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Draft Report

GEOMORPHIC CHANGE AT TAMARISK REMOVAL AND CONTROL STUDY REACHES IN THE CANYON OF LODORE, GREEN RIVER, DINOSAUR NATIONAL MONUMENT

Isaac J. Larsen[1]

John C. Schmidt[1]

[1]Department of Aquatic, Watershed, and Earth Resources

Utah State University

Logan, Utah 84322-5210

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Abstract

The largest temporary, in-channel sand storage locations in the Green River in the Canyon of Lodore are the ponded backwaters found upstream from debris fan constrictions in the upstream, low-gradient segment of the canyon. Mean channel depth in the middle, high-gradient segment of the canyon and at sites downstream from constrictions varies little, indicating that these areas are less dynamic short-term sand storage reservoirs. Eddy sandbars are built to their largest volumes and highest elevations by large floods, but the deposits are eroded by lower discharges and volumes return to pre-flood values in less than 2-years. Additionally, the 9 years of channel cross-section data collected at study reaches in Dinosaur National Monument indicate that there are no apparent long-term changes in sand storage within the study reaches.

Introduction

Operation of Flaming Gorge Dam has altered the hydrology of downstream reaches of the Green River. The alteration has been greatest in the 104-km section of the river between the dam and Echo Park, where the relatively unregulated Yampa River joins the Green River. Flow regulation has greatly reduced the magnitude and frequency of large floods in the Canyon of Lodore, reducing the 2-year flood by 57 %(Grams and Schmidt, 2002). The reduction of the large discharges that are largely responsible for channel form has led to channel narrowing and aggradation through the accretion of inset floodplains (Grams and Schmidt, 2002).

The invasion of non-native tamarisk occurred concurrently with the reduction of large floods. Tamarisk have stabilized the newly formed deposits by adding binding root strength, preventing floods from eroding these deposits. Channel narrowing and stabilization of these deposits has led to reduced habitat complexity through the reduction of geomorphic activity.

The data presented here are part of an ongoing effort to monitor flow, sediment transport, and channel form of the Green River in Dinosaur National Monument (Grams, 1997; Grams et al., 1999; Grams and Schmidt, 1999; 2002; Martin et al., 1998). This report describes measurements of channel form made in 2003 in four study reaches in the Canyon of Lodore that are the sites of an ongoing experiment concerning the geomorphic effects of tamarisk. The purpose of this report is to summarize field activities related to cross-section monitoring during 2003 and to present selected data collected during that time, and during prior surveys, in order to examine trends in channel change that have occurred during the past 9 years.

Study Area

The Canyon of Lodore begins 74 kilometers downstream from Flaming Gorge Dam and ends 30 km further downstream at the confluence of the Green and Yampa Rivers in Echo Park (Fig. 1). The geomorphology of the Green River in Dinosaur National Monument consists of a series of repeating fan-eddy complexes (Grams and Schmidt, 1999). The fan-eddy complex consists of debris fan constrictions that create downstream areas of recirculating flow and eddy sandbars and upstream areas of ponded backwater (Schmidt and Rubin, 1995). Important sand storage locations throughout the canyon include eddy bars and the channel bed in areas within ponded backwaters. Each of the four study reaches with benchmarked cross-sections spans the length of a fan eddy-complex and includes cross-sections through the ponded backwaters upstream from debris fans and cross-sections that cross-eddy sandbars downstream from fans.

Grams and Schmidt (1999) divided the Canyon of Lodore into three distinct segments: a low-gradient upstream segment, a high-gradient middle segment with abundant debris fans, and a low-gradient lower segment. The adjacent Wade and Curtis and Winnies reaches are located in the upper low-gradient segment of the canyon, near river miles 241 and 240, respectively. The paired Mile 233 and Triplet Falls reaches are located further downstream in the middle, high gradient segment near river miles 233 and 232, respectively.

Methods

The eight cross-sections in each study reach were resurveyed between August 18 and 21, 2003. Data collection consisted of topographic surveys of the ground surface and the wadeable portions of the channel and bathymetric surveys of the channel bed conducted with a fathometer

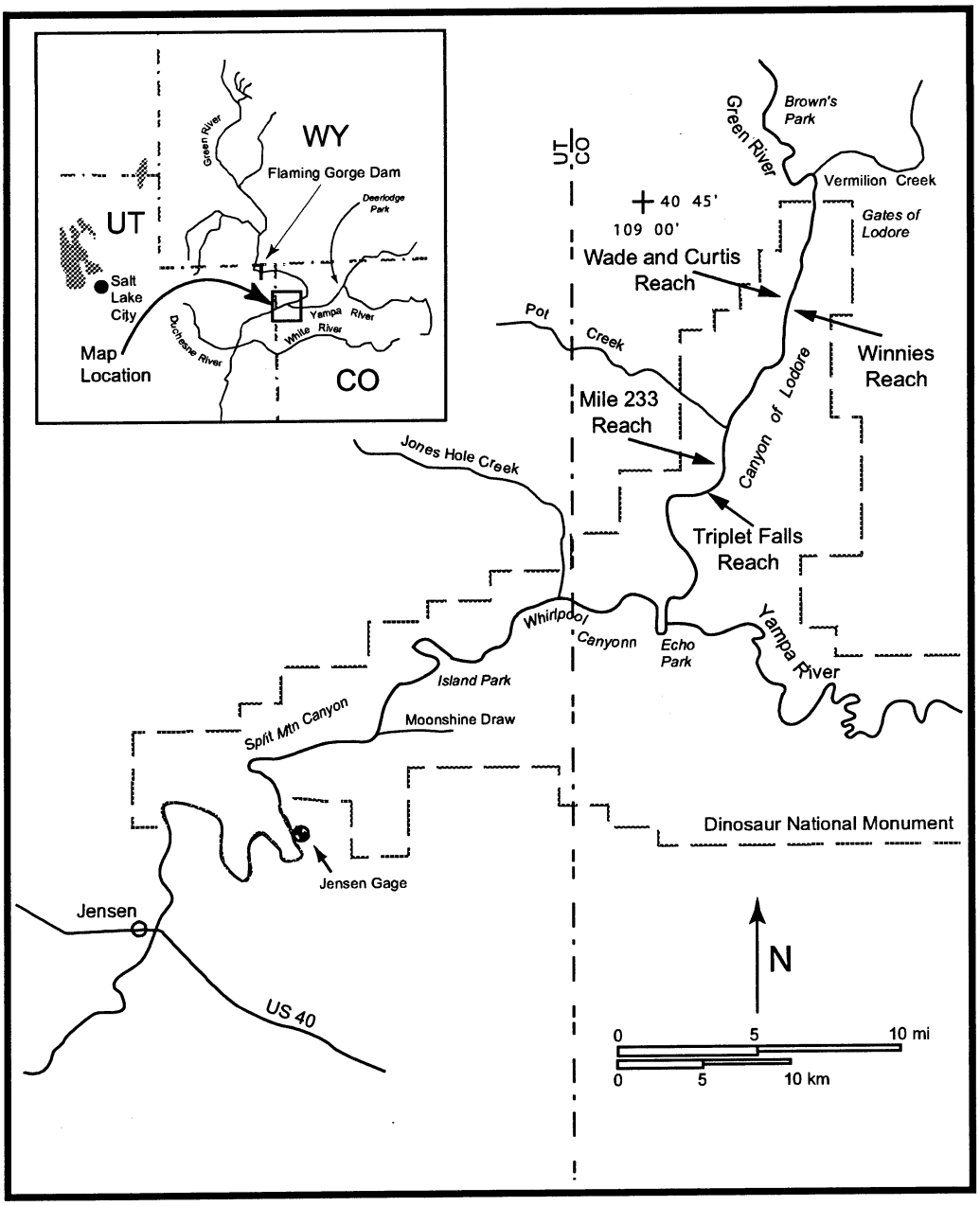

Figure 1. Study area map.

mounted on a boat. These two data sets were combined by surveying bed elevations common to both methods.

Topographic data at all cross-sections were collected in July 2001 but extend as far back as June 1994 for some cross-sections (Fig. 2) (Grams, 1997). Cross-section data for all survey dates were used to calculate metrics of cross-section form including: area, wetted perimeter, hydraulic radius, mean depth, maximum depth, and top width. To be consistent, all metrics were calculated with reference to a common vertical datum: in this case, the elevation of the water surface measured in August 2003 when discharge was approximately 800 ft^3s^{-1}.

In this report, we present data on one metric of channel condition, mean channel depth. Time series analysis of mean channel depth was aggregated based on the location of each study reach in terms of the three river segments of Grams and Schmidt (1999) described above, and the geomorphic setting of each cross-section. Based on these criteria, cross-sections were grouped as those in the low-gradient upstream segment of the canyon, those in the high-gradient middle segment of the canyon, those located in ponded backwaters upstream from constrictions, and those located downstream from constrictions. Channel width changes little from one survey to the next; therefore variations in mean channel depth represent changes in the elevation of the channel bed. Aggradation or degradation of the bed occurs due to the addition or removal of sand, thus, changes in mean channel depth represent changes in the volume of sand stored on the bed of the river.

In addition to channel cross-section metrics, changes in sand volume described at a cross-section were calculated for those cross-sections that cross eddy sandbar or channel-margin deposits. Sand area was calculated for two zones, sand area between the 800 ft^3s^{-1} and 4400

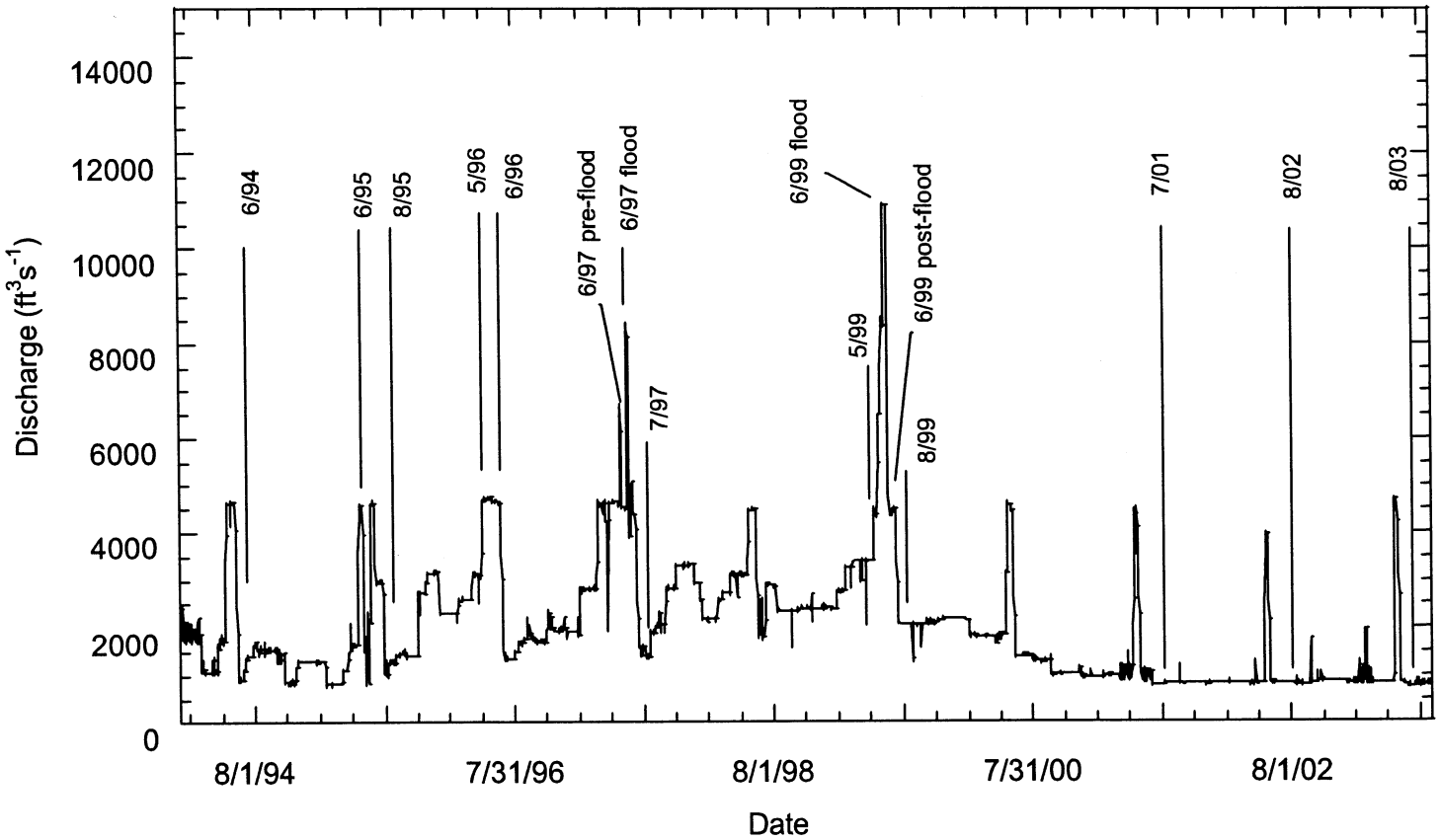

Figure 2. Hydrograph of mean daily discharge on the Green River near Greendale, UT between January 1, 1994 and August 31, 2003. Lines and dates indicate times when measurments have been made in the Canyon of Lodore.

ft^3s^{-1} stage and sand area above the 4400 ft^3s^{-1} stage. The methods used to calculate sand area are shown in Figure 3. The area of sand in each cross-section was normalized to the lowest value, so that comparisons could be made among cross-sections.

Results

Cross-section change

Examples of geomorphic change typical of the two distinct depositional environments, eddy sandbars and channel-margin deposits, are shown in Figures 4 and 5 using examples from Cross-Section Four in the Winnies Reach. Change representative of those measured at eddy bars is shown in Figure 4. The volume of the bar progressively increased during the summer of 1999. The elevation of the bar rose by 0.7 m between May 19 and June 15 during discharges associated with the June 1999 flood release of 10,900 ft^3s^{-1}. The volume of the bar continued to increase following the peak discharge, while the bar was inundated, with a maximum elevation of 1.1 m greater than the pre-flood elevation measured on June 27 and August 1, 1999. As elevation of the bar increased, the elevation of the eddy-return channel at the channel margin deepened (Fig. 4). Survey data show that the volume of the bar decreased in following years of lower flows and that the eddy-return channel filled, similar to patterns measured in Grand Canyon (Fig. 4). The elevation of the bar in August 2002 was similar to values recorded in May 1999 before the flood release, and the elevation of the bar decreased by an additional 0.8 m between August 2002 and August 2003 (Fig. 4). Thus, substantial bar reworking can occur during years of low floods; the primary changes are the erosion of high flood bars.

Geomorphic change of a typical channel-margin deposit is described for the site on the river-left of Cross-Section Four in the Winnies Reach (Fig. 5). This cross-section was first

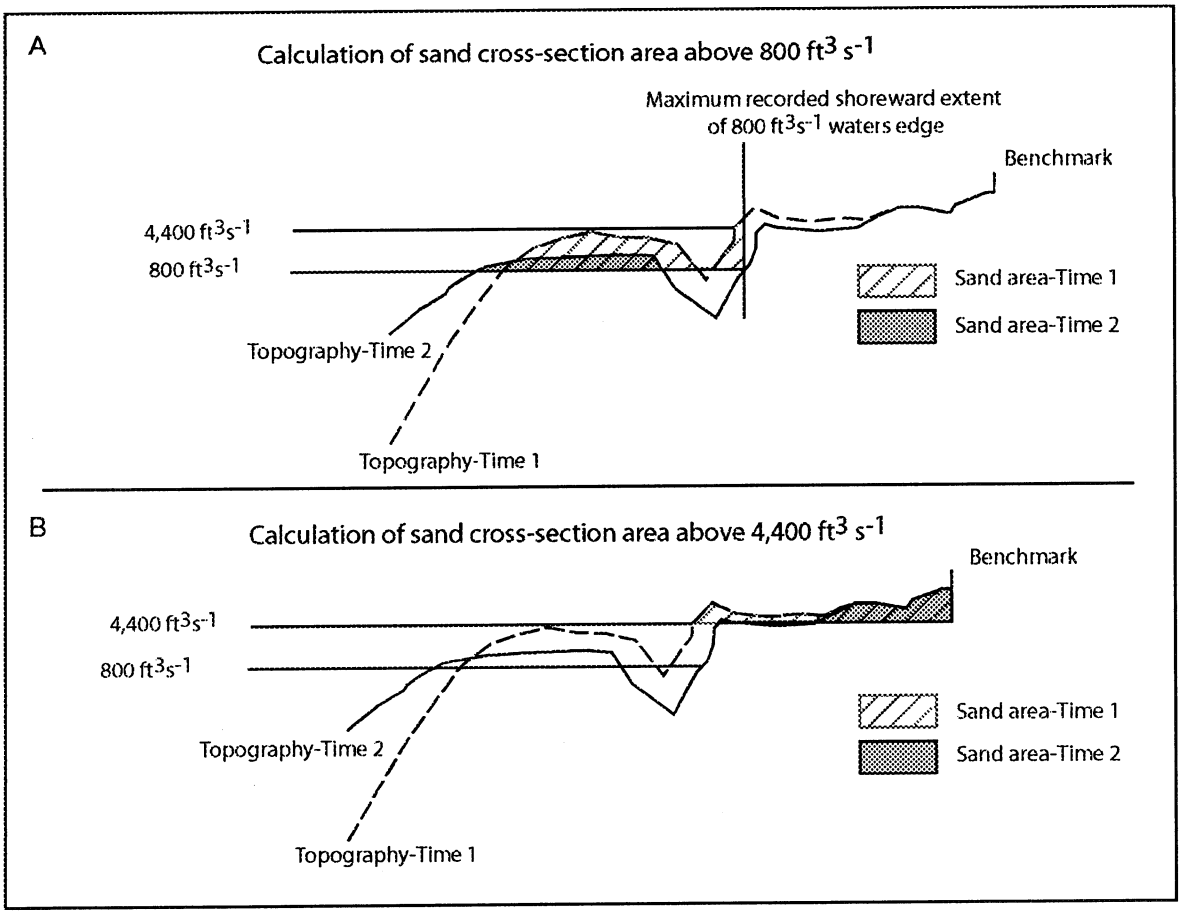

Figure 3. A. The cross-sectional area of sand deposits between the 800 ft^3s^{-1} and 4,400 ft^3s^{-1} water surfaces were calculated by creating a polygon of the sand in this zone and calculating its area. The lower surface of the polygon is the 800 ft^3s^{-1} stage, the shoreward limit of the polygon was chosen to be the maximum shoreward extent of the 800 ft^3s^{-1} water surface, the upper and riverward surface of the polygon is the surveyed topography, or the 4,400 ft^3s^{-1} stage if the deposit extended above that surface. B. The cross-sectional area of sand deposits above the 4,400 ft^3s^{-1} water surfaces were calculated similarly, by creating a polygon and calculating the area. The lower bounding surface of the polygon is the 4400 ft^3s^{-1} water surface, the shoreward bounding surface is the location of the cross-section benchmark, and the top and riverward bounds of the polygon are the surveyed topography. Sand areas for each cross-section were normalized to the lowest value measured at each site.

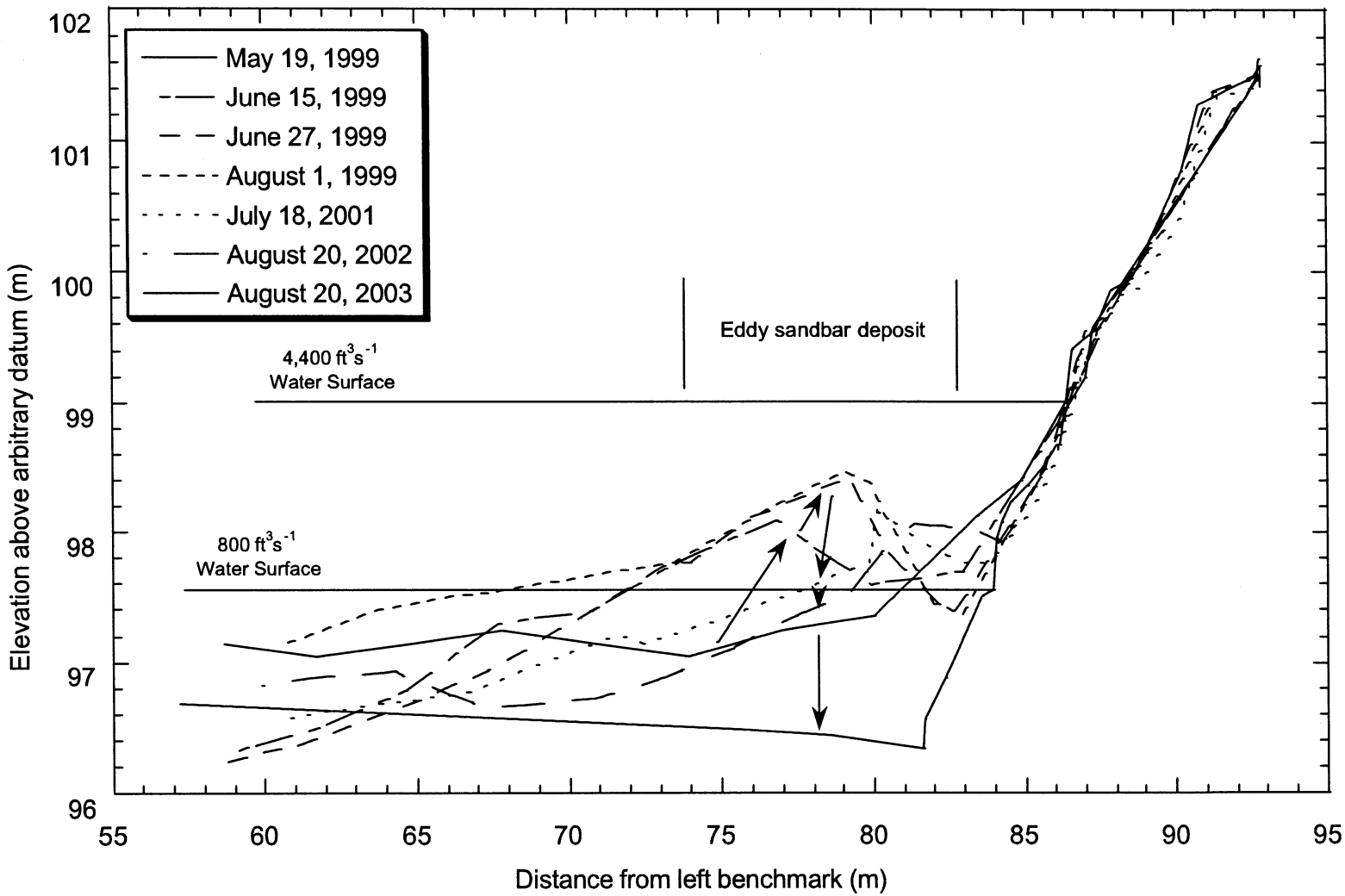

Figure 4. Topographic evolution of the downstream portion of the eddy sandbar located on river right of Cross-Section Four in the Winnies Reach. The arrows track the topography through time. The bar increased in volume during the June 15, 1999 flood and the highest volume was measured following high discharges in August, 1999. The volume of the bar has since decreased in volume, reaching its lowest value in August, 2003.

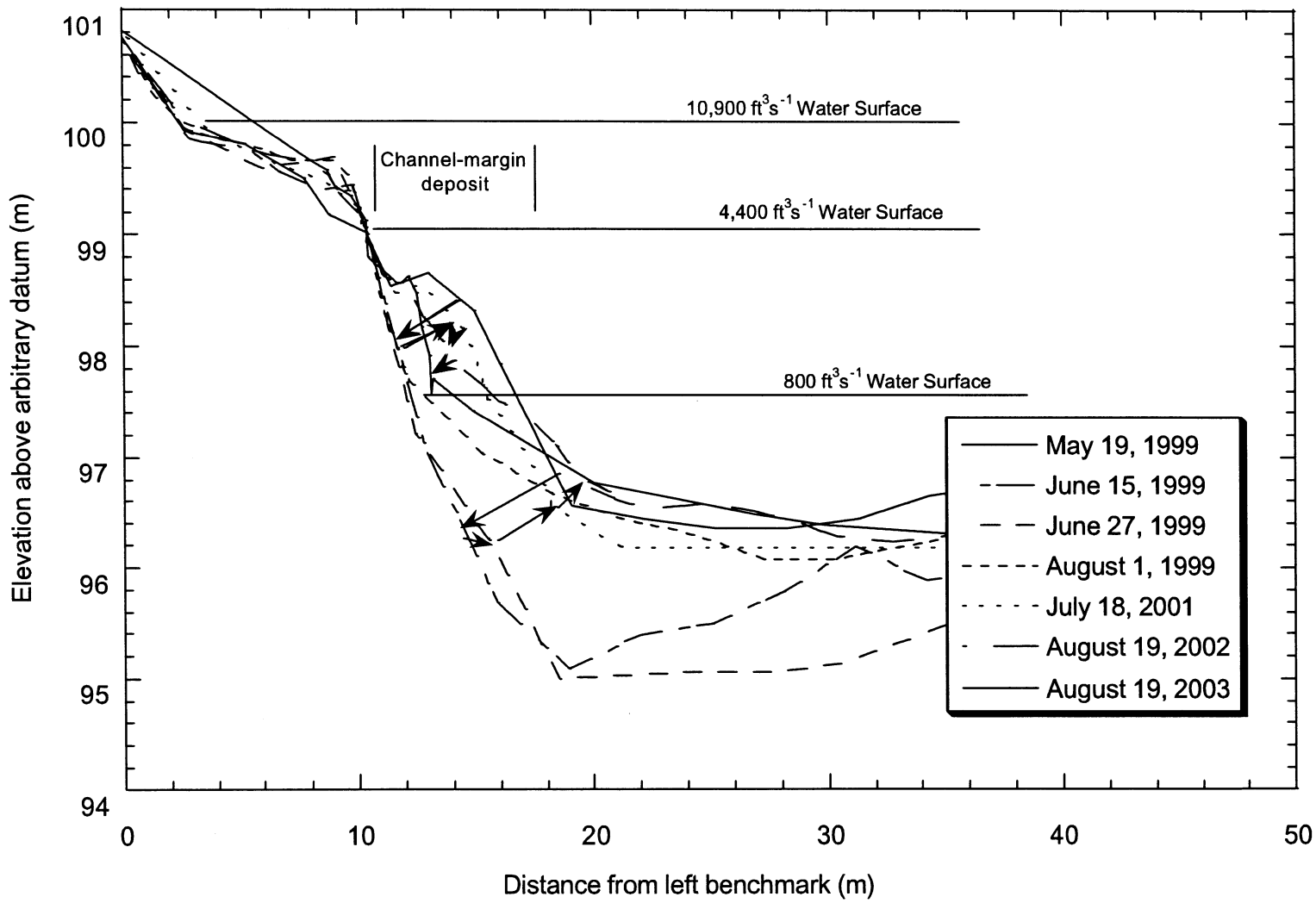

Figure 5. River-left side of Winnies Reach Cross-Section 4. The arrows track the ground surface through time. An approximately 3.8 m wide channel margin deposit was scoured during the June 1999 flood. Sediment has since been redeposited and in August 2003 the channel was 1.5 m narrower than following the June 1999 flood.

surveyed in May 1999 prior to the 10,900 ft^3s^{-1} that occurred in June 1999. The channel-margin deposits scoured during the June 1999 flood, and the bank retreated approximately 3.8 m. Subsequent surveys show the channel has narrowed since the June 1999 flood, and, in August 200,3 the left side of the channel was approximately 1.5 m narrower than it was following the 1999 flood.

Time series analysis of change in mean channel depth based on the location of the study reach indicates that there is greater variation in mean depth at those cross-sections in the upper low-gradient segment of the canyon than those in the middle, high-gradient segment of the canyon (Figs. 6 and 7). This suggests that the upper segment of the canyon is a temporary storage site for sand. The mean depth of individual cross-sections in the upper segment of the canyon commonly varies by more than 0.5 m, and the maximum change for a single cross-section is greater than 3 m (Fig. 6). In contrast, in the middle segment of the canyon mean channel depth has remained fairly constant. In general, the mean depth of individual cross-sections varies by less than 0.5 m and the maximum fluctuation for a single cross-section is less than 1 m (Fig. 7).

Comparison of mean channel depth based upon geomorphic setting indicates that sites located in ponded backwaters exhibit more change, and are thus more dynamic storage locations than those located downstream from constrictions (Figs. 8 and 9). At cross-sections located in ponded backwaters that include surveys made prior to July 2001, mean depth fluctuations were commonly greater than 1 m, whereas fluctuations greater than 1 m were rare for those cross-sections located downstream from constrictions.

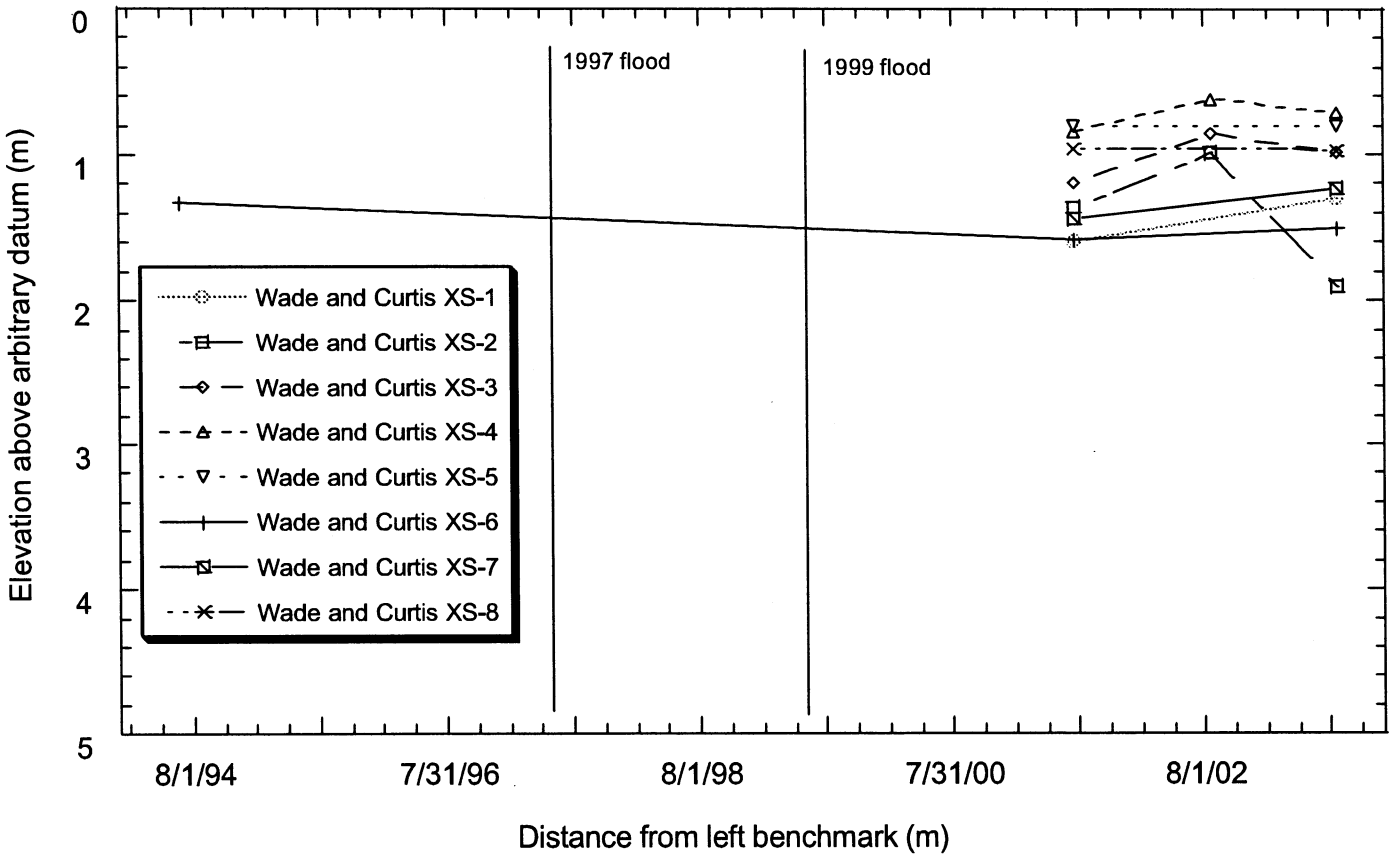

Figure 6a. Mean channel depth at cross-sections in the Wade and Curtis Reach in the upper, low-gradient segment of the canyon. Mean channel depth generally remained constant at these cross-sections between July 2001 and August 2003.

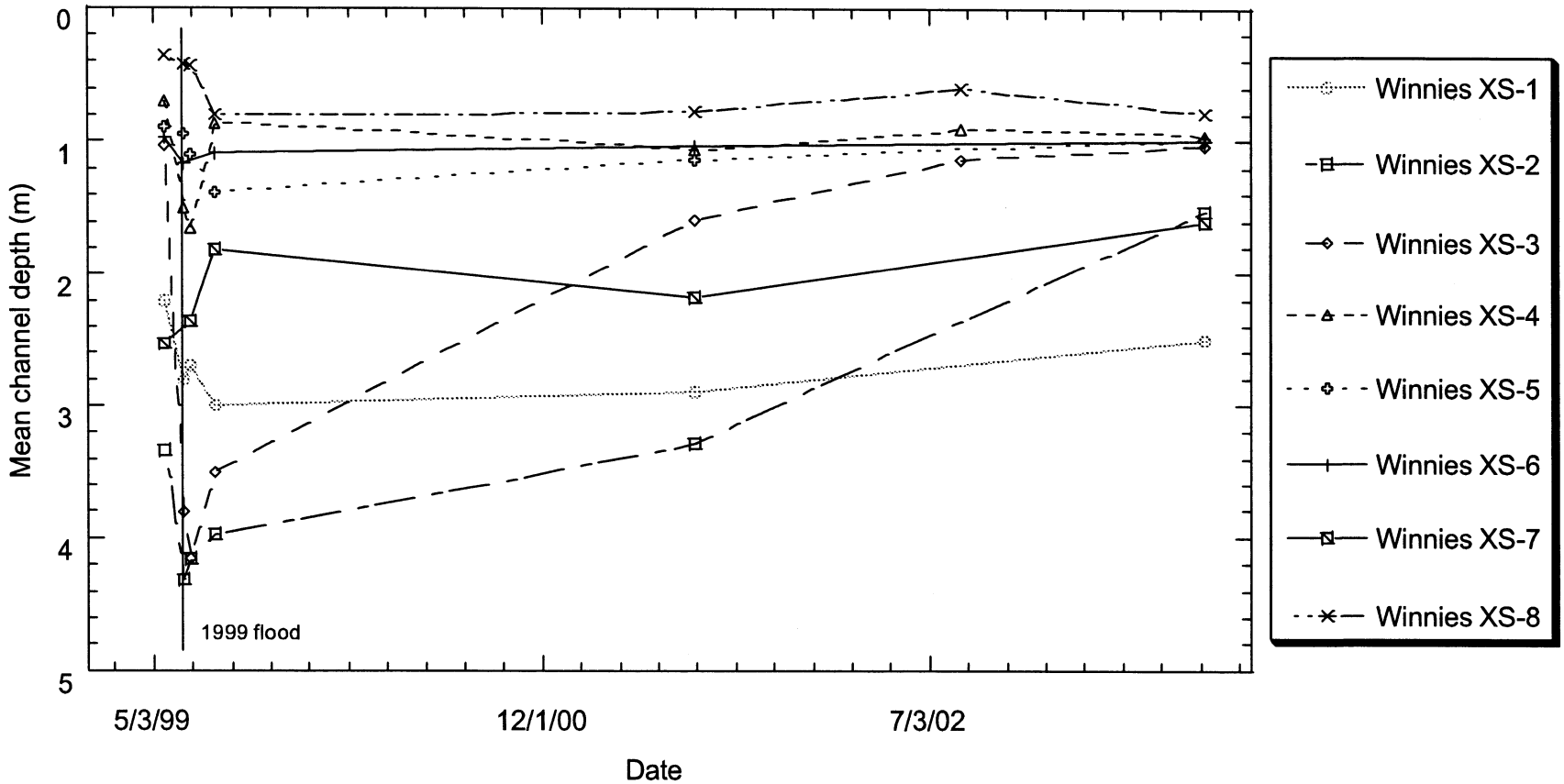

Figure 6b. Mean channel depth at cross-sections located in the Winnies Reach in the upper, low-gradient segment of the canyon. Cross-sections 1-6 and 8 scoured during the June 1999 flood, whereas cross-section 7 aggraded. The mean channel depth at cross-sections that scoured in June 1999 has generally decreased since the flood.

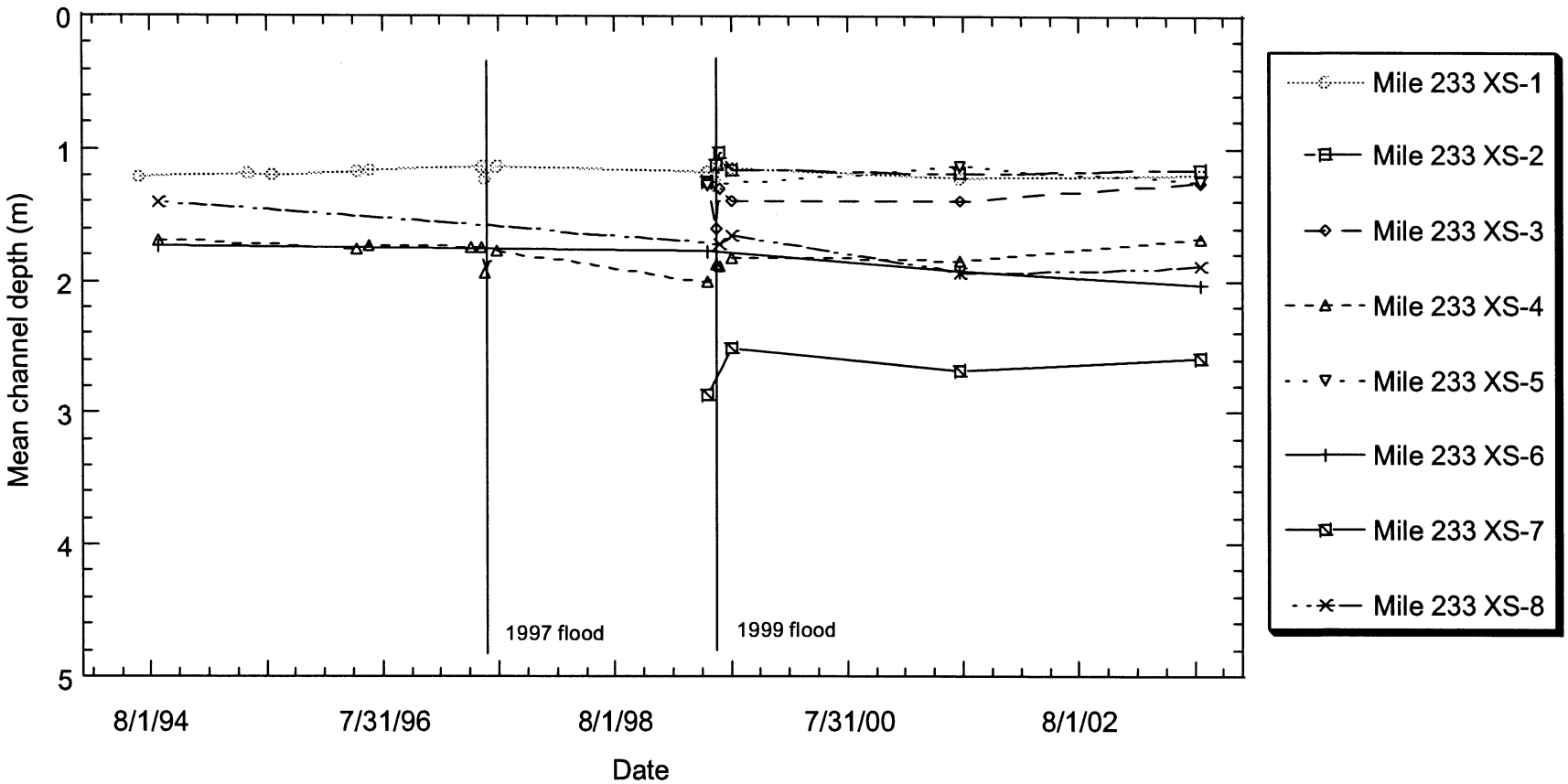

Figure 7a. Mean channel depth at cross-sections located in the Mile 233 Reach in the middle, high-gradient segment of the canyon. Cross-section 4 scoured during the June 1997 flood but aggraded during the June 1999 flood, whereas cross-section 1 scoured during both floods. Cross-sections 2, 7 and 8 aggraded during the 1999 flood. Cross-section 3 scoured during the 1999 flood, but aggraded to near pre-flood values in the weeks following the flood. The magnitude of these changes is small; most changes in mean channel depth are less than 0.5 m.

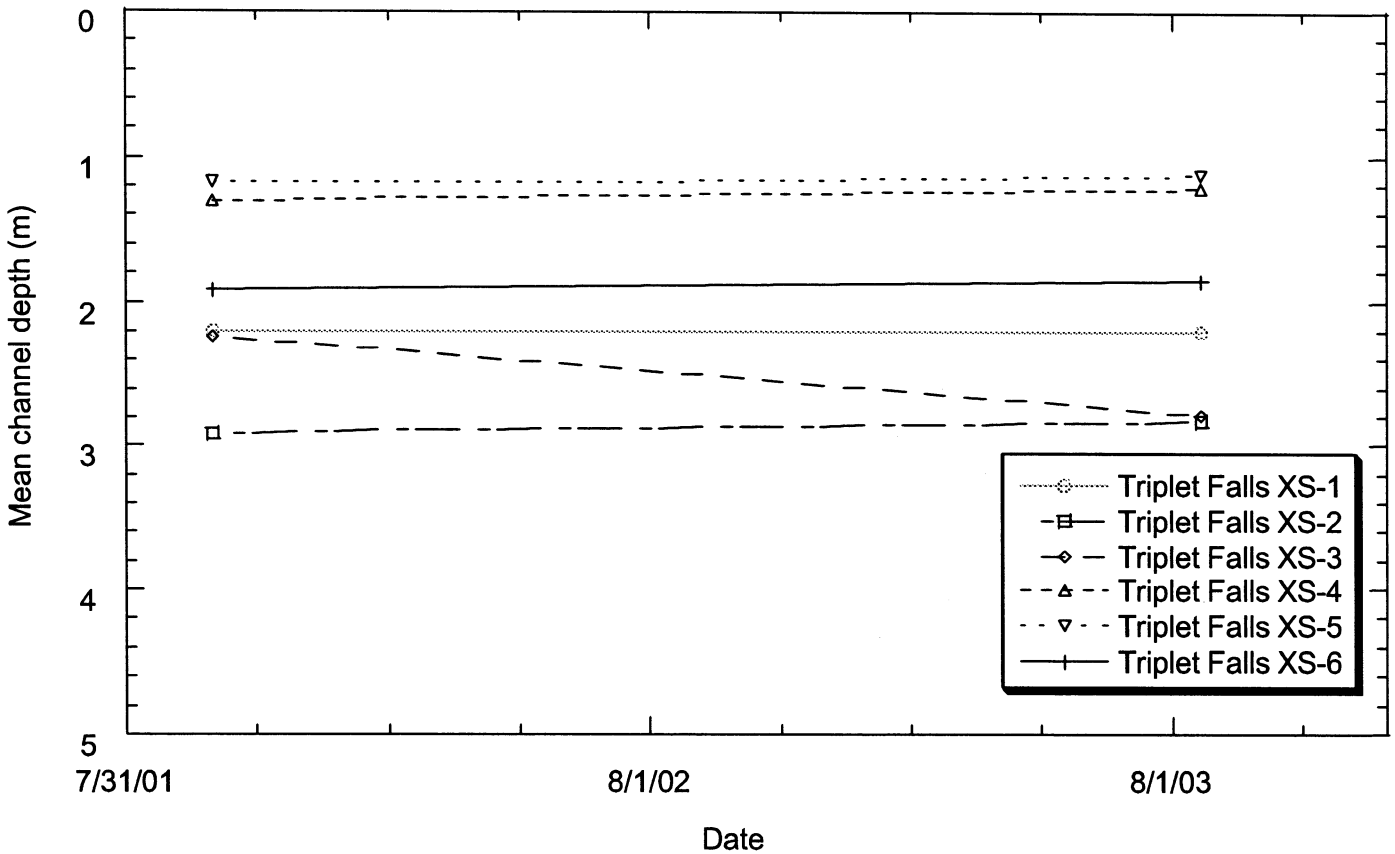

Figure 7b. Mean channel depth at cross-sections in the Triplet Falls reach, located in the middle, high gradient segment of the canyon. Mean channel depth changed very little between September 2001 and August 2003.

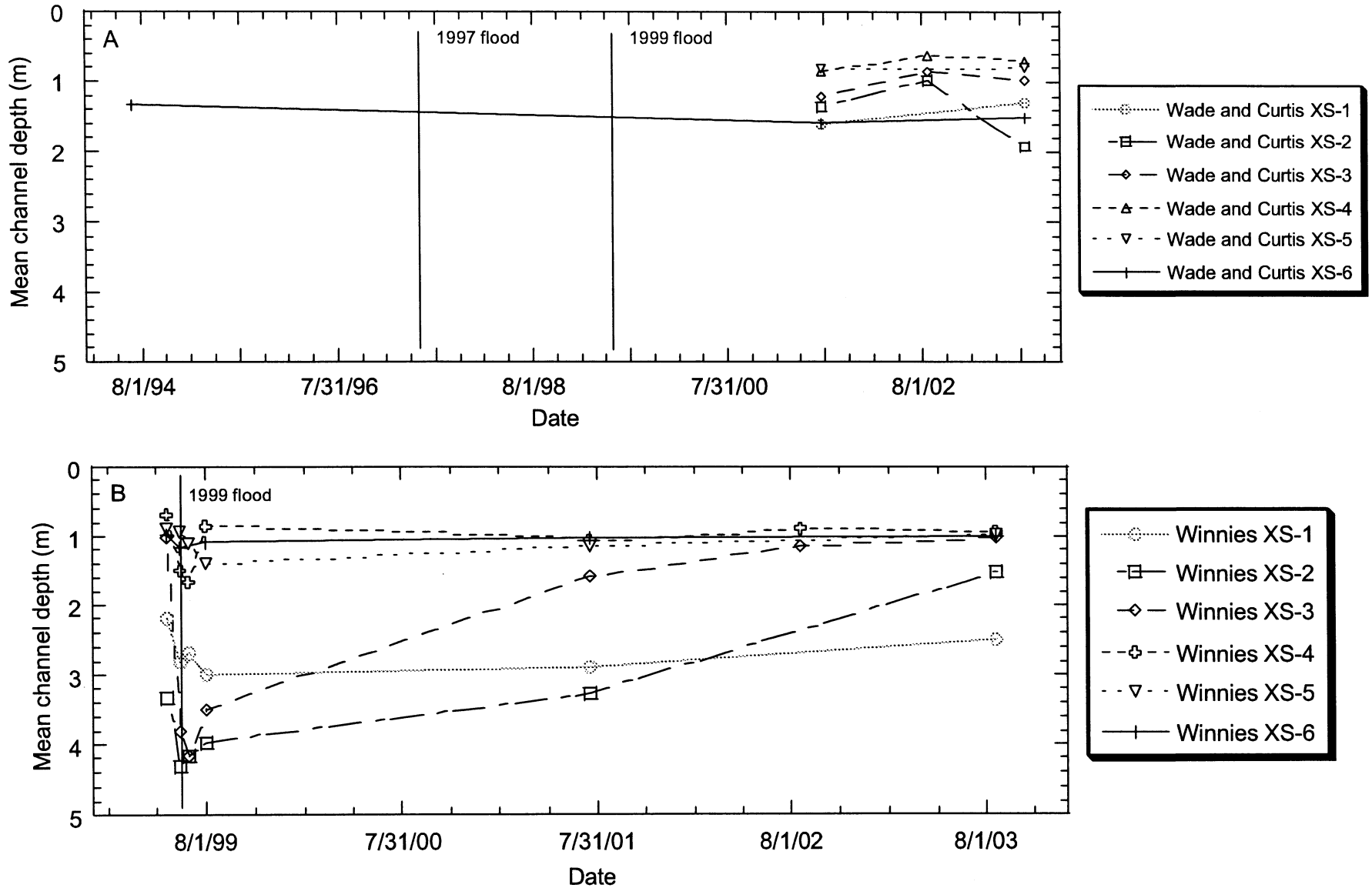

Figure 8a and 8b. Mean channel depth at cross-sections located in ponded backwaters in the Wade and Curtis and Winnies reaches. Cross-sections through ponded backwaters in the Wade and Curtis reach have changed little. All Winnies cross-sections in ponded backwaters scoured during the June 1999 flood and subsequently filled. Note the different horizontal scales in a and b.

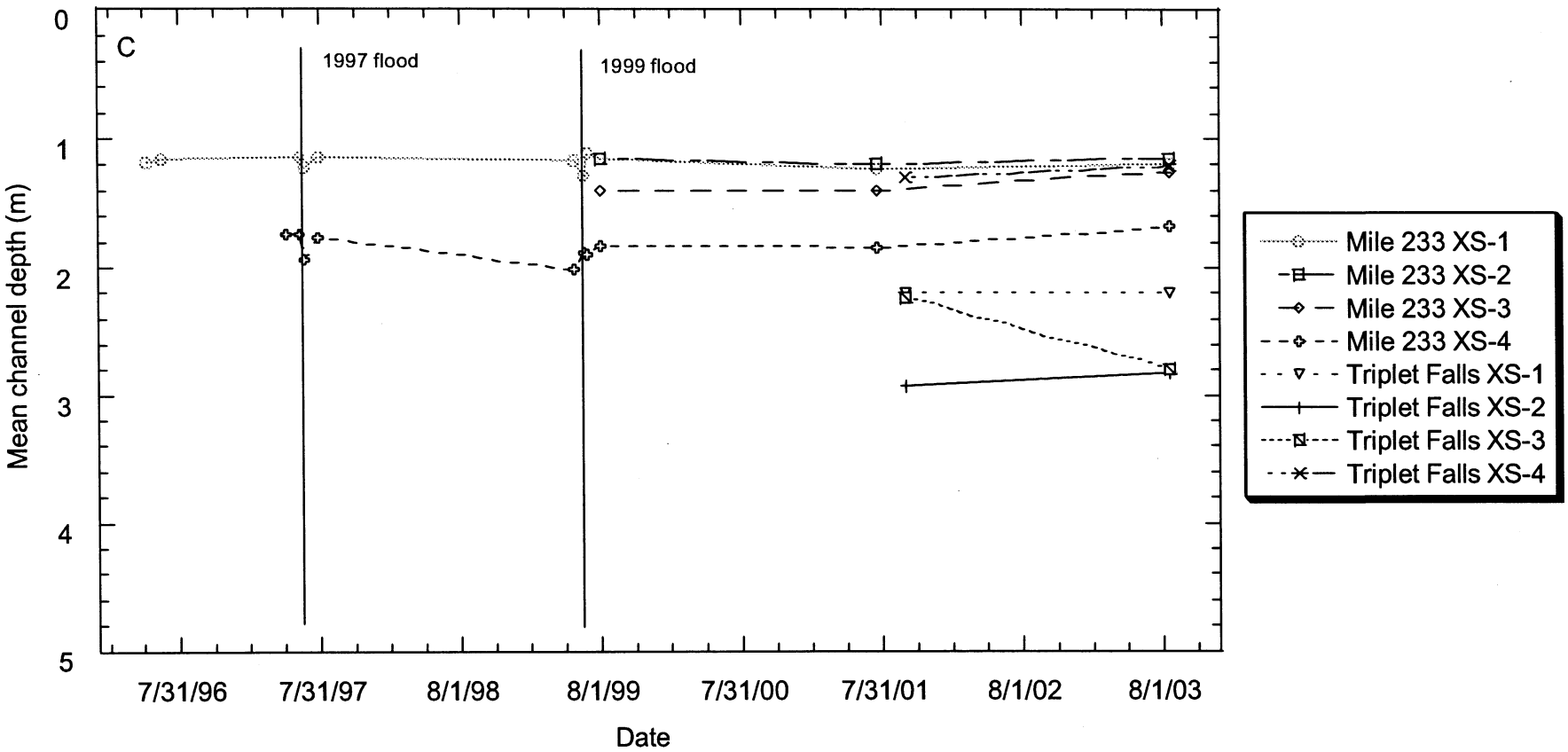

Figure 8c. Mean channel depth for cross-sections located in ponded backwaters in the Mile 233 and Triplet Falls reaches. At the Mile 233 reach, cross-section 4 scoured during the June 1997 flood but aggraded during the June 1999 flood, whereas cross-section 1 scoured during both floods. Cross-sections 2, 7 and 8 aggraded during the 1999 flood. Cross-section 3 scoured during the 1999 flood, but aggraded to pre-flood values in the weeks following the flood. The cross-sections at ponded backwaters in the Triplet Falls reach have not experienced a large flood and mean channel depth has changed little.

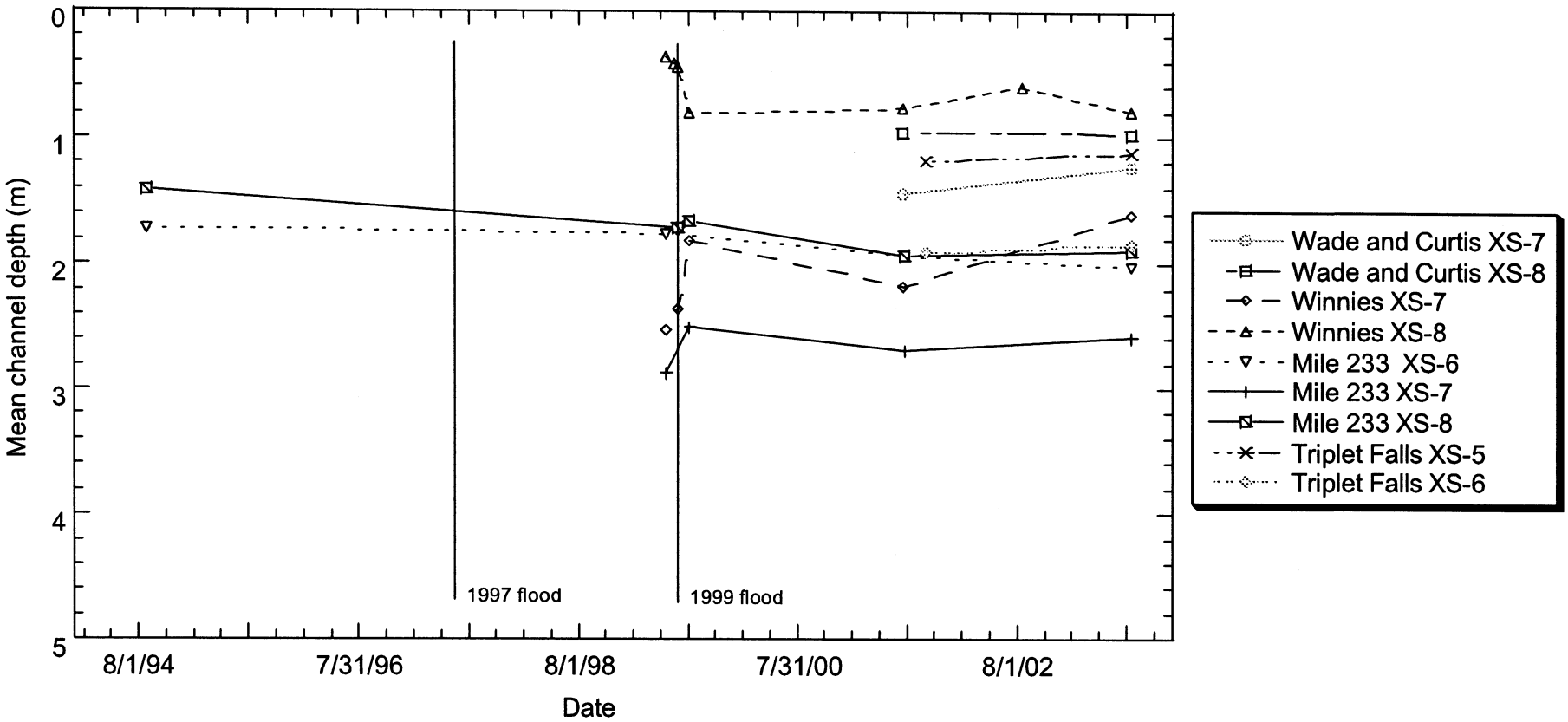

Figure 9. Mean channel depth for all cross-sections located downstream from constrictions. Wade and Curtis XS-7 and Winnies XS-7 filled, and Winnies XS-8 scoured during the 1999 flood.

For all cross-sections, the most dramatic changes in mean depth occur during and following floods, such as those that occurred in 1997 and 1999. The direction of the change in mean depth was variable, occurring as scour in some cases and aggradation in others, but several channel cross-sections reached their deepest recorded value following the June 1999 flood release and have subsequently aggraded (Figs. 6 and 7).

Sand Volume Change at Cross-Sections

Time series analysis of the volume of sand between the 800 and 4,400 ft^3s^{-1} stages shows that the volume of most deposits increases dramatically during floods, decreases sharply immediately following floods, then slowly declines during intervening periods of low flow (Fig. 10). We represent volume change as changes in cross-section area of sand above a stage at each cross-section. The greatest volume of sand deposits were measured during the peak discharges associated with the June 1999 flood (Fig. 10). Following floods, the sand volume typically declined, reaching values similar to the pre-flood volume (Fig. 10). Some eddy sand bars, such as the bar at Mile 233 Cross-Section One, exhibit dynamic scour and fill but undergo only small fluctuations in sand volume.

Times series analysis of sand volume above 4,400 ft^3s^{-1} shows a similar trend to the 800 to 4,400 ft^3s^{-1} data. Sand volumes tend to reach peak values during flood discharges and diminish as they are eroded by lower magnitude discharges, and, over time, approach pre-flood levels (Fig. 11). Data collected at Cross-Section Three in the Winnies Reach illustrates this observation (Fig. 12).

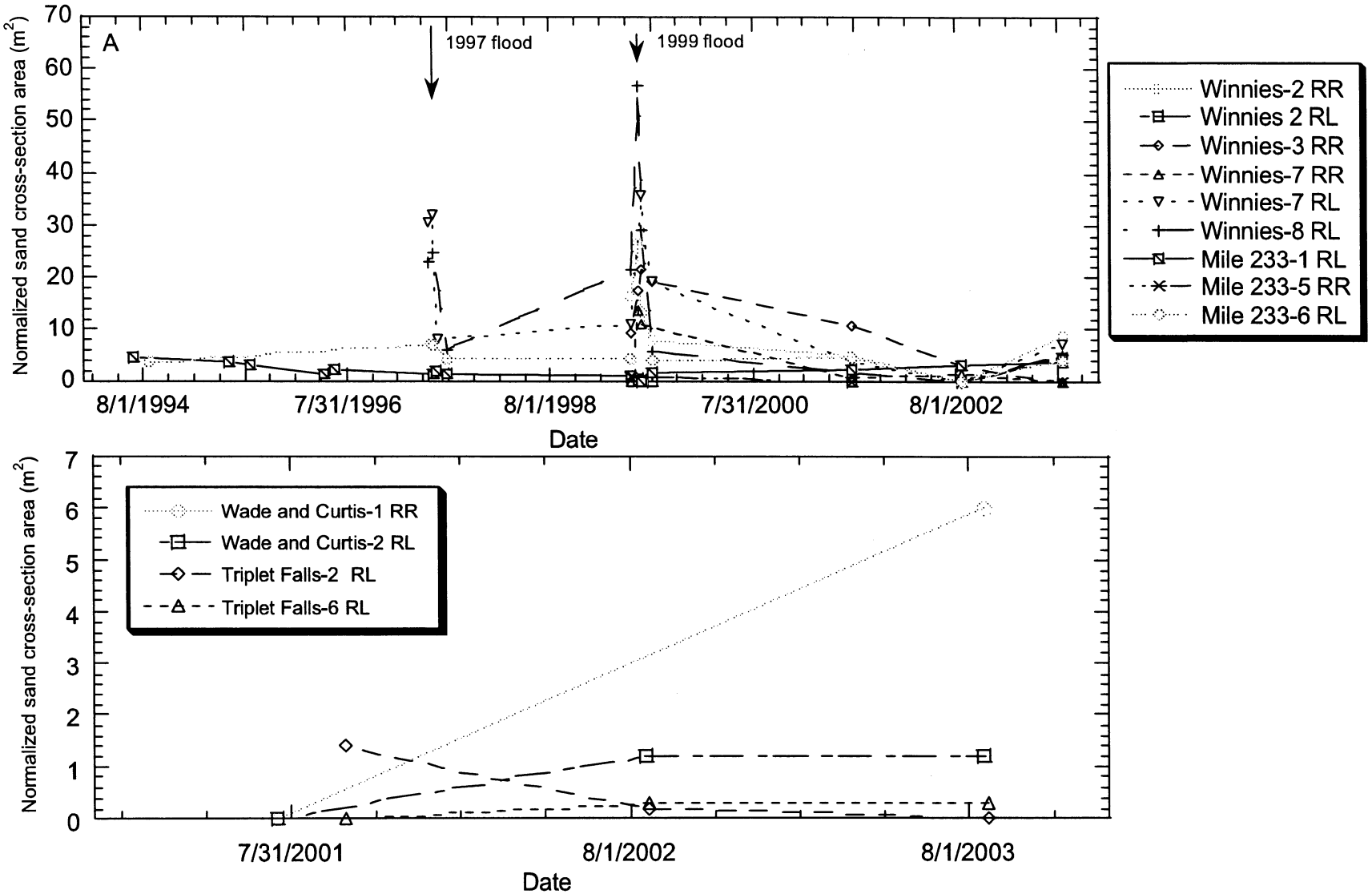

Figure 10. A. Normalized sand area between the 800ft^{3}s^{-1} and 4,400 ft^{3}s^{-1} stages for cross-sections with data prior to 2001. During the 1997 flood the volume of eddy sandbars at cross-sections Winnies 7 and 8 and Mile 233 cross-section 1 increased, whereas the volume of the bar at cross-section 1 at Mile 233 decreased. During the 1999 flood sandbar volumes increased at Winnies cross-sections 2, 3,4,7, and 8, whereas volumes decreased at Mile 233 cross-sections 1 and 6. In nearly all cases, sandbar volumes measured imediately following the 1999 flood were less than volumes measured during the flood. B. Sandbar volumes for cross-sections with post-2001 data have generaly changed little.

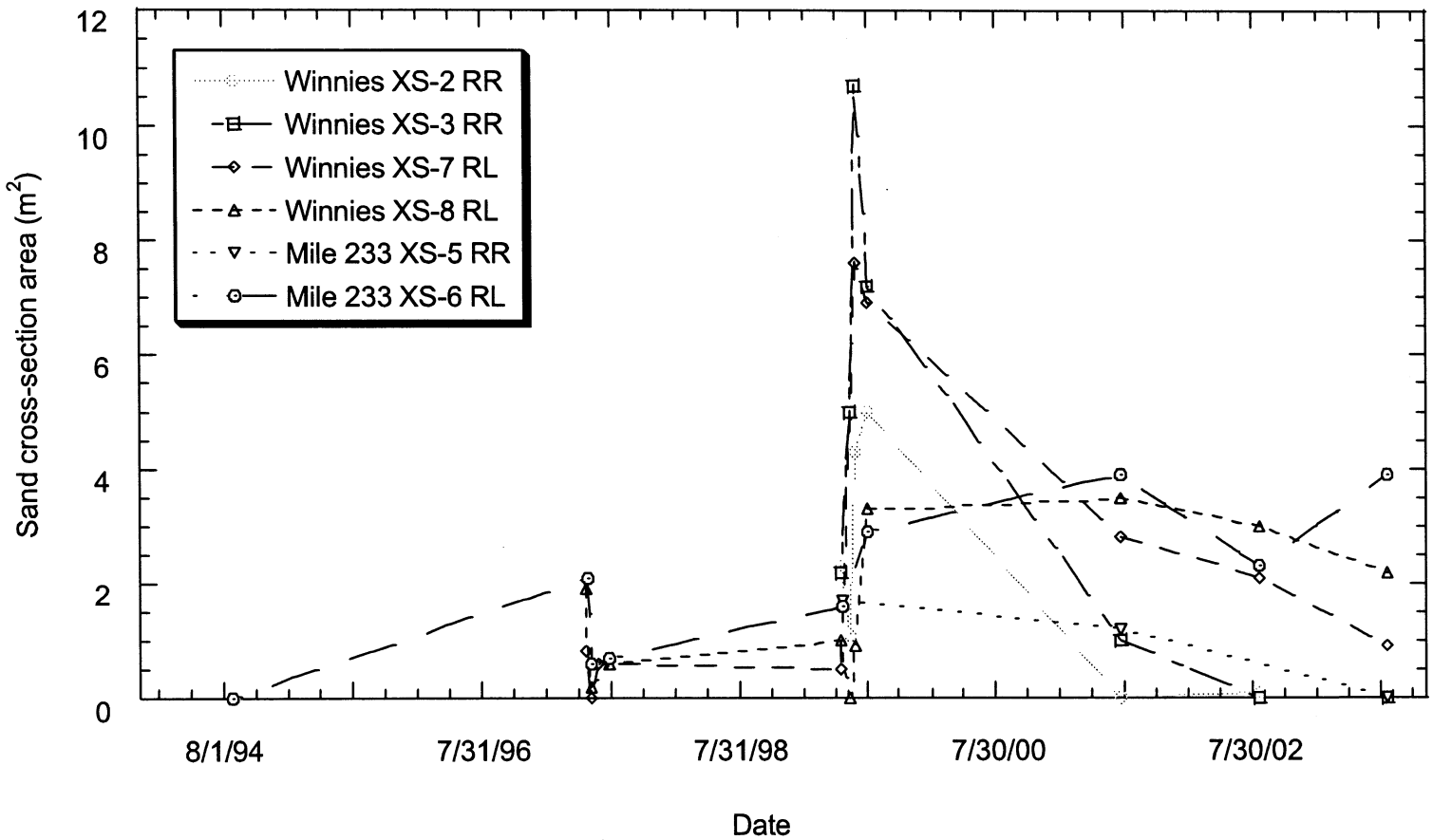

Figure 11. Time series plot of sandbar volume above the 4400 ft^3s^{-1} stage. During the 1997 flood, sandbar volumes decreased at cross-sections at Winnies-7, Winnies-8, and Mile 233-6. During the 1999 flood sandbars at Winnies-3, Winnies-7, and Mile 233-6 increased, whereas sandbars at cross-section Winnies-2 and 8 decreased during the flood but showed volume increases during surveys several weeks following the flood. The incease in area at Mile 233 cross-section 6 from 2002-2003 is due to debris flow aggradation of the sand deposit.

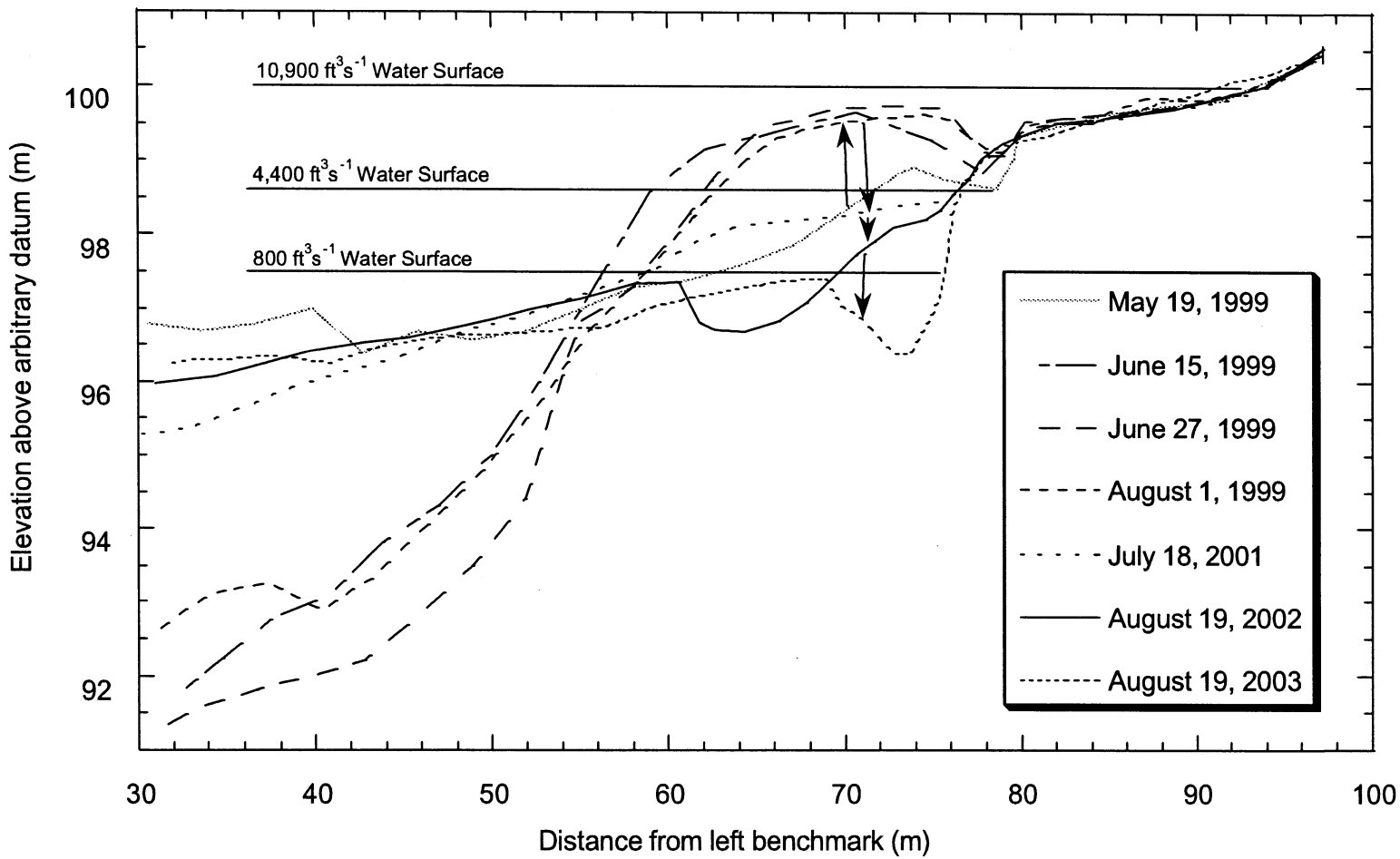

Figure 12. The eddy sandbar on river left of Winnies cross-section 3. The arrows track the topography of the bar through time. The bar reached its maximum volume during the June 1999 flood, and maintained a large, but somewhat smaller volume until at least August 1999. By July 2001 the bar volume approached the May 1999, pre-flood value, and the deposit continued to erode in 2002 and 2003.

Summary

Monitoring of channel cross-section form over the last nine years has revealed the following trends:

1) There are no apparent long-term trends in sand storage at monitoring sites in the Canyon of Lodore, i.e. the channel is not appreciably aggrading or degrading over time.
2) The largest apparent temporary in-channel sand storage sites are at sites located in ponded backwaters, particularly those located in the upper, low-gradient segment of the canyon.
3) The largest sandbars are present during or immediately following large floods. These bars are deposited quickly and are subsequently eroded by lower-magnitude discharges.

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