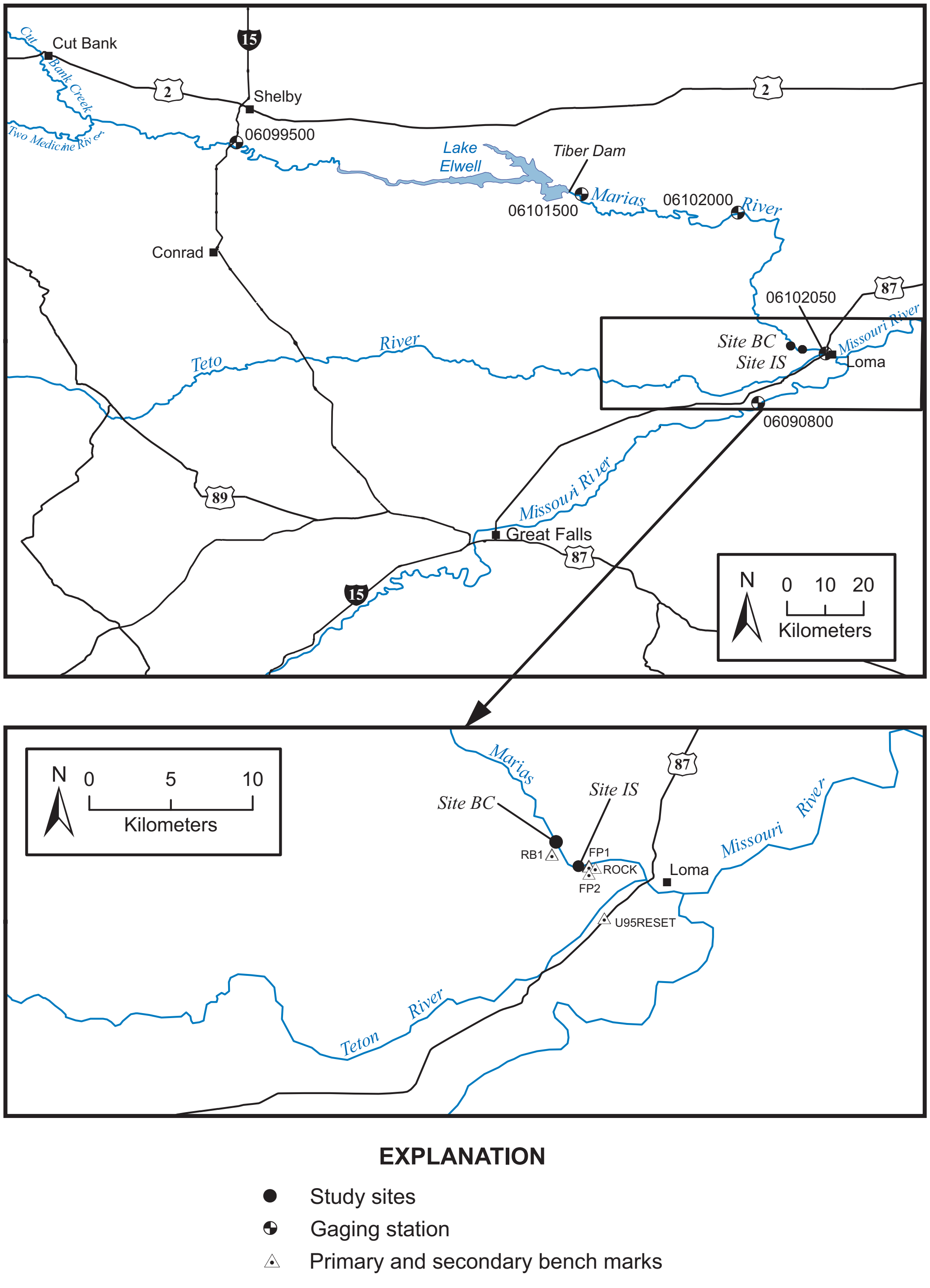


Figure 1. Marias River. Intensive study sites, primary and secondary benchmarks, and selected U. S. Geological Survey gaging stations are indicated by symbols described in the figure explanation.

minimum and maximum capacity of 7.09×10^8 and 1.65×10^9 m^3, respectively (Stober, 1963). From the Cut Bank–Two Medicine confluence to Lake Elwell, the Marias River flows through relatively undeveloped regions (Rood and Mahoney, 1995).

Streamflow records (U.S. Geological Survey, 2007) from four gages provide the basic data for describing the effects of Tiber Dam on the hydrology of the lower Marias River and for placing the 2006 high-flow release in a historical context. The gage Marias River near Shelby, Mont., (unique identification number 06099500) is upstream from Lake Elwell (fig. 1) and has the longest period of record, from 1902 to present, although data for several years before 1920 are missing. The gage Marias River near Brinkman, Mont. (06102000) functioned from 1921 through 1956, before the completion of Tiber Dam. The Marias River near Chester, Mont. (06101500) gage replaced the Brinkman gage and is the gage measuring streamflow immediately downstream from Tiber Dam, with records from 1955 to present (fig. 1). The Marias River near Loma, Mont. (06102050) gage is close to the confluence with the Missouri River and is the nearest gage to our intensive study sites (fig. 1). This gage operated from 1959 through 1972 and seasonally from 2003 to present.

Our analysis of streamflow is based on mean daily flows and annual peak flows downloaded from the national data base of streamflow records (U.S. Geological Survey, 2007). We summarized annual values by water year (for example, water year 2005 is October 2005 through September 2006). Peak values are maximum instantaneous discharges as reported in peak values files for the respective gages (U.S. Geological Survey, 2007). The substitution of annual maximum mean daily discharge for gage 06099500 was used in 1947 when peak discharge was missing from the peak values file.

Tiber Dam was constructed for purposes of water storage and flood control. Those purposes have been achieved as clearly indicated by the contrast between pre-dam mean daily hydrographs from gage 06099500 (upstream from Lake Elwell, fig. 1) and gage 0610200 near Tiber Dam before it was constructed with post-dam mean daily hydrographs from above and below the dam (gages 06099500 and 06101500, respectively) (fig. 2). High flows in April through June have been substantially reduced, and low flows throughout most of the rest of the year have been augmented.

The flood-control effectiveness of Tiber Dam is further evident from comparing annual peak flows at the gage upstream from the dam to gages near the dam before and after dam completion in 1956 (fig. 3). From 1957 to 2006, the 165.5 m^3/s design capacity of the outlet works at Tiber Dam has been exceeded in only 1964 (2 percent of years at gage 06101500). In contrast, gage 06099500 above Tiber Dam had flows above 165.5 m^3/s in 46 percent of the years during the same interval. The highest post-dam discharge downstream from Tiber Dam was 294.5 m^3/s in 1964. This discharge was exceeded in 18 percent of the years in the same interval upstream from the dam with 2 years (1964 and 1975) having discharges greater than 2,000 m^3/s upstream from the dam (fig. 3). Pre-dam records from upstream and downstream from the dam location indicate that discharges substantially above 165.5 m^3/s occurred in many years before construction of Tiber Dam. Gage 06099500 above the dam had discharges that exceeded 165.5 m^3/s in 47 percent of the years 1922–1955, whereas gage 6102000 downstream from the dam exceeded 165.5 m^3/s in 41 percent of the years in the same interval.

Information about flows before 1920 is progressively less certain and more indirect farther back in time. Gage 06099500 began operation in 1902 but is missing 4 years of record. The record at this gage indicates that flows exceeded 165.5 m^3/s in 62 percent of years before 1922. Based on a discharge of 1,982 m^3/s for gage 06102000 on the Marias River in 1908 and on high flows in 1908 and 1909 at gage 06090800 at Fort Benton on the Missouri River, it seems likely that flows exceeded 165.5 m^3/s on the Marias River in 12 of 20 years (60 percent) between

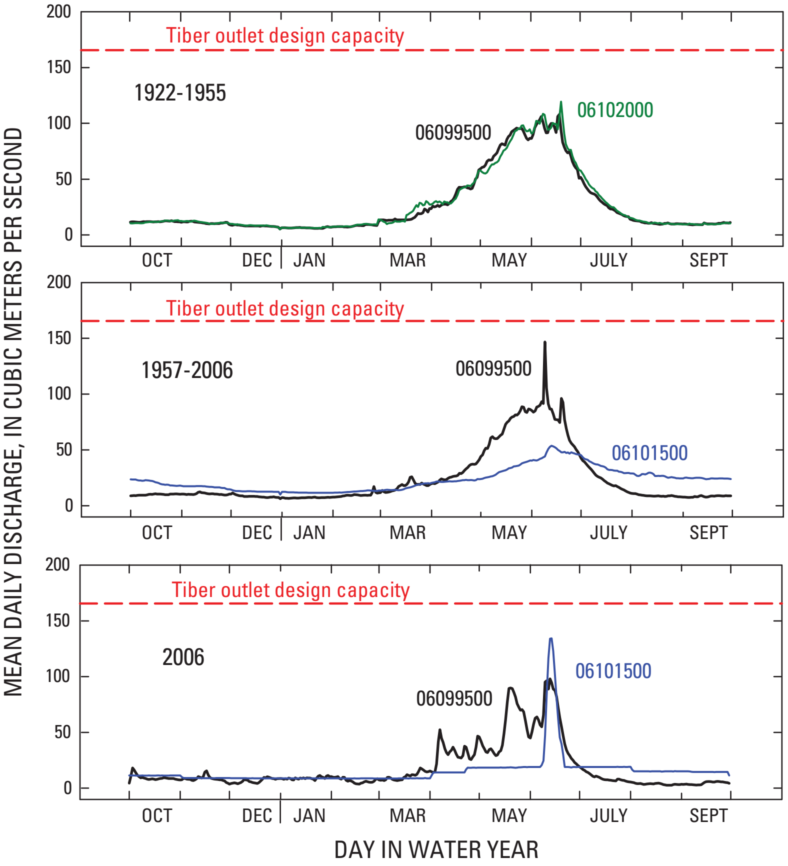


Figure 2. Mean daily discharge at selected Marias River gages in 2006 and in periods before (1922–1955) and after (1957–2006) Tiber Dam. Gage 06099500 is upstream from Tiber Dam and gages 06101500 and 06102000 are downstream from the dam (fig. 1).

1902 and 1921. The gage at Fort Benton on the main-stem Missouri River began operation in 1891, although records before 1901 are relatively unreliable. However, the regional nature of flooding in many of the years of highest flows (Boner and Stermitz, 1967; U.S. Geological Survey, 1949, 1957) and the correspondence of years with high flows on both rivers (for example, 1916, 1927, 1948, 1953, 1964, 1975) suggest that gage 06090800 on the Missouri provides some indication of what flows were like on the Marias River. Although less reliable, these records indicate that the period 1891 to 1901 was wetter—more years with high flows—than any 20-year period since 1920. Only indirect evidence is available for streamflow before 1890. Intensive work on the age structure of flood-plain trees on the Yellowstone River in central Mont. suggests that a disproportionately larger fraction of the Yellowstone River bottomland was disturbed in the mid-1800s than has been the case since 1920 (Merigliano and Polzin, 2003). Direct correlation between streamflow on the Yellowstone River and Marias River is questionable because of the distance between the headwaters and potentially different weather patterns. Results of Merigliano and Polzin (2003) do suggest that peak flows on the Yellowstone River in the east side of the Continental Divide in Mont. were at least as large and frequent, and probably somewhat larger and more frequent, in the latter half of the 1800s than they have been since 1920.

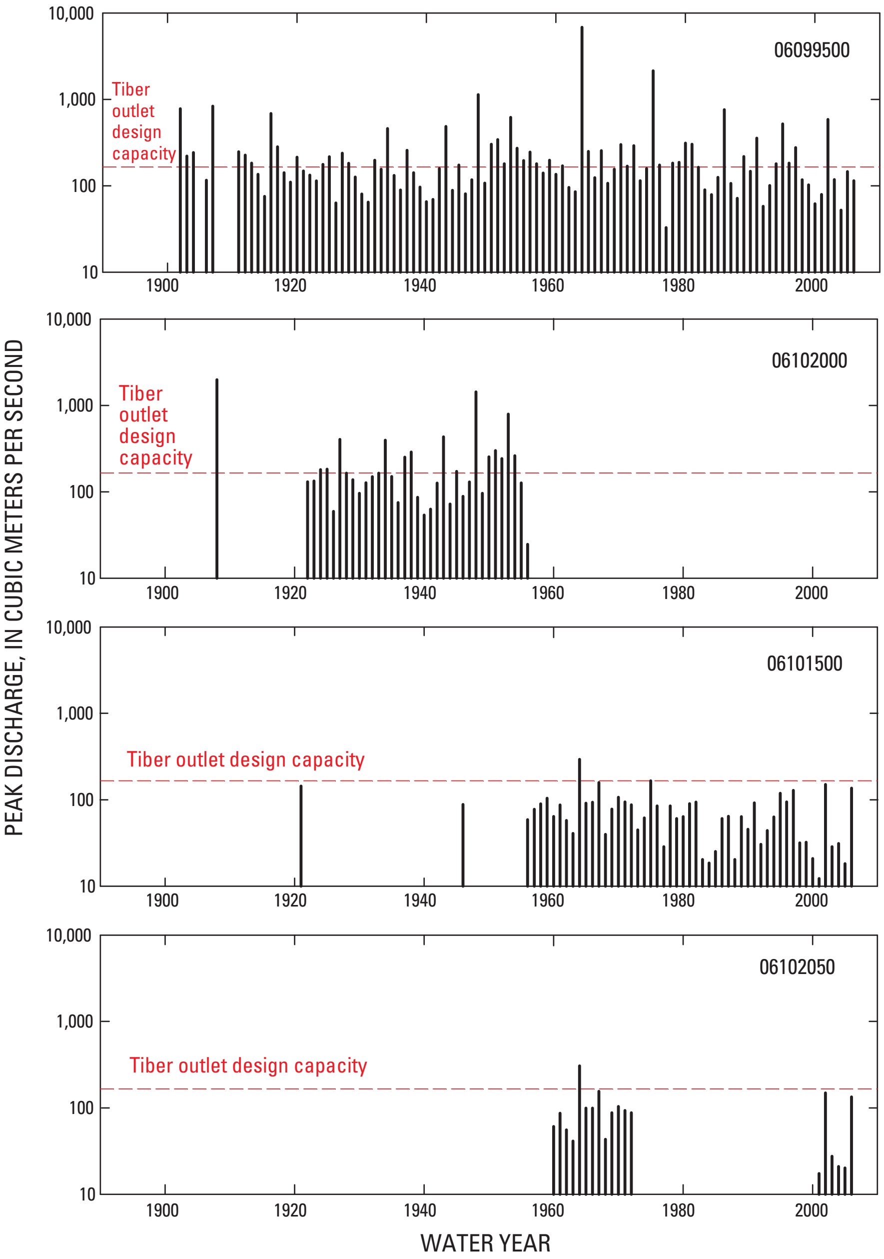


Figure 3. Annual peak discharge at selected Marias River gages. Gage 06099500 is upstream from Tiber Dam and gages 06101500, 06102000, and 06102050 are downstream from the dam (fig. 1). Annual maximum mean daily discharge is used in place of peak discharge for all gages in 2006 and for gage 06099500 in 1947.

The flood of 1964 was an exceptional event that deserves special discussion. This was the only time since completion of Tiber Dam that releases exceeded the design capacity of the outlet works. Heavy rains on June 7–8, 1964, combined with late snowmelt runoff to produce widespread regional flooding in northwestern Mont., with streams recording peak discharges 2 to 11.5 times their probable 50-year floods (Boner and Stermitz, 1967). Similar heavy rains combined with snowmelt in late May–June also produced widespread regional flooding in 1948 and 1953 (U.S. Geological Survey, 1949, 1957). In 1964, however, flooding on the Marias River was exacerbated by failures of two irrigation dams and a community water-supply dam on tributaries. The most catastrophic failure was Swift Dam on Birch Creek, a tributary to Two Medicine River, which joins with Cut Bank Creek to form the Marias River (fig. 1). Peak discharge on Birch Creek 27 km downstream from the failed Swift Dam was estimated as 24,950 m^3/s. Peak discharge at Shelby, Mont., on the Marias River (gage 06099500) was 6,825 m^3/s (fig. 3). Tiber Dam was effective in storing the vast majority of this water in Lake Elwell, attenuating the peak flow on the Marias River to 295 m^3/s at gage 06101500 downstream from the dam (fig. 3).

Ice damming and mechanical breakup of ice dams are important, though episodic, influences on channel form and bottomland disturbance of many northern rivers. Winter ice has been identified as an important control on the extent of riparian cottonwood on several rivers in north-central Mont., including the Missouri River downstream from the confluence with the Marias (Scott and others, 1997; Auble and Scott, 1998) and the Milk River upstream from Fresno Dam (Smith and Pearce, 2000). Significant winter ice occurs on the Marias River. At gage 06099500 upstream from Tiber Dam, 25 percent of the 56 years since 1948 with records of both maximum stage and maximum discharge had maximum stages (generally ice-related in February and March) that were not associated with the maximum discharge of the year.

Much of the preceding discussion of hydrology has focused on the storage-based role of Tiber Dam in redistributing water volumes over time—attenuating peaks and augmenting low flows. Total flow volume also changes from upstream to downstream as a function of tributary and ground-water inflows, seepage loss to ground water, irrigation and other withdrawals, and evaporation from reservoir storage pools. Before construction of Tiber Dam (interval 1922–1955), the overall mean daily discharge was 26.2 m^3/s at the upstream gage 06099500 with a slight increase to 26.9 m^3/s at gage 06102000 in the vicinity of the dam. In the interval 1956–2006 following dam construction, the overall mean discharge at the upstream gage 06099500 was 23.5 m^3/s compared to a slightly lower value of 23.2 m^3/s at gage 06101500 downstream from Tiber Dam. Fewer records are available for the change in discharge from near Tiber Dam farther downstream to gage 6102050 near Loma, Mont., and recent records for 06102050 are only seasonal. We compared differences in mean daily discharge by individual month (May through October) between gage 06101500 immediately downstream from Tiber Dam and gage 6102050 near Loma for the post-dam periods 1960–1972 and 2001–2006 when both gages were operating (fig. 4). The early period of Tiber Dam operation showed a spread of differences by month and year roughly centered on no net change. The short period of record since 2001 has a tighter cluster of differences more consistently representing a net depletion of water during May through October.

Cottonwood and Russian-olive

Declines in riparian cottonwood (*Populus* spp.) forests downstream from dams have been noted on multiple rivers draining the Rocky Mountains in Mont. and southern Canada (Rood and Heinze-Milne, 1989; Rood and Mahoney, 1990). Rood and Mahoney (1995) found a severe deficiency of cottonwood seedlings downstream from Tiber Dam on the Marias and predicted a progressive decline of riparian cottonwood forests downstream from the dam in the absence of a more dynamic river flow pattern. Multiple species of cottonwood and hybrids between them grow along the Marias River—plains cottonwood (*Populus deltoides*), narrowleaf cottonwood (*P. angustifolia*), black cottonwood (*P. trichocarpa*), and possibly balsam poplar (*P. balsamifera*). Cottonwood in the vicinity of our study sites on the lower Marias near the

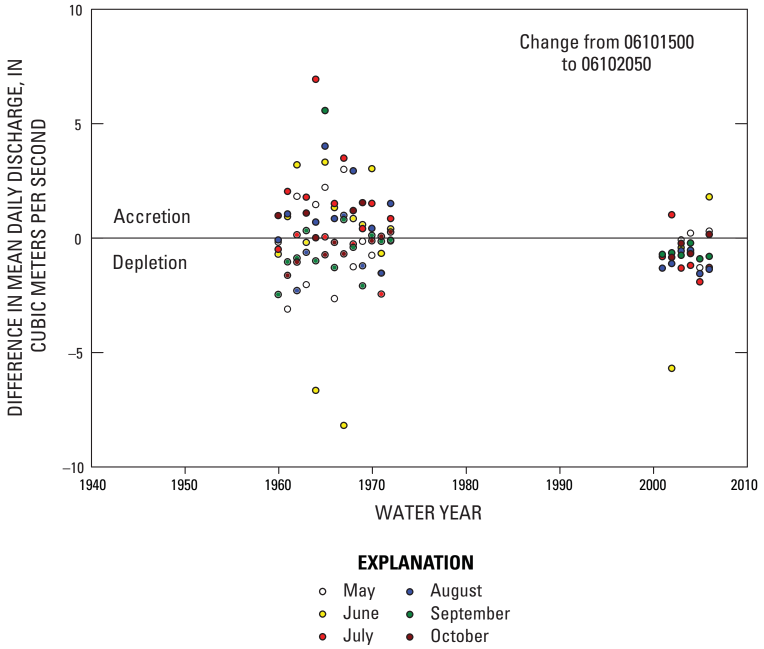


Figure 4. Changes in mean daily discharge by month and year from gage 06101500 to gage 06102050. Gage locations are illustrated in figure 1.

confluence with the Missouri were plains cottonwood along with some possible hybrids with narrowleaf cottonwood. Rood and Mahoney (1995) reported no problem with the health of mature cottonwood downstream from Tiber Dam. They suggested several possible mechanisms for the lack of seed regeneration downstream from the dam: (1) reduced flooding disturbance has led to encroachment of competing grass, shrubs, and sedges; (2) altered hydrographs do not provide spring peak and gradually declining stage most suitable for cottonwood seed establishment; and (3) reduced geomorphic change has limited the creation of suitable bare, moist sites. Additionally, they suggest that (4) sediment trapping behind the dam has limited expansion of suitable bare, moist point bars; and (5) reduced flooding and sediment supply may have resulted in channel incision and reduction of suitable establishment sites.

Downstream response of the riparian forest to Tiber Dam has been complicated by the introduction of Russian-olive (*Elaeagnus angustifolia*), a small, nitrogen-fixing species of tree planted for windbreaks and wildlife enhancement (Lesica and Miles, 1999, 2001). Russian-olive has large, predominantly animal-dispersed seeds that can germinate at various times under a variety of shade conditions—in contrast to the short-lived, early-summer-released seeds of cottonwood that establish well only on bare open sites (Shafroth and others, 1995). Although the increase and spread of Russian-olive is slow because of reproductive rate per tree and the roughly 10 years required to reach reproductive maturity, it is capable of becoming established in the understory of existing mature cottonwood. Thus, Russian-olive is replacing cottonwood in areas of the bottomland that are still close enough to alluvial ground water to support trees, but that are no longer subject to the physical disturbances of flooding, erosion, and deposition that create suitable seedling establishment sites for the native cottonwood and willow. This replacement under a more stabilized flow regime is further enhanced by differential beaver herbivory that is more focused on cottonwood than Russian-olive (Lesica and Miles, 2001; Pearce and Smith 2001).

Limnology and Aquatic Communities

Stober (1962, 1963) conducted basic limnological studies on the Marias River at a station 16 km upstream from Lake Elwell, within the reservoir, and at a number of stations in the 130-km reach downstream from Tiber Dam to near Loma where the Teton River enters the Marias. Summer water temperatures and turbidity downstream from Tiber Dam were influenced by the volume of lake release and depth within the lake from which the release was made, as well as atmospheric conditions. In summer of 1961, average daily water temperatures were 11° C cooler immediately downstream from the dam than upstream from the dam. Tiber Dam had a marked effect on river water temperatures for at least 38 km downstream, with stations farther downstream approaching the temperature regime of the river upstream from Lake Elwell. Turbidity (measured as suspended material in mg/L) ranged from 1.8 to 75 mg/L in spring–summer of 1960 and 4 to 63 mg/L in 1961, with maximum values associated with spring runoff. Turbidity was generally reduced downstream from the dam, with a gradual increase with increasing distance downstream. A station immediately downstream from the dam ranged from 0.06 to 6.0 mg/L in 1960 and 0.11 to 33 mg/L in 1961. Corresponding values approximately 130 km downstream from the dam were 0.59 to 28.5 mg/L in 1960 and 3.1 to 465 mg/l in 1961. These measurements are consistent with the "silt shadow" observed by Rood and Mahoney (1995) based on June 27, 1991, suspended-sediment samples at four stations in a 35-km reach upstream from Lake Elwell and five stations in a 35-km reach downstream from Tiber Dam. Stations upstream from the dam averaged from 0.17 to 0.31 mg/L, whereas the station immediately downsteam from Tiber Dam had an average value of less than0.02 mg/L, with concentrations increasing to 0.10 mg/L 35 km downstream from the dam.

Total dissolved solids (mg/L) reported by Stober (1962) were 395 mg/L 16 km upstream from Lake Elwell, 429 mg/L 1.6 km below Tiber Dam, and 392 mg/L 48 km below the dam. Spot measurements of pH by Stober (1962) on August 2, 1960, were 7.5 upstream from Lake Elwell and 7.6 downstream from the dam. Individual measurements of pH reported by Garvin and Botz (1975) include values of 6.9 and 7.7 well upstream from Tiber Dam near Shelby, Mont., on June 14 and October 4, 1950; 8.0 immediately downstream from Tiber Dam on October 18, 1973; and 8.5 downstream from Tiber Dam near Loma, Mont., on April 17, 1974.

Stober (1962, 1963) found generally low densities of phytoplankton in the river and Lake Elwell, with somewhat lower densities in the river downstream from the dam. Dense mats of filamentous algae (*Cladophora* spp.) were observed in riffle areas in the first 10 km downstream from the dam. Gardner and Berg (1983) noted similar importance of aquatic vegetation in the 8-km reach downstream from Tiber Dam. *Cladophora* spp. dominated immediately downstream from the dam in 1982, with substantial amounts of *Chara* spp. (stonewort) and some *Potamogeton* spp. (pondweed) farther downstream. Phytoplankton at downstream stations was largely indigenous and not contributed by the reservoir. Diatoms constituted more than 90 percent and 85 percent of the phytoplankton at all river stations in 1960 and 1961, respectively.

Stober (1962, 1963) found that zooplanton was generally scarce in the Marias River, with greater average densities downstream from the dam than upstream, but with a decrease in densities with distance downstream from the dam. Posewitz (1962), Berg (1981), and Gardner and Berg (1983) reported sampling of macroinvertebrate communities from the Marias River downstream from Tiber Dam. The aquatic macroinvertebrate community in the 34-km reach immediately downstream from Tiber Dam was relatively simple compared to stations farther downriver. In 1982, the below-dam reach was dominated by mayflies (Ephemeroptera), caddisflies (Trichoptera), true flies (Diptera), and stoneflies (Plecoptera), constituting 56, 22, 10, and 9 percent, respectively, of macroinvertebrates collected from kick samples (Gardner and Berg 1983). Sampling by Berg (1981) and Posewitz (1962) indicated a shift toward more silt-tolerant and depositional habitat forms such as *Baetisca* spp., *Hexagenia* spp., *Ephron* spp., *Heptagenia* spp., and *Acroneuria* spp. farther downstream toward the mouth of the Marias River.

Fish community sampling of the Marias River was reported by Gardner and Berg (1982, 1983), Berg (1981), and Posewitz (1962). The 34-km reach downstream from Tiber Dam supports a cold-water fishery, with mountain whitefish (*Prosopium williamsoni*), longnose sucker (*Catostomus catostomus*), and longnose dace (*Rhinichthys cataractae*) the most abundant species. Rainbow and brown trout (*Oncorhynchus mykiss* and *Salmo trutta*) were not abundant but exhibited high growth rates (Gardner and Berg, 1983). Sauger (*Sander canadensis*) abundance increased gradually downstream from Tiber Dam to the mouth of the Teton River and over all was the most common game fish in the Marias River downstream from Tiber Dam (Gardner and Berg, 1982). Berg (1981) reported significant annual spawning migrations of several fish species from the Missouri River into the lower Marias, including sauger, shovelnose sturgeon (*Scaphirhynchus platorynchus*), blue sucker (*Cycleptus elongatus*), smallmouth buffalo (*Ictiobus bubalus*), and bigmouth buffalo (*Ictiobus cyprinellus*). Gardner and Berg (1983) observed shovelnose sturgeon, blue sucker, smallmouth buffalo, and bigmouth buffalo as spawning migrants as far upstream on the lower Marias as the 34-km reach immediately downstream from Tiber Dam.

Pallid Sturgeon

The pallid sturgeon (*Scaphirhynchus albus*) is a bottom dweller of warm, turbid rivers. In 1990, the pallid sturgeon, one of the largest and rarest fish species known to inhabit the Missouri and Mississippi drainages, was listed by the U.S. Fish and Wildlife Service (USFWS) as endangered in USFWS regions 3, 4, and 6 (Dryer and Sandvol, 1993). The species' historical range included the Missouri River, the lower and middle Mississippi River, and the lower reaches of the Kansas, Platte, and Yellowstone Rivers (Bailey and Cross, 1954). Today, however, the pallid sturgeon is believed to occupy little of its original range, and there are only five reaches along the Missouri River and three along the Mississippi River where the species is known to occur with any frequency (Dryer and Sandvol, 1993). Precise causes of pallid sturgeon decline are unclear and include a number of possibilities—habitat changes, barriers to migration and dispersal, reduced food resources, pollution, overfishing, and hybridization with *Scaphirhynchus platorynchus* (Dryer and Sandvol, 1993).

Along the Missouri River, one reach from which the pallid sturgeon is still reported with relative frequency is the reach between its confluence with the Marias River and Fort Peck Reservoir—a large reservoir created in the early 1940s with the completion of Fort Peck Dam. Fisheries biologists, however, believe that the pallid sturgeon population in that reach is not self-sustaining (Dryer and Sandvol, 1993). There are several ways in which dam construction and associated changes in streamflow and the riverine environment may be limiting pallid sturgeon reproduction.

Reproductive life history is believed to have involved movement of adults over large distances to spawn in the spring and early summer, coinciding with the timing of natural high flows. Following successful spawning, larval fish likely drifted substantial distances downstream. Fragmentation of the river corridor by dams may block the spawning movement of adults (for example fish downstream from Fort Peck Dam cannot access spawning locations upstream from Fort Peck). Reduced high flows, reduced sediment supply, and altered water quality downstream from dams may not be providing adequate physical cues (for example, velocity, turbidity, temperature) to trigger adult spawning migration. Altered flow and sediment regimes downstream from dams may not be providing adequate conditions at spawning sites. After spawning, fragmentation of the corridor may not be allowing enough downstream distance for larval and juvenile fish to drift before they encounter unsuitable conditions in reservoirs behind dams (for example, Fort Peck Reservoir). Flow attenuation downstream from dams may be reducing food supply by limiting inputs of organic material from the flood plain and may be decreasing the availability and suitability of shallow, slow-velocity back channels and inundated flood-plain surfaces that young fish encounter as they drift downstream. At a higher level, alteration of streamflow and sediment regimes downstream from dams may have reduced channel and flood-plain heterogeneity by attenuating the geofluvial disturbance processes (for example, channel scouring, aggradation, and meandering) that renew and create spawning, brood-rearing, and feeding habitats (Dryer and Sandvol, 1993).

Effects of a High-Flow Release on Channel Geometry

Methods

We measured topography and water surfaces at 10 cross sections at each of two sites on the lower portion of the Marias River downstream from Tiber Dam (figs. 1 and 5). Cross sections are numbered sequentially in the upstream direction; left and right orientation along each cross section is based on looking downstream, and distances along each cross section increase from 0 at the left head pin. Site IS (Island), which is composed of cross sections 1–10, contains a large channel island on the right (looking downstream) and a steep cut bank at the left channel edge (fig. 6). Site BC (Back Channel) has a narrow island on river left and a distinctive back channel feature on river right (fig. 6). Site BC is composed of cross sections 11–20. Data were collected during three sampling trips. Pre-release measurements were made of topography from May 27 to May 30, 2006, and water surfaces were measured on June 1, 2006. Measurements of water-surface elevations during the high-flow release were conducted on June 14, 2006. Post-release topographic measurements were made September 19–22, 2006.

We determined positions using a survey-grade GPS (Global Positioning System) consisting of a Trimble 4800 base station and rover, a Trimble TSC1 survey controller, and a Trimark radio repeater operating in Real-Time Kinematic (RTK) mode. Survey control was based on an initial base station occupation of National Geodetic Survey (National Geodetic Survey-National Oceanic and Atmospheric Administration, 2006) control point U95RESET (PID AB7734), with site measurements made from secondary benchmarks (fig. 1). Rebar left and right headpins were established for each of the 20 cross sections. Pre-release topography and water-surface surveys were then conducted in a stake-out-to-line mode on lines defined between the head pins for each cross section. These same lines between head pins were also used in a stake-out-to-line survey of water-surface elevations during the high-flow release on June 14, 2006. The post-release survey of topography was conducted in a stake-out-to-point mode reoccupying the points along each cross section from the pre-release topographic survey. Almost all of the surveying was done by wading. Exceptions were the edges of several steep banks and some of the water-surface elevations during the high-flow release (June 14, 2006), which were accomplished from a small boat.

We used Trimble Geomatics Office software to process GPS observations. Horizontal coordinate information is referenced to the North American Datum of 1983 (1999) (NAD 83[99]) and vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88) based on occupation of NGS control point U95RESET (PID AB7734) (National Geodetic Survey, 2006). Tables of horizontal and vertical coordinate data for reference points (benchmarks and head pins), water surfaces, and topographic points along cross

Figure 5. Aerial imagery of study region on lower Marias River from 2005. Head pins of cross sections at Sites IS and BC are depicted as solid circles. Grid lines are Universal Transverse Mercator (UTM, Zone 12) projection of latitude and longitude referenced to NAD 83(99) horizontal datum. Note contrast between width of cross sections containing the post-dam flood plain and the width of the zone containing mature cottonwood trees and relict channel locations. Imagery is from National Agriculture Imagery Program (2005).

sections are available at *http://pubs.usgs.gov/*. These geospatial coordinates are reported as projected in UTM Zone 12 North to two decimal places. We used a combination of SAS 9.1, Excel, WinXSPRO, ArcGIS9.2, and SigmaPlot 10 for data analysis and display.

Results

The high-flow release from Tiber Dam in 2006 occurred in mid-June. Timing of the peak was very close to when the highest average daily flow occurred in the pre-dam period and was essentially identical to when the 2006 peak occurred on gage 06099500 upstream from the dam (fig. 2). Downstream from Tiber Dam, the ascending limb of the hydrograph in April, May, and early June was severely attenuated, but the sharply descending limb following the release was not substantially different from the natural descending limb observed upstream from the dam.

The magnitude of the high-flow release was somewhat higher (maximum daily discharge of 134 m^3/s on June 15 at gage 06101500) than maximum flow upstream from the dam (maximum daily discharge of 98 m^3/s on June 14 at gage 069099500). Although the high flow of 2006 was substantial compared to the annual average of 71 m^3/s for maximum daily discharge downstream from the dam since 1957, it was less than the outlet works design capacity of 165.5 m^3/s. Furthermore, it was a relatively modest high flow compared to unmodified flows as represented either by pre-dam peak flows downstream from the dam or post-dam flows upstream from the dam (figs. 2 and 3).

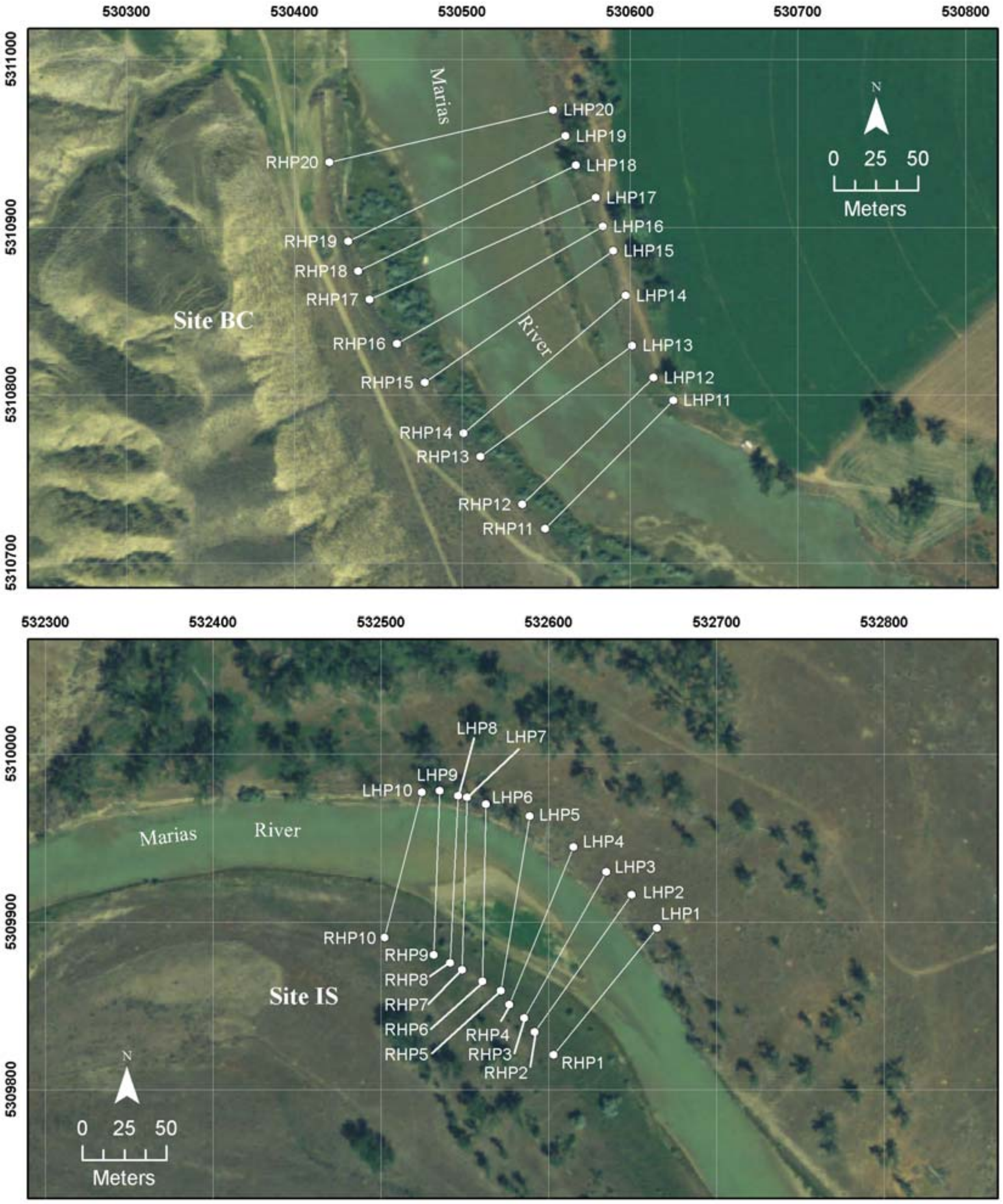


Figure 6. Aerial imagery of Sites IS and BC on Marias River from 2005. Cross sections are numbered in upstream direction with 1–10 at Site IS and 11–20 at Site BC. Solid circles indicate position of left (LHP) and right (RHP) headpins of each cross section. Imagery is from National Agriculture Imagery Program (2005).

Changes in channel morphology for each cross section, along with the observed water-surface elevations, are depicted in figures 7–11 for Site IS and figures 12–16 for Site BC. Discharge values associated with the water surfaces are based on mean daily discharge estimates for gage 06102050 near Loma, Mont., and closest to the study sites. They differ somewhat from the long-term gage 06101500 downstream from the dam in part because of transit time between the gages. Water surfaces for the 19-m^3/s discharge were measured on June 1, 2006, at edges of all flowing channels, with the exception of one aberrant measurement on a slippery bank on the side channel of cross section 8. Here, the side-channel water surface was assumed to be flat using the single reliable edge measurement. Measurements of water surfaces at the high discharge of 109 m^3/s were made on June 14, 2006, and are based on edges of only the main channel, with side-channel elevations plotted as equal to the nearest edge of the main channel for each cross section.

At Site IS the channel bed and channel island were dominantly sand with some gravel. Banks and flood-plain surfaces were composed of sand and smaller particles. The channel at Site BC was dominantly cobbles to small boulders with substantial areas of flat, exposed bedrock. The flood plain and channel island were dominantly sand and finer material with some isolated cobble patches in the back channel.

The most distinctive response at the IS site was aggradation and vegetation removal and burial on the channel island (figs. 7–11, 17, and 18). Before the high-flow release, this island surface was covered by dense herbaceous vegetation, dominantly *Melilotus* spp., with some cottonwood and willow seedlings. The surface was completely inundated by the high flow, vegetation was almost completely removed or buried, and the top of the island aggraded 20 to 100 cm across most of its surface. Aggradation was partially offset by incision in the deeper part of the channel and some erosion from the steep cut bank on river left, looking downstream (for example, cross sections 3 and 4, figs. 8 and 17). A substantial area of low flood plain on the right side of the river was inundated by the high flow without significant overall aggradation or any substantial reduction in vegetative cover. There was some distinctive, though limited, deposition of sand on the bank edge of the flood-plain surface where water depths, velocities, and transport capacity likely declined most quickly (fig. 19 and cross sections 9 and 10 of fig. 11). The high flow at Site IS also resulted in noticeable movement of large woody debris along the bank and caused the collapse of a large dead cottonwood on the lip of the left cut bank of the river (figs. 17 and 18).

The most distinctive response at Site BC was occupation of the back channel on river right at high flow (figs. 12–16 and 20). There was very little channel change at Site BC. There was some aggradation of sediment and movement of large woody debris on the small island on river left and some degradation in the small side channel between this island and the left bank (figs. 12–16 and 21). However, this island was not generally overtopped by the high flow and did not have extensive aggradation or vegetation removal. The back channel on river right (facing downstream) was connected to the main channel at both the upstream and downstream ends (fig. 20) but had very little channel change except for some slight aggradation at the most upstream cross sections (fig. 16).

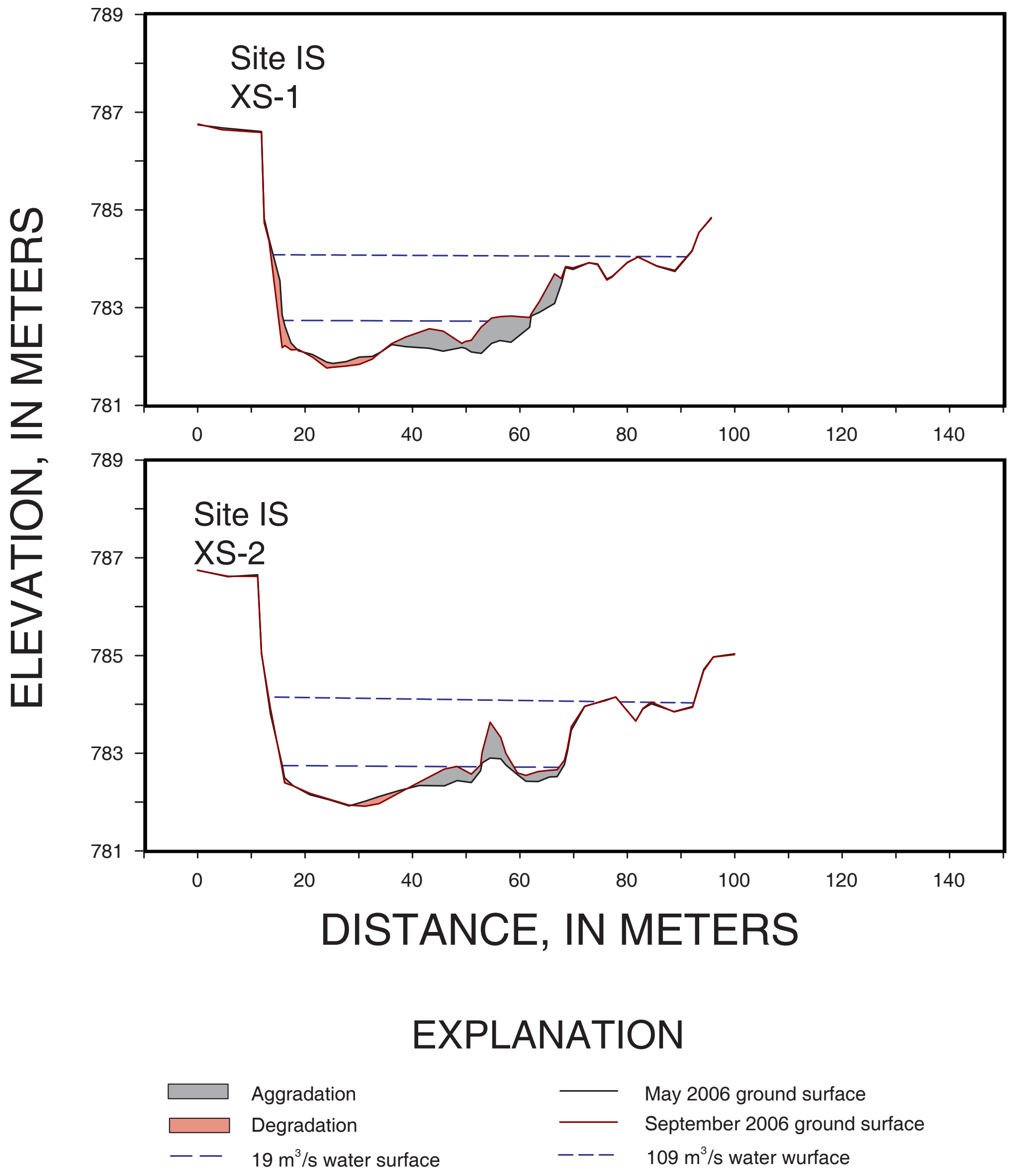


Figure 7. Cross sections 1 and 2 at Site IS. Distance along cross section is from left (facing downstream) to right head pins.

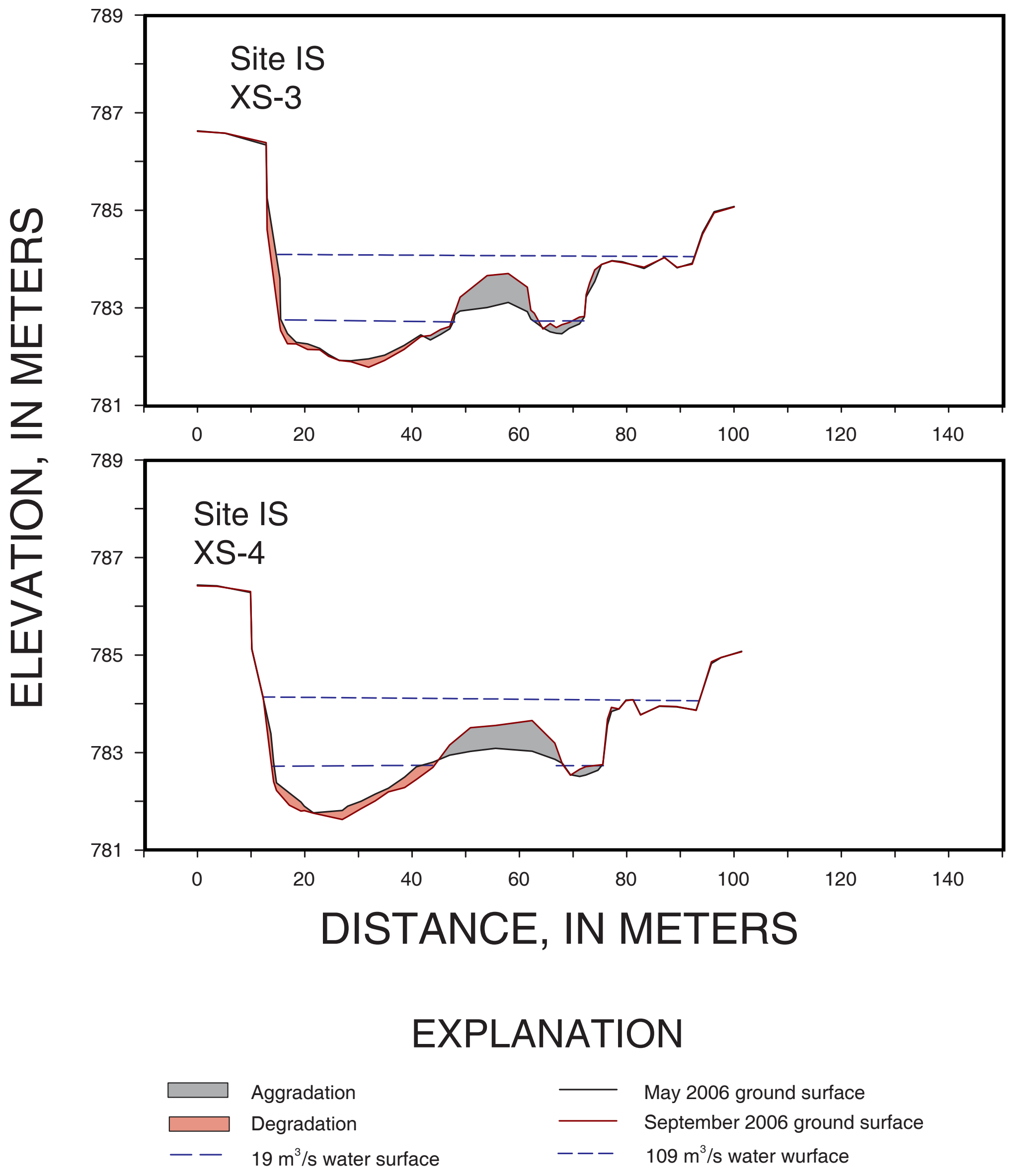


Figure 8. Cross sections 3 and 4 at Site IS. Distance along cross section is from left (facing downstream) to right head pins.

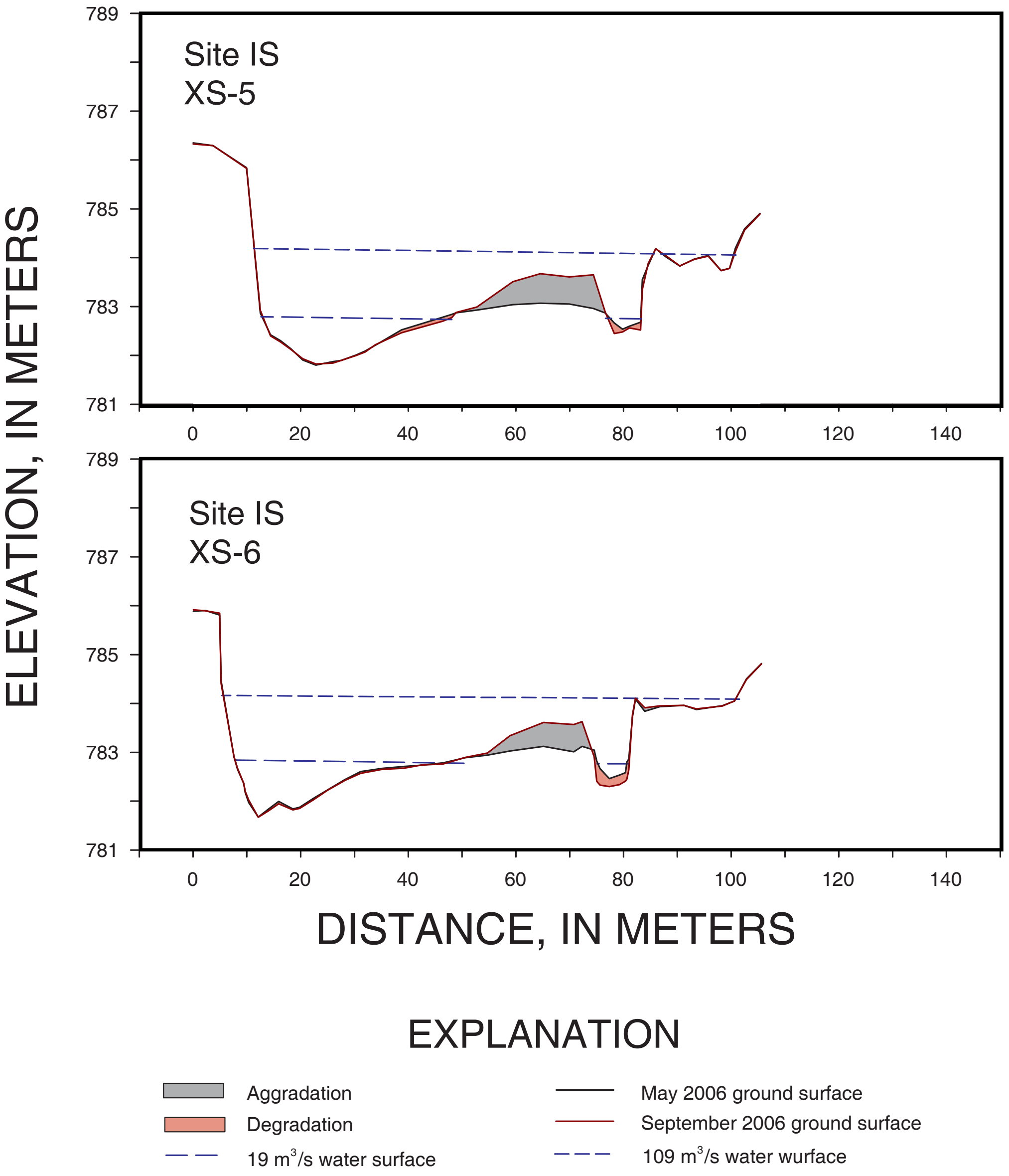


Figure 9. Cross sections 5 and 6 at Site IS. Distance along cross section is from left (facing downstream) to right head pins.

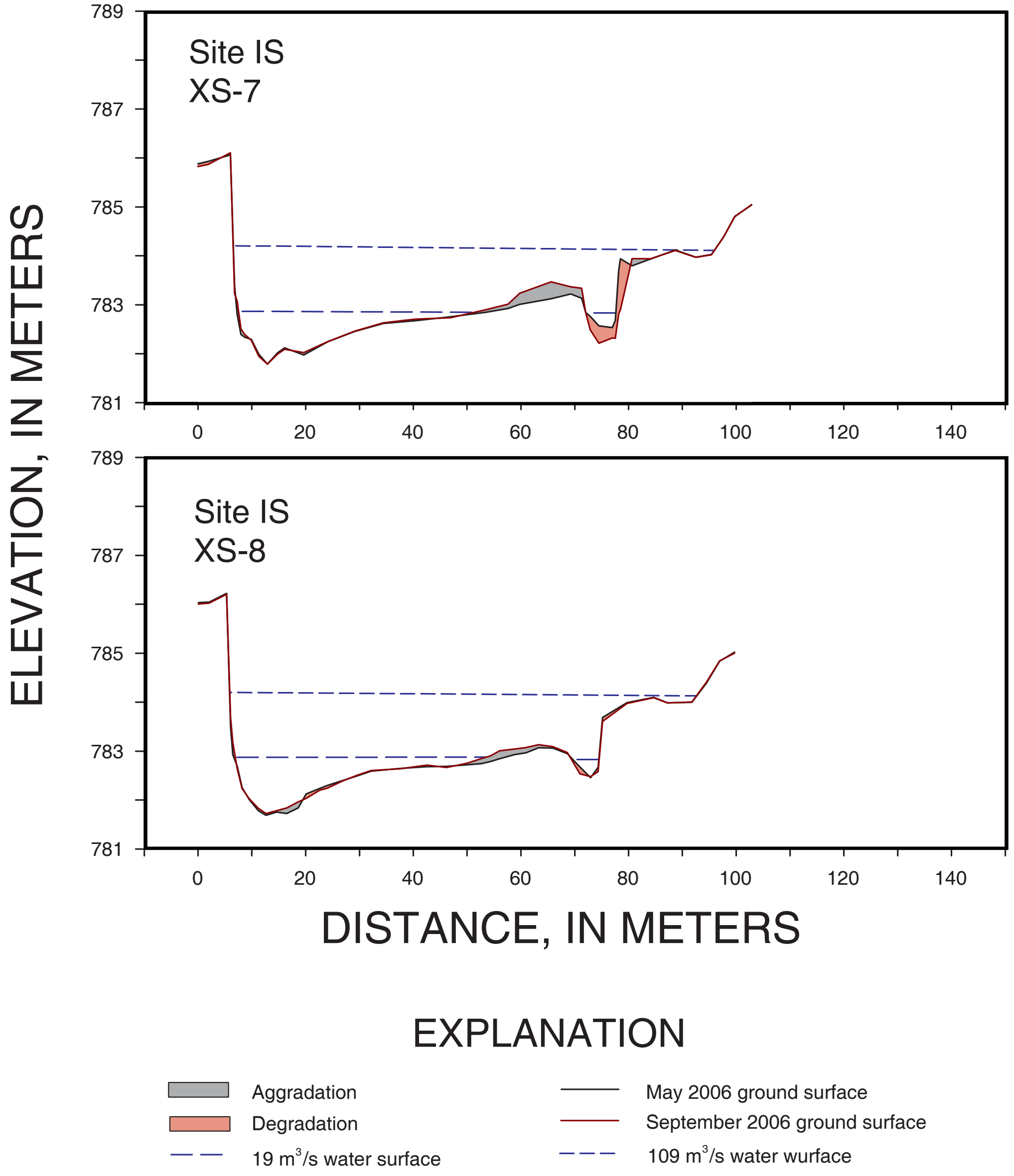


Figure 10. Cross sections 7 and 8 at Site IS. Distance along cross section is from left (facing downstream) to right head pins.

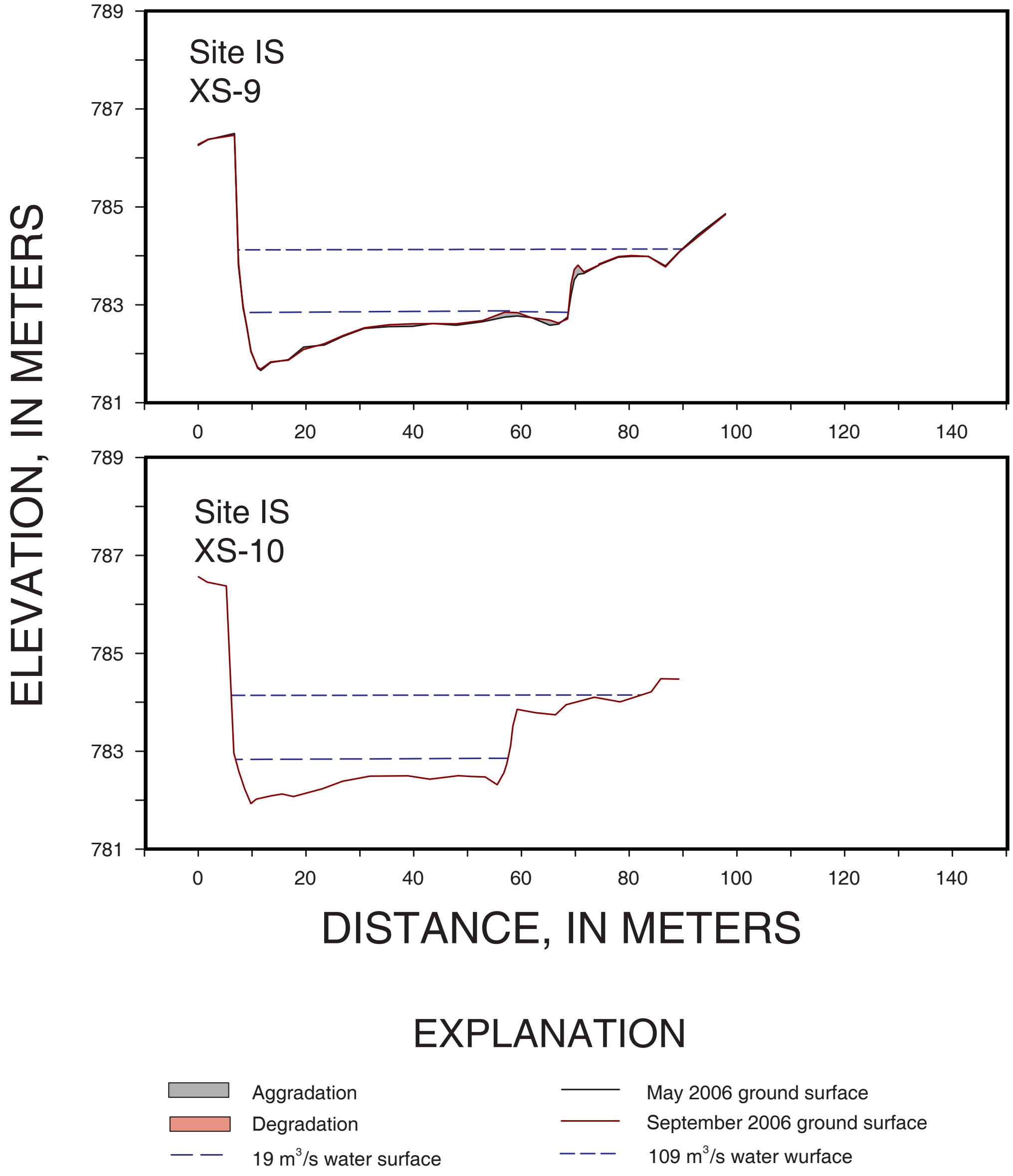


Figure 11. Cross sections 9 and 10 at Site IS. Distance along cross section is from left (facing downstream) to right head pins.

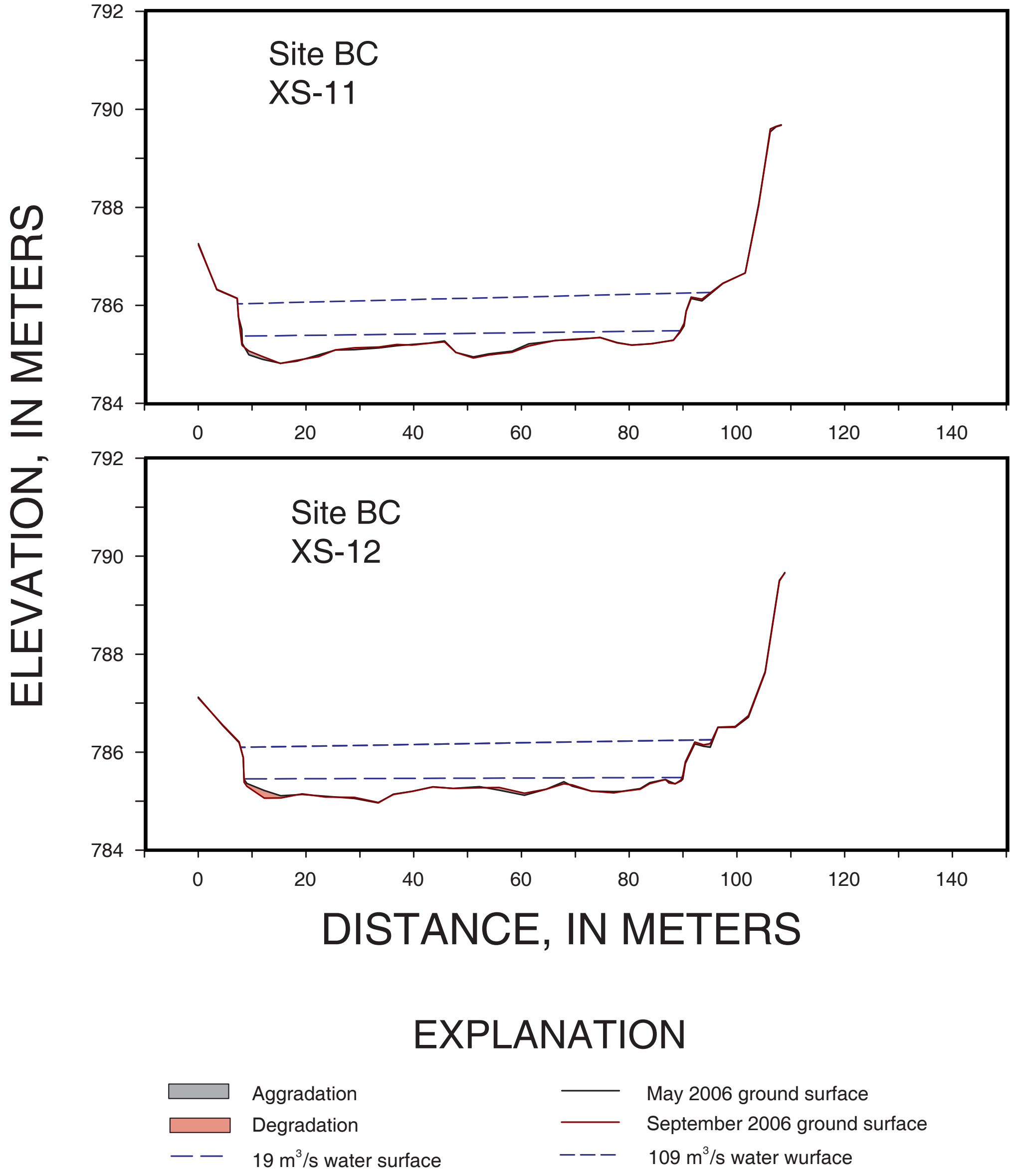


Figure 12. Cross sections 11 and 12 at Site BC. Distance along cross section is from left (facing downstream) to right head pins.

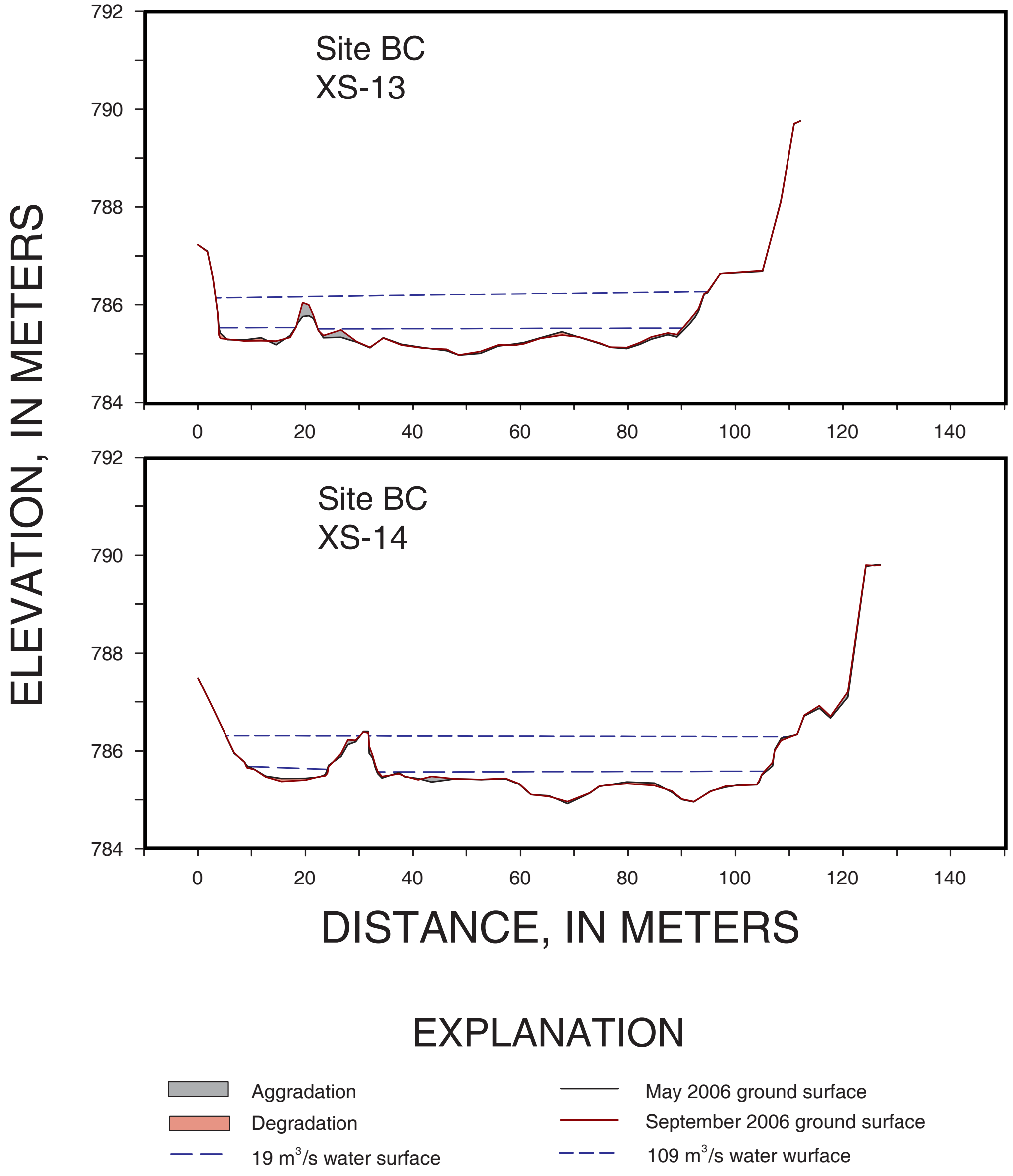


Figure 13. Cross sections 13 and 14 at Site BC. Distance along cross section is from left (facing downstream) to right head pins.

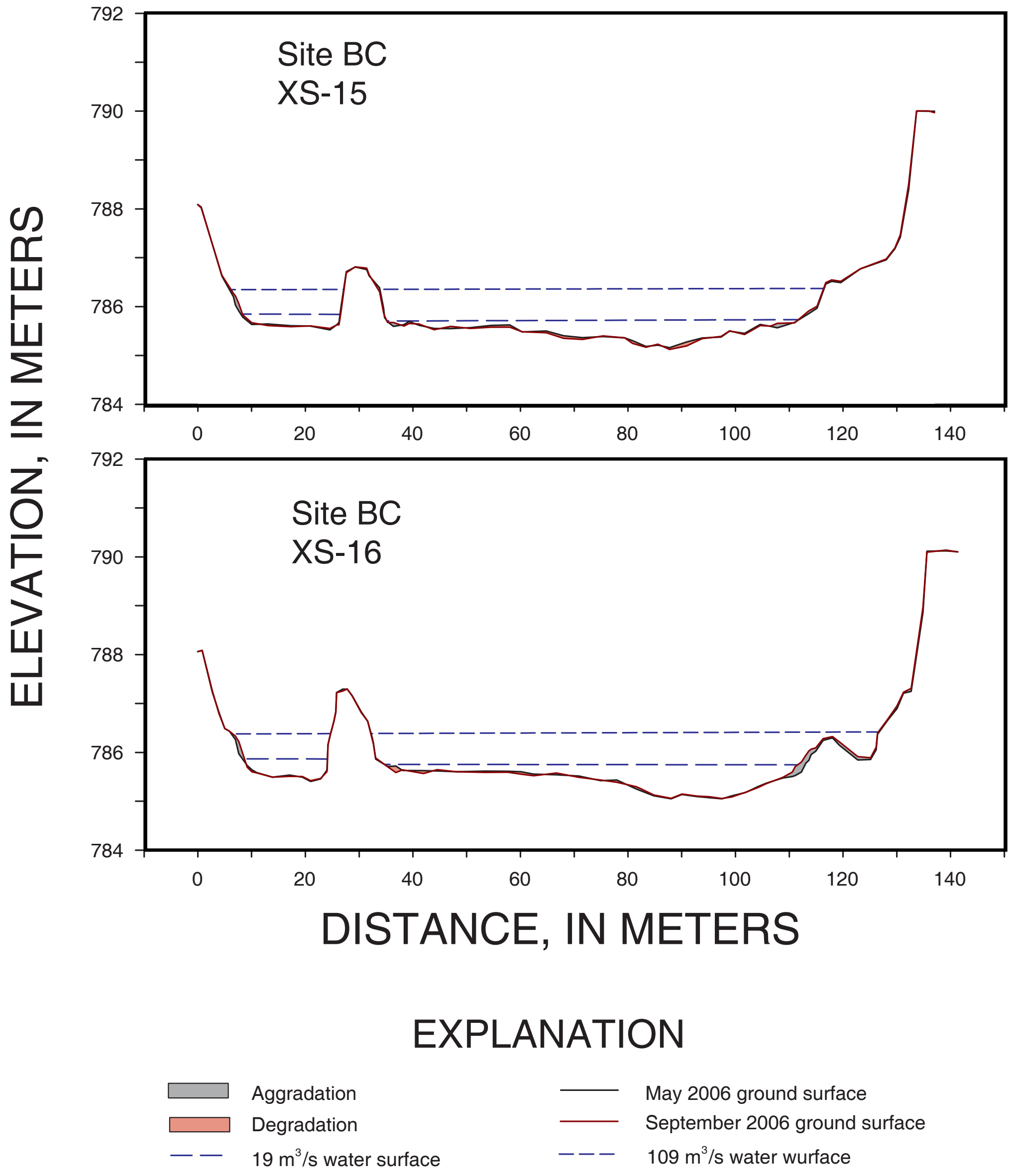


Figure 14. Cross sections 15 and 16 at Site BC. Distance along cross section is from left (facing downstream) to right head pins.

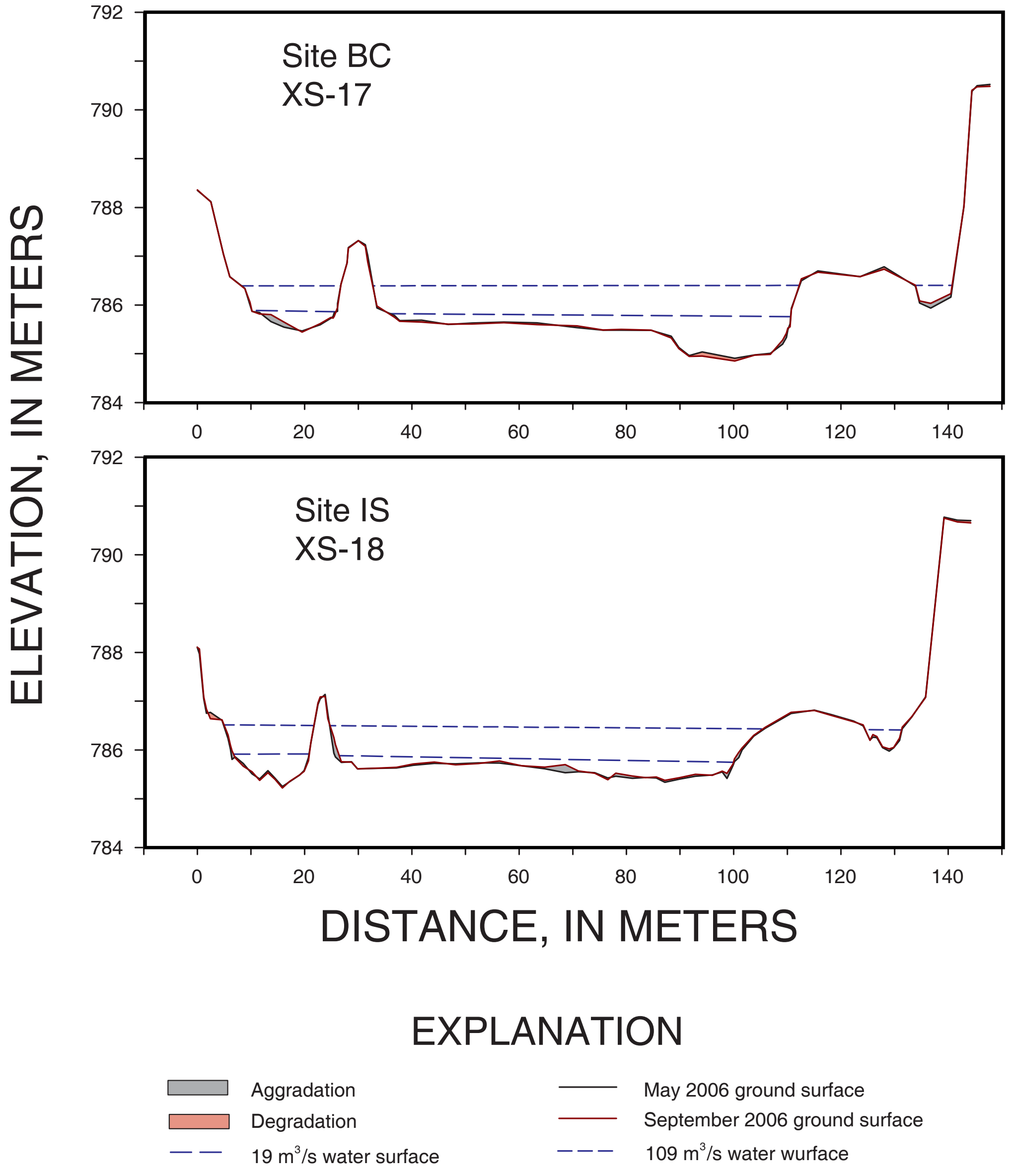


Figure 15. Cross sections 17 and 18 at Site BC. Distance along cross section is from left (facing downstream) to right head pins.

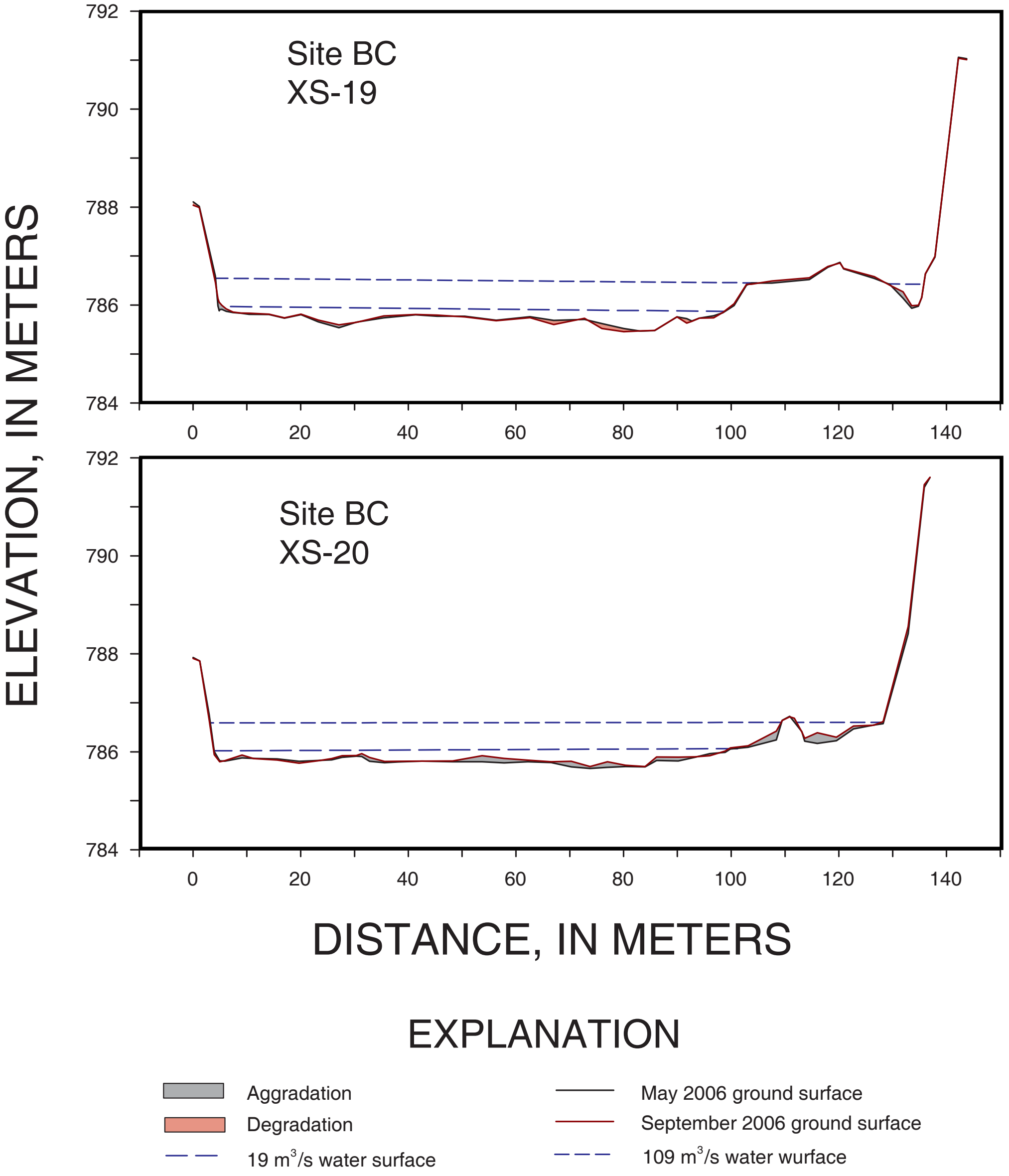
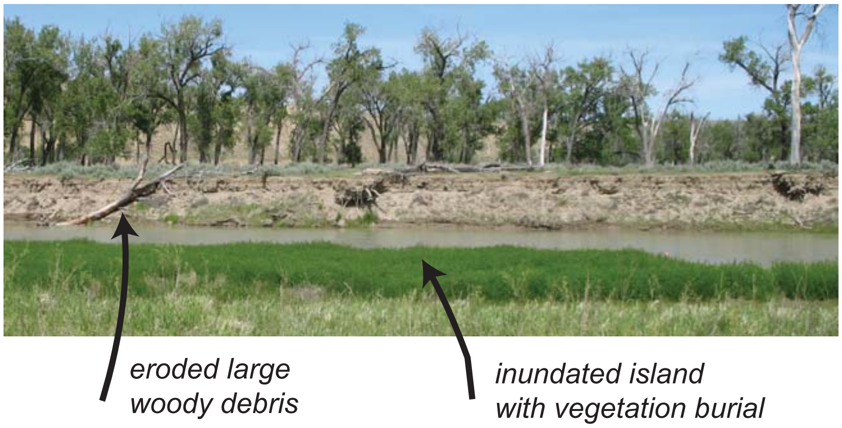


Figure 16. Cross sections 19 and 20 at Site BC. Distance along cross section is from left (facing downstream) to right head pins.

May 2006



June 2006 High Flow

September 2006

Figure 17. Cross section 3 at Site IS from right (facing downstream) head pin.

May 2006

June 2006 High Flow

September 2006

Figure 18. Cross section 2 at Site IS from left (facing downstream) head pin.

Figure 19. Deposition creating primary levee landform on bank lip of right (facing downstream) bank near cross section 10 at Site IS. Dense, 1- to 2-m-tall plants in foreground on bank are willow, *Salix exigua.* Photograph is oriented looking downstream and was taken September 22, 2006.

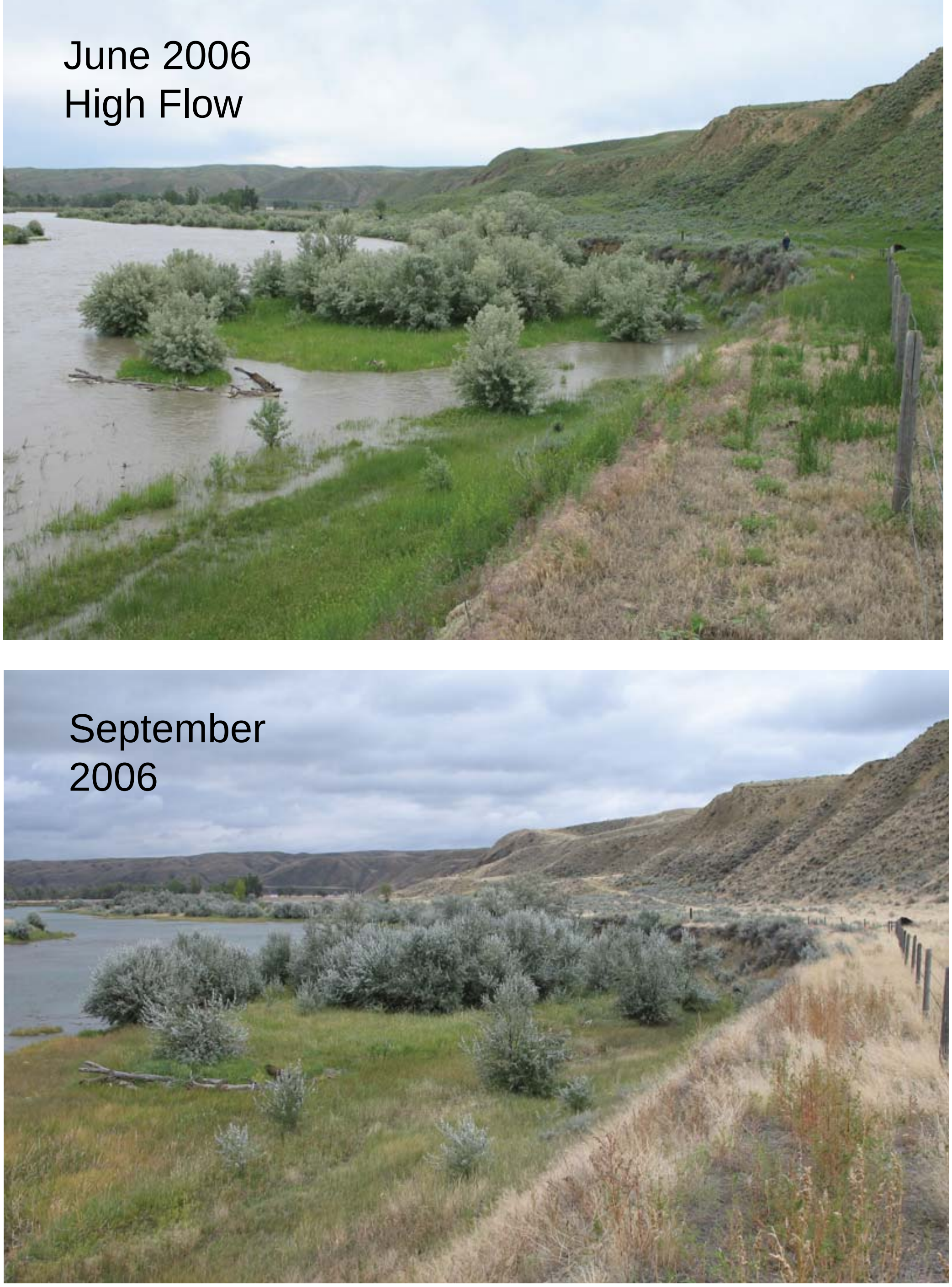


Figure 20. Flowing back channel at Site BC. View is looking downstream at site from upstream from cross section 20 on right (facing downstream) bank. Right bank is dominated by Russian-olive, *Elaeagnus angustifolia*.

May
2006

June 2006
High Flow

September
2006

Figure 21. Cross section 14 at Site BC from left (facing downstream) head pin. Note tree bole lodged where flow overtops and cuts across small island.

Both sites exhibited overall aggradation (fig. 22) during the interval containing the high flow. All individual cross sections at Site IS and almost all cross sections at Site BC had more aggradation than degradation, although both sites had areas of both aggradation and degradation. Site IS was considerably more dynamic than the bedrock-influenced Site BC, with average overall aggradation among cross sections of 4.4 m^2 per cross section, more than 3.5 times the overall average cross-sectional aggradation of 1.2 m^2 per cross section at Site BC. At Site IS, wetted perimeter increased 72 percent, from 50 m at the pre-release discharge of 19 m^3/s to 86 m at a high-flow discharge of 109 m^3/s (fig. 23). The BC Site was considerably wider and shallower, with an average wetted perimeter of 91 m at 19 m^3/s. The higher discharge of 109 m^3/s resulted in a smaller proportional increase of 18 percent in wetted perimeter at Site BC to 107 m.

Channel-bed profiles, as determined from thalweg (lowest point in channel) elevations at the cross sections, changed very little as a result of the high flow (fig. 24). There was some deepening at the most downstream cross sections at Site IS where substantial aggradation occurred on and around the island. Overall bed gradient from first to last cross section at each site was 0.2 and 1.0 m/km before and after the high flow, respectively, at Site IS and substantially steeper at Site BC (3.5 before and 3.7 m/km after the high flow). Water surface profiles at 19 m^3/s (June 1, 2006) and 109 m^3/s (June 14, 2006) were estimated by the average of water-surface elevations at either edge of the main channel and the horizontal location of the thalweg at each cross section in late May 2006 (fig. 24). At Site IS, overall water-surface slopes were 0.7 m/km at 19 m^3/s and 0.5 m/km at 109 m^3/s, whereas the steeper Site BC had slopes of 2.6 m/km at 19 m^3/s and 1.9 m/km at 109 m^3/s.

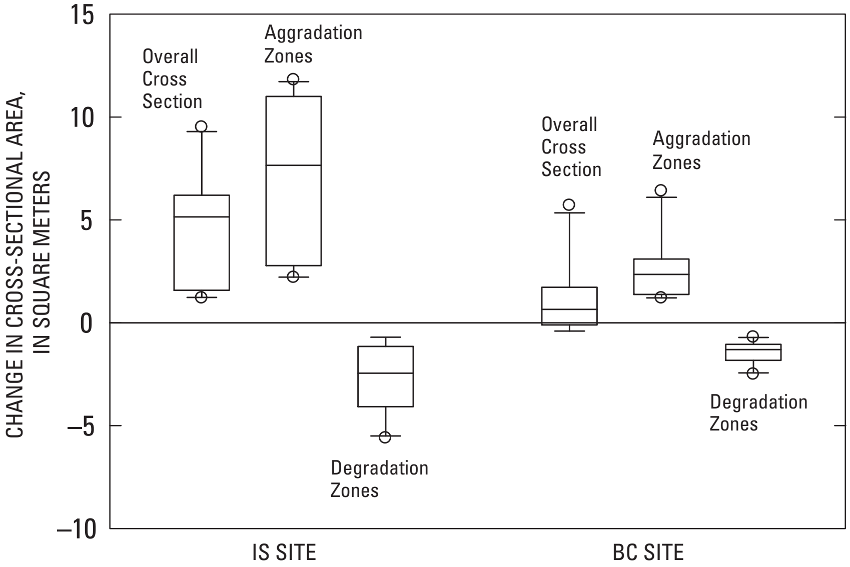


Figure 22. Box plots of changes in cross-sectional area. All values represent net change from before to after the 2006 high flow. Cross-sectional values are the total for each cross section of zones of aggradation and degradation within each cross section. The horizontal line within each box is the median of 10 cross sections at each site, tops and bottoms of the box are the 75th and 25th percentile respectively, the vertical whiskers capped with a horizontal line are the 90th and 10th percentiles, and individual observations beyond the 90th and 10th percentiles, are represented by open circles.

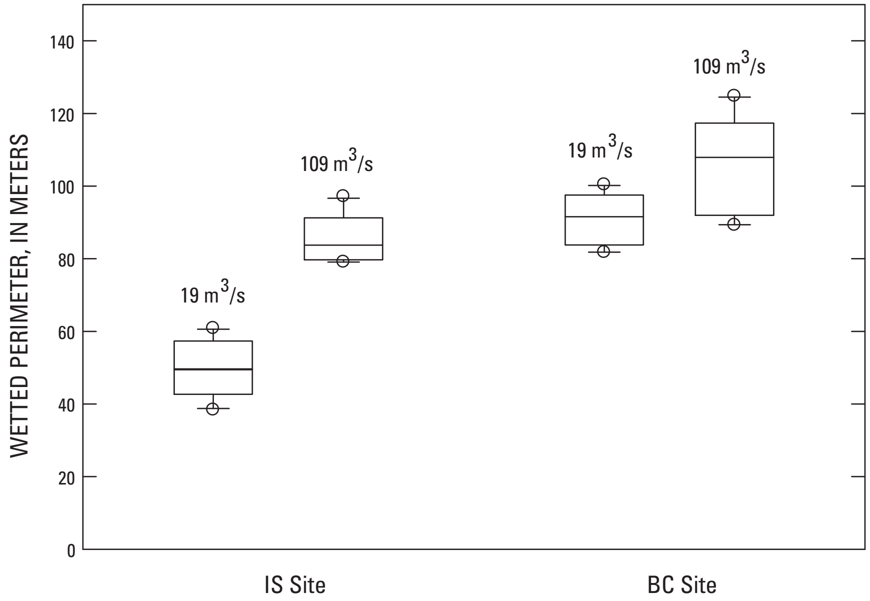


Figure 23. Box plots of wetted perimeter at cross sections. Discharge values are based on mean daily discharge near Loma (gage 06102050) on the days of water-surface measurement. The horizontal line within each box is the median of 10 cross sections at each site, tops and bottoms of the box are the 75th and 25th percentile respectively, the vertical whiskers capped with a horizontal line are the 90th and 10th percentiles, and individual observations beyond the 90th and 10th percentiles are represented by open circles.

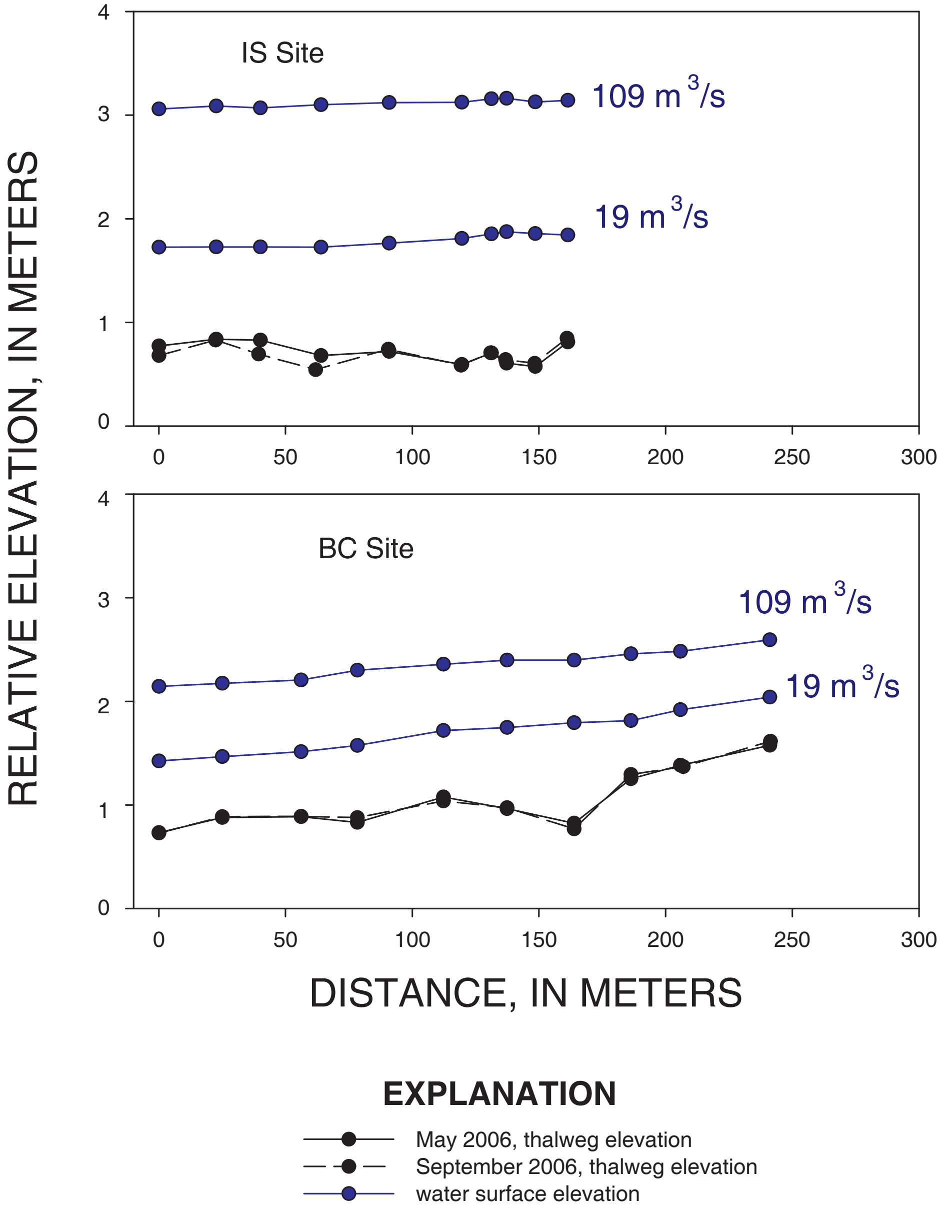


Figure 24. Profiles of bed elevation and water surface at Sites IS and BC. Channel-bed profiles were estimated by thalweg (lowest point in channel) locations and elevations at the cross sections. Water surface profiles at 19 m3/s for mean daily discharge at the gage near Loma, Mont. (06102050), on June 1, 2006, and 109 m3/s on June 14, 2006, were estimated by the average of water-surface elevations at either edge of the main channel and the horizontal location of the thalweg at each cross section in late May 2006.

Discussion

The high-flow release from Tiber Dam produced a hydrograph that was above average for downstream sites on the Marias River following dam construction. Timing of the peak and the declining limb of the release hydrograph were very similar to the historical unregulated hydrograph. The high flow produced many of the qualitative elements of ecologically important behavior that can be diminished or lost due to flow stabilization downstream from a dam. A normally dry back channel was occupied by flowing water. Islands were inundated, with vegetation removal and sediment accretion producing new disturbance patches of bare, moist substrate. Cut banks were eroded. Large woody debris was added to the river and redistributed. Flood-plain surfaces were inundated, producing substantial increases in wetted perimeter and spatially distinctive deposition patterns of natural levee formation.

The 2006 release hydrograph was infrequently large in the post-dam era but was quite common in the absence of regulation. The lower Marias River has not been substantially dewatered in terms of total annual volume. However, the post-dam bounds of the riverine ecosystem in terms of frequent high flows, rare high flows, and lateral extent of the bottomland inundated by the river in the life span of organisms (for example, canopy trees) are roughly an order of magnitude smaller than for the pre-dam river. In the pre-dam Marias River flow regime, infrequent high flows were in the range of 1,420 to 2,840 m^3/s, whereas infrequent high flows in the post-dam regime are restricted to the 142- to 283-m^3/s range. At our study sites, the flooded bottomland at high flow is on the order of 100 m, with changes in width from low to high flow on a scale of tens of meters and lateral channel migration on the scale of centimeters to meters. Based on the distribution of mature cottonwood and relict channel features (figs. 5 and 6), the pre-dam river disturbed, by inundation or lateral migration, a bottomland width closer to 1 km.

The central question for environmental flow management on the lower Marias River is to what extent characteristic natural processes and structures can or cannot be preserved in a scaled-down system by maintaining or reestablishing some of the inter- and intra-annual patterns of flow variability. Our data on details of channel change associated with one high-flow release at two sites are far from adequate to address this question confidently or comprehensively. However, it does provide a starting point for framing the larger question. Sediment dynamics, as it affects channel morphology, is one of the processes that might not scale proportionately to a smaller river system because of nonlinearities in the relations between discharge magnitude and sediment movement. In some cases, reduced discharges may no longer exceed threshold critical shear stresses necessary to mobilize any of the important size classes of bed or bank sediment. Based on changes during the 2006 high-flow release, the sand-dominated Site IS does seem to be scaling as a smaller inset channel and flood-plain complex with processes of island formation and accretion, flood-plain inundation and accretion, lateral erosion into cut banks, vegetation removal and creation of new bare disturbance patches, and thalweg vertical and horizontal movement.

The 2006 high flow produced much less channel change at the BC Site. The presence of bedrock in the channel bed, however, suggests that this site also would have been relatively stable, at least vertically, during the pre-dam regime. The high flow put water in the back channel at Site BC but showed no tendency to produce a net deepening or scour of the back channel. Rather, the small amount of change was in the direction of filling by aggradation to plug the upper end of the back channel. This is consistent with a relatively natural trajectory for a back channel, which may become filled at the upper end and progressively isolated from the main channel over time under a natural flow regime. The more important question to be addressed by future work is how rates of formation of new back channels under the post-dam regime will compare to rates of filling and loss of back channels inundated by post-dam high flows.

Scaling of sediment dynamics downstream from dams also is complicated by the simultaneous influence of dams on both sediment transport and sediment supply. Attenuation of peak flows downstream from a dam reduces sediment transport capacity, whereas trapping of sediment in the reservoir behind the dam reduces sediment supply. Immediately downstream from the dam, the reduction in sediment supply can dominate and produce a “sediment shadow” where “hungry” water released from the dam results in net channel degradation, incision, and coarsening of the bed material. This response has been reported for Marias River reaches immediately downstream from Tiber Dam (Gardner and Berg, 1983; Rood and Mahoney, 1995). We observed overall aggradation at both of our study sites much farther downstream.

A complex spatial response of sediment dynamics to dam construction has been reported for some other rivers such as the Green River downstream from Flaming Gorge Dam (Andrews, 1986). Sediment supply can increase with distance downstream from the dam faster than transport capacity increases, as mobilization of bed and bank sediment storage, in combination with tributary sediment inputs, adds sediment faster than the high flows and transport capacity increase. Thus, in some cases, a dam-produced zone of sediment deficit and channel degradation near downstream from the dam can transition farther downstream into a zone of sediment aggradation where supply exceeds transport capacity. Our measurements of channel change associated with a single high flow are far from sufficient to construct an overall sediment budget. However, they are consistent with these sites being in the far-downstream zone of sediment aggradation. At a minimum, they provide no evidence for a sediment supply limitation at these sites under the current post-dam regime.

Riparian vegetation occupies the area between the extreme outer bounds of the river’s influence and the permanent channel locations that are inundated too consistently to support anything but fully aquatic plants. Substantial reductions in infrequent high flows that reduce lateral inundation and channel movement can thus have substantial effects on riparian vegetation. The largest and most prominent change in riparian vegetation involves the transient response of the large area that was historical flood plain and channel under the pre-dam flow regime but that is outside the bounds of the new inset flood plain and band of potential lateral channel locations under the new post-dam flow regime. As a coarse approximation, this zone can be estimated by comparing the full width of bottomland occupied by cottonwood trees (on the order of 1 km, figs. 5 and 6) with something slightly larger than the roughly 100 m occupied by water at the 109 m^3/s we observed during the 2006 high-flow release. The plains cottonwood at our study sites establishes almost exclusively by seed on bare, moist sites recently inundated and disturbed by the river. Plains cottonwood in central Mont. has a maximum age of 150–200 years (Scott and others, 1997), so the presence of plains cottonwood today is a reasonable indication that a location has been inundated and disturbed by the river sometime in the last 200 years. In contrast, in the post-dam period, the 109-m^3/s water-surface elevations we measured were associated with a rare high flow downstream from Tiber Dam. Furthermore, a discharge of 165.5 m^3/s represents an essentially maximum discharge in the post-dam regime having been exceeded only in the 1964 dam-break event. The post-dam riverine bounds are somewhat larger than the 109-m^3/s water-surface zone both because (a) flows could be higher than 109 m^3/s and still stay below the effective maximum Tiber Dam release of 165.5 m^3/s, and (b) some lateral channel migration might occur under the post-dam flow regime. Nonetheless, a large fraction of the area inundated and disturbed by surface water and channel movement under the pre-dam flow regime is now effectively a terrace and is no longer subject to surface-water flow.

On the Marias River, changes in riparian forest composition and extent associated with the altered flow and sediment regimes following dam construction are confounded with introduction and spread of the non-native Russian-olive (Lesica and Miles, 1999, 2001). Russian-olive is relatively shade tolerant, produces large seeds that can be dispersed by animals and that remain germinable for years, and is less palatable to beaver than native cottonwood (Lesica and Miles, 1999; Katz and Shafroth, 2003). These characteristics well suit Russian-olive to fit into riparian vegetation communities on plains rivers as a secondary successional tree, replacing cottonwood on older and less disturbed surfaces. Reduction of high flows on the Marias River downstream from Tiber Dam has reduced the creation of bottomland disturbance patches by the river compared to the pre-dam regime. Thus, Rood and Mahoney (1995) and Lesica and Miles (1999, 2001) have projected a riparian forest future under the post-dam regime of continued decline of cottonwood as mature trees die without replacement and increasing dominance of Russian-olive. The patterns of riparian tree distribution, inundation, and channel change we observed at our study sites are certainly consistent with their interpretation and projection (for example, fig. 20).

Whereas reduced disturbance of the bottomland by inundation and channel movement has effects on the natural riverine ecosystem, it was also one of the objectives of Tiber Dam from the perspective of reducing the kind of property damage and loss of life associated with flooding upstream from Tiber Dam in 1964 (Boner and Stermitz, 1967). At our study sites, the zone of disturbance by the high-flow release of 2006 was well within the head-pin to head-pin widths of cross section depicted in figures 7–16 and 23. There were some sections of fencing and some irrigation take-out structures and equipment potentially subject to damage. However, most bottomland infrastructure (buildings, fencing, and roads as well as agricultural fields) was well outside the zone of potential disturbance by flows in the 100- to 160-m^3/s range (figs. 5 and 6).

The 2006 high-flow release produced many physical changes important to fish: high flow timed to natural spawning migration, pulsed increase in aquatic area by inundation of flood plain and back channels, and recruitment and redistribution of large woody debris. The extent to which these changes mitigate adverse effects of dam construction on fish populations—and more specifically, whether they are sufficient to avoid extirpation of pallid sturgeon upstream from Fort Peck reservoir—depends on a more precise understanding of exactly how fish are using or could use various physical habitat features and the other factors that might be controlling fish populations. Fish responses to recent streamflows on the lower Marias River, including the 2006 high-flow release from Tiber Dam, are the subject of ongoing studies being conducted in cooperation with the Bureau of Reclamation (Sue Camp, Bureau of Reclamation, oral commun., 2007).

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