CURRENT AND HISTORIC STREAM CHANNEL RESPONSE TO CHANGES IN CATTLE AND ELK GRAZING PRESSURE AND BEAVER ACTIVITY

by

SUZANNE CATHERINE FOUTY

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Dr. Patricia F. McDowell, Chair of the Examining Committee

Date

Committee in charge: Dr. Patricia F. McDowell, Chair
Dr. Patrick Bartlein
Dr. Shaul Cohen
Dr. Jeffrey Ostler
Dr. Robert L. Beschta

Accepted by:

Dean of the Graduate School

An Abstract of the Dissertation of

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Approved: ______________________________
Dr. Patricia F. McDowell

Livestock grazing and beaver trapping alter streams hydrologically and geomorphically leading to declines in the quality and extent of stream-riparian ecosystems. The influence of reductions in grazing pressure and fluctuating levels of beaver activity (treatments) on channel capacity was studied at 108 channel cross-sections, located on eight headwater streams in Montana and Arizona. Cross-sections were surveyed two or three times over a two-to-five year period to determine annual rates of change as a function of treatment. Most cross-sections in the cattle and elk exclosures and grazed areas showed minimal changes in area (< 10 percent). Large decreases in cross-section area were observed in reaches with intact beaver dams, especially near the dams. The beaver ponds reduced channel capacity between 50 to 100% in most reaches, compared to ≤ 25% in reaches without beaver ponds. The ponds effectively restored the hydrologic connection between the stream and valley floor in less than one year. Upon

dam failure, channel capacity increased within a year by 40 percent or more as the ponds drained and sediment eroded.

A conceptual model describing geomorphic and hydrologic response of a drainage basin to the entry of beavers and then their removal or abandonment was developed, based on a literature review and field data. The model suggests that the simultaneous existence of discontinuous arroyos and wetlands, observed by Euro-American expeditions to the Southwest prior to settlement, may in fact reflect landscapes transforming due to recent beaver trapping rather than a recent climate shift. Beaver-dam failures would trigger channelization and thus greater flood magnitudes as water was more rapidly routed from upper to lower watersheds.

The study suggests that Euro-American trapping and grazing, though temporally and spatially separated, combined with two recent periods of above-average precipitation to transform drainage networks in the West and increase stream ecosystem sensitivity to climatic variability. This transformation pre-dates the installation of stream gages and the data collection that forms the current basis of our understanding hydraulic geometry and fluvial processes. Consequently, current hydraulic geometry relationships and our understanding of stream sensitivity to climatic variability reflect highly disturbed watersheds and ecosystems, not intact systems.

CURRICULUM VITA

NAME OF AUTHOR: Suzanne Catherine Fouty

PLACE OF BIRTH: Seattle, Washington

DATE OF BIRTH: August 23, 1956

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon
University of Arizona
University of Washington
University of Michigan
North Seattle Community College
Central Washington State University
Washington State University

DEGREES AWARDED:

Doctor of Philosophy in Geography, 2003, University of Oregon
Master of Science in Geological Sciences, 1989, University of Arizona
Bachelor of Science in Geology, 1982, University of Washington

AREAS OF SPECIAL INTEREST:

Current and historic influences of livestock grazing and beaver trapping on stream and riparian systems
Stream and riparian restoration
Human and environment relationships as it pertains to restoring ecosystems
Scientific and public perceptions of rivers, beavers, cattle, and wolves
Stream channel changes and community stability in the face of climate change

PROFESSIONAL EXPERIENCE:

Graduate Teaching Fellow, University of Oregon, Eugene, 1995-1999.

Course Instructor - Geomorphology (Geography 311), Department of Geography, University of Oregon, Eugene, Winter 1997.

Independent Consultant - Forest Service, Bureau of Land Management, The Nature Conservancy, Environmental Protection Agency (subcontractor), Montana and Arizona 1994 – 1998.

Seasonal Hydrologist/Hydrologic Intern, Forest Service, California and Montana, Summer 1991, Summer 1992, Summer 1993.

Outdoor Environmental Educator, Yosemite Institute, Yosemite National Park, California 1990 – 1992.

Water Resource Specialist II, New Mexico Environment Department/ Underground Storage Tank Bureau, Santa Fe, 1989 – 1990.

Hydrologic Intern, Tucson Water, Tucson, 1987 – 1989.

Hydrologic Technician, U. S. Geological Survey, Carson City, Nevada, Summer 1985.

Physical Technician, U. S. Geological Survey, Menlo Park, California, 1983 – 1984.

Field Assistant, University of Washington, Department of Geology, Kenya, East Africa, Summer 1982.

GRANTS, AWARDS AND HONORS:

University of Oregon Doctoral Dissertation Fellowship, 1999

University of Oregon - Department of Geography Travel Grant, 1998

University of Oregon - Department of Geography Summer Research Grant, 1996, 1997, 1998

Pacific Northwest Forest Sciences Laboratory (Corvallis, Oregon), 1998

Madison Valley Rangelands Group (Ennis, Montana), 1997

USDA Forest Service Beaverhead-Deerlodge National Forest (Dillon, Montana), 1995, 1997, 1998

USDA Forest Service Apache-Sitgreaves National Forest (Springerville, Arizona), 1994, 1997

The Nature Conservancy (Tucson, Arizona), 1994

Bureau of Land Management Dillon Resource Area (Dillon, Montana), 1994, 1995

The Lore Kahn Foundation (Livingston, Montana), 1993, 1994

PUBLICATIONS:

Fouty, S. C. 2002. Cattle and Streams – Piecing together a story of change. *In* Welfare Ranching: The Subsidized Destruction of the American West (G. Wuerthner and M. Matteson eds). Island Press, Washington, p. 185 – 187.

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I am haunted by waters.

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CHAPTER I

INTRODUCTION

Stream ecosystems in many of the lower 48 states have undergone tremendous change since the mid-1500s as a result of regional-scale Euro-American disturbances. Widespread and extensive beaver trapping began in the mid-1500s in response to European market demands (Phillips 1961) as Europeans arrived on the North American continent and discovered the abundance of beavers. Initially, Native Peoples did the bulk of the trapping, bringing their pelts to European trading posts situated along major rivers. Later, Euro-Americans dominated the trapping particularly in the West, many working for fur trading companies (Chittenden 1954; Phillips 1961). The extensive and systematic trapping was the first of many Euro-American regional-scale disturbances that would occur on the North American continent and preceded most Euro-American settlements.

The widespread removal of beavers was followed decades later by a second period of regional disturbances as settlers, their settlement activities, and livestock dramatically reduced riparian and upland vegetation, triggering a loss of stream-bank stability and an increase in flood magnitudes and frequencies (Cooke and Reeves 1976). Over the course of these two disturbance periods, streams changed from complex, often multi-channeled systems with extensive riparian zones, many with beaver ponds (Pattie

183; Burroughs 1961), to wide and/or entrenched, single-thread streams with narrow riparian zones (Cooke and Reeves 1976; Sedell and Froggatt 1984). As channels incised and widened, the channel size increased enabling greater discharges to be transported in the channel before the flood waters overtopped the stream banks (i.e. available channel capacity increased). The result was a decrease in the frequency of valley-floor flooding (Campbell et al. 1972; Shankman and Pugh 1992), and a severance in the hydrologic connection between streams and their valley floors. The consequences of this hydrologic disconnection included lowered water tables, decreased soil moisture, and an increase in flood magnitudes and their frequency (Cooke and Reeves 1976; Chapter 3). Valley-floor vegetation shifted from dense cover of riparian species to more xeric species and the width of the riparian zone began to decrease (Bryan 1928b; Hastings and Turner 1965; Cooke and Reeves 1976; Hendrickson and Minckley 1984). The lower rooting density, percent cover, and abundance of the xeric species further reduced the stream-bank and valley-floor resistance to stream erosion increasing the potential for additional channel widening and all of the attendant changes.

The loss of the stream and valley-floor hydrologic connection has had, and continues to have, serious consequences for nonhuman and human communities. It has resulted in: 1) a reduction in the width and complexity of the riparian zone, 2) a decrease in the quality, extent, and diversity of fish and wildlife habitat, 3) an increase in the depth to the valley water table, 4) an increase in the magnitude of flood peaks and therefore their potential for channel erosion, and 5) a decrease in late summer or drought-year low flows and in water quality. These changes not only influence the viability of migratory bird, fish, wildlife, and plant populations and communities and human communities, but also increased the sensitivity of stream ecosystems to climatic variability.

The consequences of the hydrologic disconnection are most noticeable in the Southwest and Intermountain West, an arid and semi-arid region bounded by the Rocky Mountains to the east and the Cascades and Sierra Nevadas to the west. In this region, streams make up only one to two percent of the landscape but are critical habitat for 60 to 80 percent of all wild species (U. S. GAO 1988a) and essential to the survival of human communities. Yet, the limited information that exists indicates that thousands of miles of stream and riparian corridors are in poor condition and in need of restoration (U. S. GAO 1992). Therefore, it is critical to identify how these corridors might be rapidly restored and the factors and land uses controlling their rates of recovery. Successful restoration of stream systems, however, requires an understanding of fluvial processes, the components and feedback loops present in these systems, and how historical and current land use influence channel evolution.

Two human disturbances that have had, and continue to have, a significant influence on stream channels and their adjacent riparian areas throughout much of the western United States, and perhaps elsewhere, are beaver trapping and cattle grazing. However, few studies exist examining 1) how changes in beaver-dam integrity influence channel morphology and local and downstream hydrology or 2) how channel morphology responds to reductions in cattle-grazing pressure. And no studies exist that quantify how elk-grazing pressure influences channel morphology or the relative contributions of cattle versus elk grazing on the evolution of current channel geometry. The lack of information about the respective contributions of elk and cattle has become problematic because elk numbers are increasing in many areas that are heavily grazed by cattle, and both species utilize the same spatial and vegetative aspects of the landscape (Irwin et al. 1994; Singer et al. 1994). Increased interest in the use of beavers as agents of stream restoration highlights the need to understand the actual, rather than hypothetical, influence of abundant beaver dams on stream hydrology and channel morphology. Therefore, this dissertation seeks to fill the information void by examining how changes in elk and cattle grazing pressure and beaver activity influence the short-term evolution of stream-channel morphology and hydrology.

The dissertation has three chapters in addition to this introduction. Chapter 2 examines how two human disturbances (cattle grazing and beaver trapping) and two natural disturbances (elk grazing and beaver-dam failures) influence stream-channel morphology and the hydrologic connection between streams and their valley floors. Five cattle and elk grazing treatments are examined for their effect on channel geometry and range from complete exclusion of cattle and elk to grazing by both. Two levels of beaver-dam integrity are examined: intact beaver dams and failing beaver dams. The variable of interest in this chapter is the "geomorphic" channel cross-section area, defined as the bank-to-bank channel. This channel was selected rather than the hydrologic bankfull channel because it is the geomorphic channel that must undergo a reduction in cross-section area if the stream is to reconnect hydrologically with its valley floor. Channel cross-sections were surveyed two to three times over a two-to-five year period and the data used to determine changes in the cross-section area as a function of treatment. The baseline channel cross-sections and reach characteristics were measured at the time an area underwent a change in cattle and/or elk grazing pressure or within a year of the change. Measurements in reaches with changing levels of beaver activity could not be as tightly constrained because the beavers and the beaver trappers operated independently of the land-management agencies.

Chapter 3 presents a conceptual model of the fluvial processes and the geomorphic and hydrologic responses of streams to beaver colonization and beaver trapping or abandonment of a drainage. The conceptual model provides a mechanism capable of explaining the discontinuous arroyos, the active tributary incisions, and the relative abundance of wetlands and ponds observed by early expeditions and General Land Office surveys that post-date trapping but pre-date Euro-American settlement and grazing in the Southwest and Intermountain West. The conceptual model, literature review, and original field data are used to demonstrate the ability of beavers to accelerate stream and riparian restoration. The chapter also shows how placing current conceptual models, hydraulic geometry relationships, and studies of past changes in a broader historical and disturbance context that includes beaver trapping can alter the interpretations and conclusions of prior research.

Chapter 4 is the final chapter and concludes the dissertation with a discussion of the implications of chapters 2 and 3 on the discipline of fluvial geomorphology. The chapter discusses how our interpretation and understanding of the recent evolution of stream and riparian ecosystems and their sensitivity to climatic variability changes when viewed in light of early beaver trapping and later livestock grazing. It also reiterates how the magnitude and nature of historic disturbances and channel changes continue to influence the evolution of current channel morphology.

The combination of the three chapters reveals the complexity and challenges inherent in trying to restore stream ecosystems altered by regional-scale and chronic human disturbances. The three chapters demonstrate the importance of understanding not only fluvial processes and physical factors inhibiting restoration but also the historical and societal factors that inhibit restoration. The recognition of the various physical, historical and societal factors involved in any attempt at watershed restoration should result in the development of more successful strategies for restoring these ecosystems. This dissertation hopefully contributes to that process.

CHAPTER II

CURRENT STREAM CHANNEL RESPONSE TO CHANGES IN CATTLE AND ELK GRAZING PRESSURE AND BEAVER-DAM INTEGRITY IN SOUTHWESTERN MONTANA AND EAST-CENTRAL ARIZONA

Introduction

Fluvial processes, channel characteristics, and human land uses interact over time and space via feedback loops to influence the evolution of channel morphology and the degree to which streams and valley floors are connected hydrologically (i.e. how frequently the valley floor is flooded). Euro-American land uses over the last 300 years have caused channels to widen, straighten, and incise, thereby severing the hydrologic connection and reducing the quality and extent of critical riparian corridors (Cooke and Reeves 1976; Cronon 1983; Wiens 2001). Restoration of those ecosystems that depend on this connection requires a better understanding of how historic and current human activities and fluvial processes interact to influence the ongoing evolution of the channel cross-sectional area and geometry. Therefore, this chapter compares the impact of cattle, elk, and beavers on channel cross-sections because 1) these species exert considerable influence on the evolution of channel morphology and the riparian zone, 2) humans have greatly altered their numbers and distributions on the landscape, and 3) this alteration of numbers and distribution has set in motion fluvial processes that have hydrologically disconnected streams from their valley floors. The importance of each species on stream systems is discussed separately. The fluvial processes of interest are those that lead to reductions in channel cross-section area and the recovery of the stream and valley floor hydrologic connection.

The goal of my research was to identify 1) the initial response of channel cross-sections to reductions in cattle and elk grazing pressure and shifts in beaver-dam integrity over a two-to-five-year period, 2) the rates and directions of those changes, and 3) the processes and factors that determine those rates and directions of change. Five cattle and elk grazing treatments were examined, ranging from complete exclusion of both cattle and elk to grazing by both. Two levels of beaver-dam integrity were examined: intact beaver dams and failing beaver dams. I established 108 channel cross-sections on 42 reaches: 13 reaches in east-central Arizona and 29 reaches in southwest Montana encompassing one watershed in Arizona and three watersheds in Montana (Figure 1). The cross-sections were monumented and repeatedly surveyed over a two-to-five-year period to determine how the channel cross-sections responded to the different treatments. Similar cattle and elk grazing treatments were examined in Arizona and Montana in order to determine if climate influenced the rates, directions and processes of cross-section area change. A review of the climate characteristics of the study sites found, however, that the climate was fairly similar between the two areas, especially when contrasted with the more arid regions of the Intermountain West.

The data collected at the cross-sections were used to answer the following questions.

1. What factors, other than the study treatments, may be controlling direction and amount of change in the channel cross-section areas? Is the magnitude of their influence great enough to preclude identifying a treatment influence?

2. What is the response (rates, directions, and processes) of the channel cross-sections to reductions in cattle and elk grazing pressure and changes in beaver-dam integrity? Are the rates, directions, and processes similar or different? Why?

3. What is the geomorphic significance of the cross-section area change as it relates to reconnecting the stream hydrologically to its valley floor?

4. What are the time scales of channel change, potential trends, and the effectiveness of the different study treatments as strategies for restoring the stream and valley-flood hydrologic connection?

5. What factors limit the ability of streams to reconnect hydrologically with their valley floors?

The study streams flow through meadows and comprise first through fourth-order streams. The majority of the streams have drainage areas less than 15 km^2 and the channels are typically less than 10 m wide. Stream banks are relatively homogeneous in their stratigraphy and are composed of sand loams and silt loams, making the banks relatively cohesive. All of the streams were ungaged. Conversations with agency personnel, however, indicated that during the study period (1993 to 1998) the weather was neither unusually wet nor unusually dry. In addition, flood debris on the valley floor, suggestive of recent unusually high flow events, was not observed.

Figure 1. Location of the study areas in southwest Montana and east-central Arizona. (1) = Basin Creek, Montana, (2) = Muddy Creek, Montana, (3) = Price Creek, Montana, and (4) White Mountains suite, Arizona (Hay, Home, Lower Burro, Lower Stinky, and Mandan Creeks).

The geomorphic characteristic of interest in my study is the "geomorphic" channel cross-section area, defined as the bank-to-bank channel. This channel was selected because it is the geomorphic channel that must undergo a reduction in cross-section area if the stream is to reconnect hydrologically with its valley floor. Repeated measurements of this channel were made over a two-to-five year period to determine changes in the channel cross-section area. The baseline channel cross-sections and reach characteristics were measured at the time a grazing allotment or portion of the allotment underwent a change in cattle and/or elk grazing pressure or within a year of the change. Measurements in reaches with changing levels of beaver activity could not be as tightly constrained because the beavers and the beaver trappers operated independently of the land management agencies.

Three hypotheses were developed at the beginning of the study:

1. Channels inside cattle and elk exclosures will decrease in area or remain stable while channels outside exclosures will increase in area as the stream banks continue to experience grazing pressure;

2. The presence of intact beaver dams will result in rapid reductions in channel cross-section area; and

3. Cross-sections reaches with intact beaver dams will decrease in channel area more quickly and more predictably than in the cattle and elk grazing treatments.

The testing of the three hypotheses provided insights into 1) fluvial processes involved in restoration, 2) the time scales of change, and 3) the components required to restore the stream and valley floor hydrologic connection and the limitations present when attempting to restore that connection.

Background

Restoration of stream and riparian ecosystems degraded by historic and current Euro-American land uses (Bryan 1928b; Schumm et al. 1984; Shankman 1996; Wiens 2000) requires that streams and their valley floors once again become reconnected hydrologically. This reconnection can only be accomplished by reducing the available channel cross-section area that must be filled with water before flooding the valley floor, such that the valley floor floods at lower discharges. Therefore, this section begins with a discussion of the fluvial processes that lead to reductions in channel cross-section area. This subsection is followed by an examination of how cattle, elk, and beavers alter channel cross-section area and concludes with a discussion of the current studies tracking channel responses to cattle and elk grazing pressure and beaver activity.

Fluvial Processes Leading to Reductions in Channel Cross-section Area

Available channel capacity can be reduced through lateral accretion, bed aggradation, maintenance of higher water levels in the stream, or a combination of the three. The reduction in cross-section area through channel narrowing and bed aggradation requires sediment in transport and the presence of mechanisms to trap and then stabilize the bedload or suspended sediment once it is deposited. The maintenance of higher water levels in the stream requires dam structures, either human or beaver-built. Information on the potential for channel cross-section area reductions and the processes that are likely lead to a reduction can be found in 1) the characteristics and dimensions of the current channel morphology (e.g. width, depth, sinuosity), 2) bank composition (e.g. silt loam, clay, gravel) and stratigraphy (homogeneous, composite), 3) the location, abundance and composition of vegetation in the riparian zone, and 4) the presence or absence of beavers.

Researchers have identified three scenarios that can lead to channel cross-section area reductions. In the first scenario the cross-section area decreases through the deposition of sediment. Reductions in cross-section areas occur through vertical aggradation of the channel bed and bar surfaces, lateral accretion of the banks via bar development, or some combination of these processes (Hupp and Simon 1991; Hooke 1995; McKenney et al. 1995; Friedman et al. 1996; Scott et al. 1996). In high-energy environments, bedload (sands and gravels) is deposited (Hupp and Simon 1991; McKenney et al. 1995; Friedman et al. 1996). In low-energy environments, such as ponds or zones with abundant channel or bar vegetation, the sediment deposition may involve a mix of suspended load (clay and silts) and bedload (Ives 1942; Winegar 1977; Butler and Malanson 1995; Zierholz et al. 2001). The second scenario involves a flood-induced channel-widening event followed by stream incision into the newly exposed channel bed (Schumm and Lichty 1963; Burkham 1972; Pizzuto 1994; Friedman et al. 1996; Scott et al. 1996). The majority of the channel bed remains exposed except during large floods and begins to recolonize with vegetation. The exposed bed becomes part of a new floodplain, inset into the larger geomorphic channel. The third scenario involves the isolation of a secondary channel and its infilling by sediment and vegetation (Burkham 1972; Johnson et al. 1995; Hooke 1995). Depending on the energy of the depositional environment, the sediment deposited will be a mix of bedload and suspended load. In each of the three scenarios, the establishment of vegetation on the channel bed or banks or bars initiates the feedback loop between vegetation and sediment accumulation required for continued reductions in channel cross-section area. In the absence of accretion and/or aggradation, the channel cross-section area remains the same or increases, and the stream remains disconnected hydrologically from its valley floor, flooding only during large, infrequent events.

In addition to the three scenarios mentioned above, there is a fourth scenario that has generally been overlooked in the contemporary geomorphic literature: the presence of intact beaver dams. Beaver ponds effectively trap sediment and maintain elevated water levels behind the beaver dams (Apple et al. 1984; Naiman et al. 1986, 1988; Butler and Malanson 1995; this study). Both sediment deposition and higher water levels in the channel reduce the available channel capacity and thus the amount of channel area that must be filled before water begins spilling onto the valley floor. The result of this decrease in available channel capacity should be an increase in the frequency of valley-floor flooding and a rise in the valley-floor water table. In cases where beaver ponds occur, the rise in water table appears to be maintained because the hydraulic gradient between the groundwater and the stream has decreased as a result of the elevated water in the ponds (Apple et al. 1984).

Cattle, Elk, and Beaver Influences on Channel Cross-section Area

Cattle currently graze on over 250 million acres of public land (U.S. GAO 1992) and have been identified as a key agent of current and historical riparian and stream channel changes throughout much of the West (Trimble and Mendel 1995). Impacts include bank trampling, removal of upland, valley and stream-bank vegetation, and soil compaction (Cooke and Reeves 1976; Kauffman and Krueger 1984; Platts and Nelson 1985; U. S. GAO 1988a, 1988b; Trimble and Mendel 1995). Soil compaction and the removal of vegetation can reduce the infiltration capacity of the soil, increase surface runoff, and decrease stream-bank resistance to erosion. These changes in turn can lead to local and downstream channel widening and incision and increased flood magnitudes (Cooke and Reeves 1976).

Identifying the impact of cattle grazing on current bank trampling, upland reductions in vegetation and soil compaction has been complicated by increasing numbers of elk in parts of the West. Elk numbers are rebounding after years of being depressed by intense market hunting in the late 1880s and early 1900s and are increasing in watersheds that are highly degraded, extensively used by humans, and devoid of their natural predator, the wolf. Despite increased elk numbers and their competition with cattle for forage, only a few studies compare the relative influence of elk and cattle on vegetation (Irwin et al. 1994; Singer et al. 1994; Case and Kauffman 1997). Though limited in number, these few comparative studies, along with personal communication with agency specialists, reveal that elk use can result in considerable reductions in riparian vegetation and high levels of stream bank trampling when elk and cattle congregate in the riparian zone (Keigley 1997; Case and Kauffman 1997; J. Moore, USDA Forest Service, pers. com. 2000; P. Bengeyfield, USDA Forest Service, pers. com. 2000). Studies, however, comparing how cattle and elk respectively alter channel morphology, and the magnitude of their respective contributions, are absent. Therefore, the individual and combined contribution of these two ungulates to the current stream channel conditions remains uncertain and should be explored in order to better predict rates of and impediments to the restoration of the stream and valley-floor hydrologic connection.

Beavers are the final species of interest in this study. Extensive beaver trapping began in the mid-1500s on the North American continent in response to the demands of the European consumer market (Phillips 1961) and was the first large-scale human-induced disturbance that occurred on the continent. Prior to this period of extensive trapping, first by Native Peoples trading with Europeans and later by Euro-Americans, 60 to 400 million beavers are estimated to have existed on the North American continent. Current beaver numbers are estimated in the 6 to 12 million range (Naimen et al. 1988). Trapping was extensive and well organized and predates all other Euro-American disturbances except along the East Coast where settlement activities and beaver trapping occurred simultaneously (Cronon 1983).

Trapping was the dominant human activity in the Intermountain West from the early to mid 1800s (Phillips 1961; Chittenden 1954; Weber 1971). A review of early Euro-American beaver trappers' journals (Pattie 1831) and the Lewis and Clark expedition journals (Burroughs1961) reveals that prior to beaver trapping, watersheds contained abundant riparian vegetation on the valley floor, wetlands, complex waterways and beaver ponds. These early descriptions are very different from current descriptions. Now the descriptions reveal wide and incised channels, minimal wetlands, drought-tolerant vegetation on many of the valley floors and, in many cases, an absence of the cottonwoods, aspen and willows that beavers need to build and maintain their dams and populations.

The difference between historical and current stream and riparian zone conditions, combined with recent research into changes that occur in drainage systems when beavers reestablish themselves (Naiman et al. 1988; Johnston and Naiman 1990; Butler and Malanson 1995; Meentemeyer and Butler 1999) suggests that the widespread removal of beavers contributed to a dramatic transformation in stream ecosystems (Naiman et al. 1988). As dams failed and were not repaired the streams experienced a drop in base level, triggering channel incision into the fine sediments stored behind the dams, the development of a channelized drainage network, and eventually changes in the frequency and magnitude of overbank flooding onto the valley floors (Dobyns 1981; Parker et al. 1985; Fouty 1996; Chapter 3) and in valley-floor vegetation. The influence of beavers and beaver trapping on watershed hydrology, riparian vegetation, and drainage network characteristics will be examined in detail in Chapter 3.

Studies Determining Channel Responses to Reductions in Cattle and Elk Grazing Pressure and Beaver-Dam Integrity

This section discusses the current studies and methods for tracking channel responses to reductions in cattle and elk grazing pressure and changes in beaver-dam integrity. It begins with a discussion of current studies that focus on cattle influences on channel morphology because these studies are the most common.

Recognition of the impact that cattle have on upland and riparian vegetation and on stream banks has led some land management agencies and a few private and public lands ranchers to attempt stream-riparian ecosystem restoration through different management strategies. These management strategies include changes in cattle grazing pressure through rotations, shifts in season and duration of cattle grazing, or the removal of cattle via exclosures or permit buyouts. Unfortunately, the response of the stream channel and riparian systems to those strategies has not been monitored except in rare cases (P. Bengeyfield, USDA Forest Service, pers. comm. 1999) and so their effectiveness is unknown.

A U.S. General Accounting Office (GAO) report found that only about 50 percent of the Bureau of Land Management cattle allotments have any trend data (vegetation only) and that even those data were considered to be of questionable quality (U.S. GAO 1992). A similar lack of vegetation and channel morphology monitoring exists for many lands managed by the Forest Service and state agencies with some exceptions such as the Beaverhead-Deerlodge National Forest in southwest Montana (P. Bengeyfield, USDA Forest Service, pers. comm. 1998). In addition, only minimal academic research exists quantifying livestock influences on channel morphology (Medina and Martin 1988; Clifton 1987; Platt 1991; Kondolf 1993; Magilligan and McDowell 1997), and most of these studies surveyed the variable of interest only once inside and outside their exclosures making it impossible to determine trends. Therefore, there is little actual data on how current cattle grazing-management strategies influence the ongoing evolution of channel morphology, nor is there any information on what other factors are contributing to the channel changes. While the data on cattle influences on channel morphology are limited, studies examining the impact of elk on channel morphology are nonexistent. Therefore, there are no studies that compare how cattle and elk respectively alter channel morphology or the magnitude of their influence. As a result, the individual and combined influence of these two ungulates on the evolution of channel morphology remains uncertain and needs exploring in order to better predict rates of, and impediments to, recovery.

Research on how beaver dams influence downstream flood peaks and alter stream channel morphology is limited to two studies (Beedle 1991; Burns and McDonnell 1998). Burns and McDonnell (1998) compared the stream hydrographs of two small watersheds (0.4 and 0.61 km^2), one of which had a single 1.3-hectare beaver pond located at the downstream end of the small headwater stream. They found that this single pond provided minimal retention during several large runoff events. Beedle (1991) explored how storm hydrographs responded to increasing amounts of beaver pond storage as the numbers of ponds in series and the sizes of beaver ponds increased. His study watersheds were 6.2 km^2 or less and his maximum pond size was 0.6 hectares. He found that the amount of reduction in storm hydrograph peak flows varied with storm size, pond size and number, and storages capacity available prior to the flow event. Reductions in peak flows increased as the number of ponds in a series increased with five large-sized (0.6 hectare) beaver ponds in series reducing the storm peak flow by 14% for a 2-year event and 4% for a 50-year event (Beedle 1991).

A few studies have quantified the volume and estimated rates of sedimentation in beaver ponds (Naiman et al. 1986, 1988; Devito and Dillon 1993; Butler and Malanson 1995; this study) and quantified increases in the areal amount of wetlands, wet meadows and ponds in response to the return of beavers to an area (Naiman et al. 1988; Johnston and Naiman 1990). Absent, however, are studies that compare sedimentation rates over time in reaches with and without beaver dams, document the speed at which changes in dam integrity alter the stream and valley-floor hydrologic connection, or document the speed at which channel incision can occur upon dam failures. The wide distribution of beavers prior to Euro-American trapping and this more recent research on beaver influences on watershed hydrology, however, highlights the need to explore the influence of beavers and beaver trapping on the historic and current hydrologic connection.

The Use of Exclosures to Identify the Respective Influences of Different Species on Channel Morphology

The standard method used to identify how cattle influence upland and riparian vegetation, runoff rates, and channel morphology is to exclude cattle from a portion of the area of interest with fencing, creating an "exclosure." The variable of interest is then compared inside and outside the exclosure either over time or at some future time (Hubert et al. 1985; Platts and Nelson 1985; Medina and Martin 1988; Rinne 1988; Clifton 1987; Kondolf 1993; Magilligan and McDowell 1997). The exclosure approach is the method used in this study and was expanded to explore elk and beaver influences as well.

Two approaches can be taken when using the exclosure method to evaluate the influence of a species on channel morphology or vegetation. The first approach is a space-for-time substitution. In this approach, measurements are taken inside and outside an exclosure at a single point in time and compared. This is the approach most commonly used to evaluate the influence of cattle on vegetation, soils, fisheries, wildlife and channel morphology because of limitations of time and funding (e.g. Schulz and Leininger 1991; Case and Kauffman 1997; Clifton 1987; Kondolf 1993; Magilligan and McDowell 1997; Keller and Burnham 1982; Hubert et al. 1985; Platts and Nelson 1985; Overton et al. 1994; Gamougoun et al. 1984). However, the lack of pre-treatment data (e.g. condition of the channel/vegetation prior to fencing) or a pristine, ungrazed system means that control conditions, which are considered standard in laboratory experiments, are absent (Rinne 1988). Thus it has remained unclear whether the differences observed in the space-for-time substitution studies truly reflect differences in the control variable (the study objective), or simply differences in local landscape or initial site conditions prior to building the exclosure.

The lack of a control area or treatment has led Rinne (1988) to suggest a "frame of reference" or repeated survey approach. This second approach conducts a baseline survey inside and outside the exclosure and then repeats the survey over time in order to determine how the variable of interest responds in the short-term and over the long-term term to reductions in cattle and/or elk grazing pressure. The more frequent the resurvey, the better the resolution and "frame of reference," and greater the ability to predict of future changes and separate out short-term from long-term responses. The "frame of reference" approach eliminates the space-for-time substitution problem because baseline conditions are established in the first survey. I used this second approach in my study to determine the channel response to reductions in cattle and elk grazing pressure and changes in beaver-dam integrity.

Study Design

The study areas were selected based on information from the Forest Service and Bureau of Land Management regarding 1) the locations of new or soon-to-be installed exclosures, and 2) allotments with management plans that called for reductions in cattle and elk grazing pressure. Seven treatments were examined: five grazing treatments and two beaver treatments. The cattle and elk grazing treatments involved various levels of cattle and elk grazing pressure and the baseline surveys occurred just before or shortly after a reduction in grazing pressure. The beaver treatments consisted of intact versus failing beaver dams. The timing of the beaver treatments could not be tightly constrained because of the unpredictability of beaver trappers and the beavers. The resurveys document the cross-section area response to reductions in grazing pressure and changes in the integrity of beaver dams. Resurveys also help identify the potential for hydrologically reconnecting streams to their valley floors and the factors inhibiting that reconnection.

Study reaches both inside and outside cattle and elk exclosures were selected for analysis. The cross-sections and selected reach characteristics (e.g. low-flow thalweg depths and reach widths) were resurveyed over time to determine the rates, directions, and processes of cross-section area change as a function of treatment. The 108 cross-sections are distributed over 42 reaches and located in four watersheds: three in Montana and one in Arizona. Cross-section locations were monumented with rebar for accuracy and reproducibility. All cross-sections were surveyed at least twice, 32 were surveyed a third time and one was surveyed four times. The number of cross-sections per watershed was similar (26 to 28), but the number of cross-sections per treatment varied (i.e. 39 cross-sections in Riparian Guidelines reaches but only 10 in new elk exclosures). The unbalanced treatment sample sizes occurred because the physical sizes of the exclosures were small and the number of exclosures and beaver-dam controlled reaches available for analysis were limited compared to the large areas accessible to cattle and elk.

Study Sites

The study sites are located in southwestern Montana and east-central Arizona. The Montana streams include Basin, Muddy and Price Creeks, all are headwater streams to the Missouri River and occupy separate mountain ranges. Basin Creek is located in the Gravelly Mountains in southwest Montana on the Beaverhead-Deerlodge National Forest in the upper Ruby River watershed (Figure 2). Basin Creek flows west-northwest to join the Ruby River that eventually joins with the Beaverhead River to form the Jefferson River, a major tributary of the Missouri River. The lower 1.5 miles of Basin Creek is important for spawning and recruitment of salmonids to the Ruby River (USDA Forest Service1992). Muddy Creek is located in southwest Montana in the Tendoy Mountains. It is part of the Bureau of Land Management (BLM) Resource Area. Muddy Creek flows south into Big Sheep Creek, a trout fishery of national significance. Big Sheep Creek later joins the Red Rock River to become part of the Jefferson River and eventually the Missouri River (Figure 3). The west-slope cutthroat trout occurs in Muddy Creek and is a state-listed 'species of special concern' (USDI Bureau of Land Management 1993). Price Creek is located in the Centennial Mountains in the Bureau of Land Management Resource Area. Price Creek flows north out of the Centennial Mountains into the Centennial Valley where it joins the Red Rock River to become part of the Jefferson River and eventually the Missouri River (Figure 4).

The Arizona streams are Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks and are located in the White Mountains of Arizona on the Apache-Sitgreaves National Forest. All creeks are located in close proximity to each other and are not described separately (Figure 5). The streams are headwater streams to the Black River that flows into the Salt River, a tributary of the Colorado River. Hay, Stinky, Home and Burro Creeks are tributaries to the West Fork of the Black River and are targeted by the Apache Trout Recovery Plan to be managed for Apache trout (*Oncorhynchus apache*) (USDA Forest Service 1993a). Mandan Creek is a tributary to the North Fork of the East Fork of the Black River.

Figure 2. Photograph of the Basin Creek, MT area taken in the vicinity of cross-section 7 in 1995. Looking northeast.

Figure 3. Photograph of the Muddy Creek, MT area taken in the vicinity of cross-section 3 in 1993. Looking east.

Figure 4. Photograph of the Price Creek, MT area taken in the vicinity of cross-section 19 in 1995. Looking east.

Figure 5. Photograph of the White Mountains area, AZ taken in the vicinity of Lower Burro Creek cross-section 3 in 1994. Looking west.

The basin, reach, and cross-section characteristics of the study streams are summarized in Table 1. The streams are first-to-fourth order streams and drain areas ranging from 2 to 76 km^2. The majority of the streams drain less than 15 km^2. All streams flow through meadows and have fine-grained homogeneous banks. The study reaches were selected because they had similar drainage areas, valley bottom gradients and widths, stream orders, valley-floor vegetation, bank stratigraphy and composition (Table 1), and channel morphology (Figure 6, Appendix A) despite being geographically separated. Currently, all watersheds 1) have new, and in one area old, exclosures, 2) are experiencing some reduction of cattle grazing pressure, 3) have cattle grazing pressure closely monitored by the Forest Service and Bureau of Land Management personnel, and 4) have some information on elk numbers, cattle management and numbers, cattle trespass of exclosures, and beaver habitation in each area. Elk occur in all watersheds, but their numbers are relatively small except in the White Mountains where forage consumption can be considerable (J. Moore, USDA Forest Service pers. comm 2000).

Beaver activity was limited to Price Creek. Intact beaver dams existed inside the new Price Creek cattle exclosure in 1994, and dams inside the new elk exclosure were built or repaired between the summer surveys of 1994 and 1995. Bureau of Land Management (BLM) field notes indicate that beavers returned to Price Creek in the summer of 1991 and began repairing dams built prior to 1991 (O. Martinez, USDI BLM memo 1992). Beavers were trapped out of Price Creek between the 1994 and 1995 surveys (J. Roscoe, BLM, pers. comm. 2000), and the dams began failing between 1995 and 1997. By 1998 all dams had failed or were in the process of breaching.

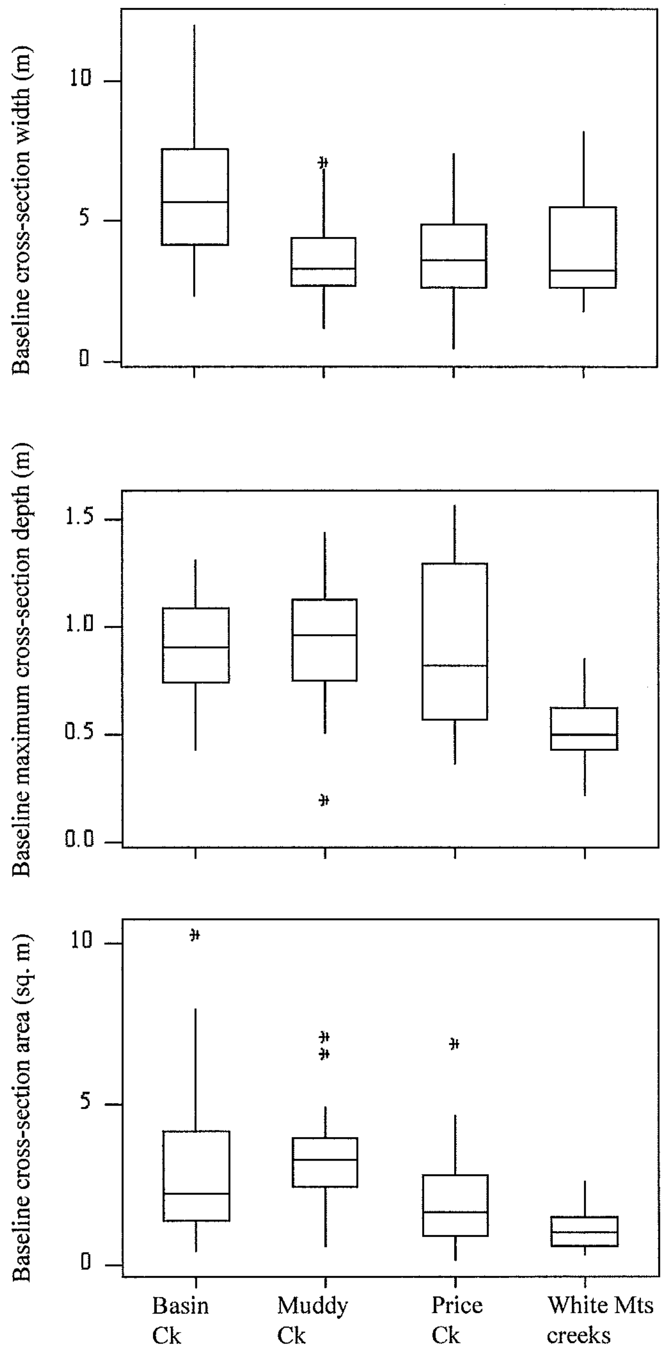


Figure 6. Geomorphic channel baseline widths, depths, and cross-section area for the four study areas. Basin Creek, MT (N = 28), Muddy Creek, MT (N = 27), Price Creek, MT (N = 26), and White Moutnains suite, AZ (N = 27).

Table 1. Summary of study area characteristics.

Parameter	Basin Ck, MT Gravelly Mountains	Muddy Ck, MT Tendoy Mountains	Price Ck, MT Centennial Mountains	Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)
Land use, Wildlife, and Fisheries Characteristics				
Land Management Agency	U.S. Forest Service – Beaverhead-Deerlodge National Forest	U. S. Bureau of Land Management – Dillon Resource Area	U. S. Bureau of Land Management – Dillon Resource Area	U.S. Forest Service – Apache-Sitgreaves National Forest
Grazing allotment name and size	Upper Ruby cattle and horse allotment The allotment, which contains Basin Creek, is 43,261 acres (175 sq. km) of public land (USDA Forest Service 1992)	Muddy Creek allotment contains 23,600 acres (96 sq. km) of which 22,000 is public land (USDI BLM 1999).	Price Creek allotment contains 20,868 acres (84 sq. km), of which 15,710 acres are public land, 4838 acres are state land, and 320 acres are private land (USDI BLM 1990).	Burro Creek allotment (contains Home, Lower Burro, Lower Stinky and Mandan creeks) is 27,301 acres (110 sq. km) and contains 14 pastures. Hayground Creek allotment (contains Hay Creek) is 7, 735 acres (31 sq. km) (K. Williams, USDA Forest Service, Apache-Sitgreaves National Forests, pers. comm. 2001).
Cattle grazing numbers: These numbers are only for general comparison. It is the spatial and temporal distribution of the cattle, rather than the actual	2,327 cow/calf pairs are permitted to grazing on the allotment from June 16 to September 30, standards permitting (J. Bowey, USDA Forest Service pers. comm. 2001).	350 cow/calf pairs are permitted to graze the allotment from June 20 to October 15 and rotate through seven pastures (J. Simons, USDA BLM, pers. comm. 2001).	500 yearlings graze from June 15 to September 15 and an additional 375 yearlings graze from August 1 to October 15. The allotment consists of five pastures, but only four are currently being	Two herds graze the Burro Creek allotment – 122 cow/calf pairs from May 16 to October 31 and 834 yearlings from June 1 to October 31. 200 cow/calf pairs and 6 horses graze the

Table 1 continued.

Parameter	Basin Ck, MT Gravelly Mountains	Muddy Ck, MT Tendoy Mountains	Price Ck, MT Centennial Mountains	Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)
numbers or AUMs that will determine impact on the stream. Therefore, an area could have low numbers or AUMs but high impact to the riparian zone. Thus management strategy is critical. (See Table 2 for distribution of treatments)			used. The four pastures are subdivided into 15 sub-pastures to allow for short-duration, high intensity grazing (J. Simons, USDI BLM, pers. comm. 2001).	Hayground allotment from May 16 to October 31 (K. Williams, USDA Forest Service, Apache-Sitgreaves National Forests, pers. comm. 2001).
Fisheries	The lower 1.5 miles of Basin Creek are important for spawning and recruitment of salmonids to the Ruby River (USDA Forest Service 1992).	The west-slope cutthroat trout occurs in Muddy Creek and is a state-listed 'species of special concern' (USDI BLM 1993).	No fish species of special concern	Three of the five creeks are targeted by the Apache Trout Recovery Plan to be managed for Apache trout (*Oncorhynchus apache*), a federally-listed threatened species (USDA Forest Service 1993).
Wildlife numbers and use of the area	Current elk populations in the entire Gravelly and Snowcrest mountain ranges are estimated at 7000 to 7500. Exact numbers are unknown because the elk tend to move through the upper Ruby River area rather than staying the entire year. Elk winter range is limited to	Watershed provides crucial winter habitat for 450 to 500 elk (Muddy Creek EA 1999). Elk utilization of woody and herbaceous vegetation is locally significant on some sections of Muddy Creek, but has not had a significant impact on stream bank stability or the riparian	Elk winter use has substantially increased in the watershed since 1979 with 350 to 425 elk currently grazing the area most winters, snow permitting (USDI BLM 1990). Drainage area of the study creek makes up only 27	Elk population in the White Mountains area around 20,000 head. In some places there is 70 to 80 percent utilization of forage before cattle ever arrive on the range, especially when winters are mild allowing them to remain in the area all year. (J. Moore, USDA

Table 1 continued.

Parameter	**Basin Ck, MT Gravelly Mountains**	**Muddy Ck, MT Tendoy Mountains**	**Price Ck, MT Centennial Mountains**	**Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)**
	the lower Ruby River area (below Basin Creek). Antelope and deer also graze the area but no information found on their numbers or distribution (USDA Forest Service 1992).	vegetation. However, wildlife is contributing to the annual impacts on stream banks, springs and riparian vegetation on the tributary streams. A small moose population uses the area and a few are usually present in the riparian zone throughout the year (USDI BLM 1999).	percent of the entire allotment and minimal evidence existed during the field surveys suggesting heavy elk use.	Forest Service, pers. comm. 2000)
		Basin Characteristics		
Drainage Basin Geology	Primarily Paleozoic and Mesozoic sandstone, shale, limestone and siltstone. Quaternary deposits consist of glacial deposits, alluvial fans and gravels, and landslide deposits and overlay these older sediments (USDA Forest Service 1992).	Limestone, along with some sandstone and shale, are the dominant parent materials found in the Muddy Creek watershed. Some igneous parent material occurs on the lower slopes and the stream terraces are predominantly poorly consolidated gravel, silt and clay (USDI BLM 1999).	Cretaceous sandstone, limestone and mudstone overlain by Tertiary volcanic rocks (Kendy and Tresch 1996).	Mainly quartz-latite flows (Pewe et al. 1984).
Drainage Basin Topography	Rolling and open topography	The valley is wide and bounded on both sides by the	Overall topography is rolling and gentle and varies from a	Rolling and open topography

Table 1 continued.

Parameter	Basin Ck, MT Gravelly Mountains	Muddy Ck, MT Tendoy Mountains	Price Ck, MT Centennial Mountains	Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)
		Tendoy Mountains. Portions of the eastern side rise abruptly from the valley floor, while the western side rises more gradually and has a rolling topography.	high mountain valley floor to mountain peaks. The creek flows through a narrow valley and is bounded on both sides by steep hillslopes.	
Mean Annual Precipitation (mm/yr)	450 to 630	300 to 510+	500 to 760	600 to 950
Seasonality of precipitation	wet springs, dry summers and wet winters	wet springs, dry summers and wet winters	wet springs, dry summers and wet winters	very dry late springs, wet summers and wet winters
		Reach and Cross-section Characteristics		
Location	Open meadows	Open meadows	Open meadows	Open meadows
Drainage areas (sq. km)	2.1 to 7.2	6 to 76	3.9 to 14.7	2.8 to 13.7
Elevations (m)	2120 to 2158	2015 to 2213	2066 to 2103	2573 to 2701
Valley widths (m)	13 to 83	15 to 198	17 to 70	15 to 137
Valley gradients (%)	1.6 - 4.2	0.4 - 1.9	1.8 - 2.5	0.5 - 2.9
Valley floor vegetation	Vegetation is lush and composed predominantly of grasses and forbs, scattered	Vegetation varies in lushness and composition. In places it is composed of grasses,	Vegetation is lush and composed of grasses, forbs, sedges, rushes, willows and	Grasses and forbs dominate with some local zones of lush sedges. Some of these sedge

Table 1 continued.

Parameter	Basin Ck, MT Gravelly Mountains	Muddy Ck, MT Tendoy Mountains	Price Ck, MT Centennial Mountains	Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)
	shrubby cinquefoil and some sagebrush and willows.	sagebrush and bunch grasses with bare ground. In other areas it is lush with rushes, sedges and some grasses. Grasses, forbs and sagebrush are common on the valley floor. The variation in vegetation appears to be a function of the proximity to springs and the height of the valley floor above the stream. Willows are abundant in some reaches, but are minimal in other areas. When willows are present, they are usually old stands located on the valley floor.	shrubby cinquefoil. Minor amounts of sagebrush occur on the valley floor in the upper portion of the study area, but are common on the valley floor below the confluence of the West Fork of Price Creek and Price Creek. Willows are abundant and range from new sprouts to older, well-established stands. The new sprouts are located on low surfaces adjacent to the current stream. The older willows are located on the valley floor that fluctuates between being an active floodplain and a terrace depending on the condition of the beaver dams.	zones appear to follow old meander bends that are now depressions on the valley floor. Lush sedges also occur on some of the low surfaces nearest the water. Willows and alders are currently absent from most of the streams. When present they are few in number.

Table 1 continued.

Parameter	**Basin Ck, MT** **Gravelly Mountains**	**Muddy Ck, MT** **Tendoy Mountains**	**Price Ck, MT** **Centennial Mountains**	**Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)**
Channel sinuosity (*see Appendix D for breakdown by reach)*	1.3 to 1.8	1.3 to 2	1.46 to 2.14	1.02 to 1.9
Bank Stratigraphy	Homogeneous	Homogeneous	Homogeneous	Homogeneous
Bank Composition Soil Survey Staff (1975) method used to determine composition.	sandy loam, silt-clay loam and clay loams. Bank compositions in places indicative of historic wet meadows	silt-clay loam to clay	sandy loam, silt-clay loam and clay loams	silt loam to clay loam. Bank compositions in places indicative of historic wet meadows
Bank Geometry and Vegetation Cover	Banks tend to be vertical or undercut and are devoid of vegetation.	Banks tend to be vertical or undercut and are devoid of vegetation.	Banks tend to be vertical or undercut and are devoid of vegetation.	Banks tend to be vertical or undercut and are devoid of vegetation.
Stream order (7.5 topographic maps)	2nd to 3rd	2nd to 4th	2nd to 3rd	1st to 3rd
Current Rosgen stream classification for cross-sections when appropriate (Rosgen 1996). Classifications determined only for those cross-sections 1) whose graphs showed no change over the study period, 2) were on straight sections,	Of 28 cross-sections Rosgen classification could only be calculated for 9 cross-sections. Six were E type channels, 2 were B type channels and one was an A type channel.	Of the 28 cross-sections a Rosgen classification could be calculated for only 4 cross-sections. Three were E type channels and one was an E-C type.	Of the 26 cross-sections a Rosgen classification could be calculated for only 4. Three were E type channels and one was a B type channel.	Of the 27 cross-sections a Rosgen classification could be calculated for only 10 cross-sections. Six were E type channels, one was a C type channel, and three were a mix of classification types: E or Gc, B or C, E or C.

Table 1 continued.

Parameter	Basin Ck, MT Gravelly Mountains	Muddy Ck, MT Tendoy Mountains	Price Ck, MT Centennial Mountains	Hay, Home, Lower Burro, Lower Stinky and Mandan Creeks, AZ in the White Mountains (referred to as the White Mountains suite)
and 3) had no beaver dam influence.				
Potential Rosgen stream types -- based on valley gradient, valley width, and bank composition and stratigraphy	E stream types and/or wet meadows	E stream types and/or wet meadows	E stream types and/or wet meadows	E stream types and/or wet meadows

The geology of the study watersheds in Montana is predominantly sedimentary rocks with some metamorphic igneous rocks present in the Muddy Creek watershed and some volcanic rocks present in the Price Creek watershed. The geology of the White Mountains in Arizona is predominantly quartz latite flows (Table 1). All the rock types weather to fine-grained sediments.

The similarity in the weathering characteristics of the study area geologies has resulted in homogeneous stream banks composed of fine-grained sediment and relatively cohesive. The selection of sites with non-stratified, relatively cohesive stream banks makes it easier to isolate the significance of reductions in cattle and elk grazing pressure on certain types of channel changes (i.e. channel widening) because the stream banks remain fairly resistant to fluvial erosion even when densely rooted vegetation is absent. This is an important consideration because most streams in the West have had their stream bank vegetation removed over the last 100 to 150 years as a result of extensive cattle and sheep grazing and agriculture.

The historical and current land uses in the study areas are also largely similar. All study areas have experienced long-term, chronic human land uses, beginning with beaver trapping in the mid-1800s and followed by extensive, unregulated cattle and sheep grazing until the 1940s and 1950s when some initial regulation began (USDA Forest Service 1992; Abruzzi 1995; Donahue 1999). Cattle grazing remains a current use, though cattle numbers and their grazing duration are much reduced compared to the late 1800s when cattle numbers ranged in the tens of thousands (J. Moore, USDA Forest Service, pers. comm. 2000; USDA Forest Service 1992). Other historical Euro-American land uses have also occurred in these watersheds. In the White Mountains, logging, railroads, road building activities and damming of cienagas have directly influenced the evolution of the channel morphology of the study creeks. About 20 non-native elk were introduced in the 1920s about 40 years after the native elk populations were extripated (1880s). By the 1930s that number had increased to 2600 head of elk and problems with elk were already being noted. By the mid-to-late 1970s and early 1980s the elk population was around 20,000 head. When the winters are mild the elk do not migrate to lower elevation but continue to utilize the area year round. The result is that in some places there is 70 to 80 percent utilization of forage before cattle ever arrive on the range (M. White, USDA Forest Service, pers. comm. 2000). In the upper Ruby River drainage area, where Basin Creek is located, road and trail construction, logging, field clearing and cultivation, and construction have occurred (USDA Forest Service 1992). In addition, fire was used as an early range-improvement tool in the upper Ruby drainage until sometime after 1925 (M. Lott, pers. comm. 1999). However, it is unclear how, or if, those land use activities have influenced the evolution of Basin Creek. At Muddy and Price Creeks, homesteading and road building have occurred, and road building may have contributed to changes in these creeks. Mining in all watersheds has been minimal.

Study Treatments

Channel responses to seven different treatments were evaluated to determine rates, directions and processes of channel change as a function of treatment. Three treatments were present in each study area (Table 2). The seven treatments are:

1. Riparian Guidelines
2. Special Emphasis Management areas
3. Old Cattle Exclosures ($\geq$ 25 years old at the time of the baseline survey)
4. New Cattle Exclosure ($\leq$ 2 years old at time of baseline survey)
5. New Elk Exclosures ($\leq$ 2 years old at time of baseline survey)
6. Intact Beaver Dams
7. Failing Beaver Dams

The Riparian Guidelines and the Special Emphasis Management (SEM) areas continue to experience cattle and, to varying degrees, some elk grazing pressure. However, both treatments were closely monitored for cattle impacts and therefore do not represent the more intensive levels of cattle grazing that historically occurred on western public lands when cattle grazing was season-long and movements were not controlled. Where the season-long cattle grazing strategy continues, there is maximum potential for stream-bank losses and retreat due to trampling and reductions in riparian vegetation. The impact of this management strategy on channel morphology went untested because it was not one of the options provided by the agencies I was working with. The other end member in the cattle and elk grazing pressure spectrum is the complete exclusion of cattle and elk. This occurs in elk exclosures and is present in the study.

The Riparian Guidelines were used in the Montana study areas and are designed specifically to improve the condition of the riparian zone. Under the Riparian Guidelines, four parameters in the riparian zone are monitored, with standards (e.g. maximum allowable limits of impact) for each parameter based on current and desired future conditions (Bengeyfield and Svaboda 1998). When the allowable limits of any of the four parameters are met, the livestock are moved from the pasture. The four parameters are: 1) forage utilization, 2) woody browse, 3) stubble height, and 4) bank trampling (Bengeyfield and Svodoba 1998). The allowable limit on bank trampling was usually reached first (Dallas 1997).

The Riparian Guidelines represent a modification of the Rest-Rotation system. Past Rest-Rotation systems only had standards for upland forage consumption. However, reliance exclusively on the upland forage criterion ignored the fact that cattle congregate in riparian areas and preferentially used this zone. As a result the riparian zones were heavily utilized and trampled while much of the upland portion of the pastures went untouched (Trimble and Mendel 1995).

Special Emphasis Management (SEM) area is the term given to riparian pastures in the White Mountains in Arizona. Prior to the initiation of riparian pastures, the study areas were managed under a Deferred-Rotation system that grazed all pastures every year, shifting only season of use. No provisions were made to protect the riparian zone. While the riparian pastures do not have specific limits set for selected parameters, such as those found within the Riparian Guidelines, the length of time that cattle are allowed into these areas is at most 5 to 14 days (J. Moore, USDA Forest Service, pers. comm. 2000).

There are two old cattle exclosures, six new cattle exclosures and three new elk exclosures in the study. The old cattle exclosures are located on Muddy Creek and were built in the mid-1960s. Cattle trespass has been minimal, and the data collected provide some information on long-term channel adjustments. Three of the six new cattle exclosures are located in Montana (Basin, Muddy and Price Creeks) and three in Arizona (Hay, Home and Lower Stinky Creeks). All cattle exclosures are accessible to elk grazing, and cattle trespass has been minimal. Two of the three new elk exclosures are in Montana (Basin and Price Creeks) and one is in Arizona (Hay Creek). These exclosures have eight-feet-high fences and exclude cattle and elk. However, only five of the six new cattle exclosures and two of the three elk exclosures could be used to test for the influence of reductions in grazing pressure on rates and directions of channel response because the Price Creek cattle and elk exclosures were influenced by beaver dams for all or part of the study (Table 2).

Table 2. Treatment, survey history and distribution of cross-sections for each study area. NEE = new elk exclosure, NCE = new cattle exclosure, OCE = Old cattle exclosure, SEMA = Special Emphasis Management area.

Treatment				Reach and Creek	Year treatment put into place	Survey years	Number of cross-sections	Reach length (m)
Cattle eliminated	Cattle and Elk eliminated	Beaver influence	Control					
				Basin Creek, MT				
X				NCE	1993	1995, 1997	5	165
	X			NEE	1993	1995, 1997	7	69, 100
			X	Riparian Guidelines	1993[1]	1995, 1997	16	163, 150, 100, 150, 100
				Muddy Creek, MT				
X				Johnson Creek OCE[2]	mid-1960s	1993, 1995, 1998	3	177/177[4]
X				Trail Creek OCE[2]	mid-1960s	1993, 1995, 1998	6	250/250[4]
X				Sourdough NCE	1993	1993, 1995, 1998	3	3000 (est.) /(107, 149)[4]
			X	Riparian Guidelines	1993[1]	1993	15	210, 150, 68, 149, 149, 149, 149
				Price Creek, MT				
X[3]		X[3]		Bdam influence in NCE	Beaver enter exclosure prior to 1994	1995, 1997, 1998	12	1950/(100, 200, 100, 100)[4]
	X[3]	X[3]		Bdam influence in NEE	Beaver enter exclosure prior to 1994	1994, 1997, 1998	4	121/121[4]
			X	Riparian Guidelines	1992[1]	1994, 1997, 1998	6	152, 152, 100
		X	X	Riparian Guidelines w/	Beaver present in lower Price Creek on and off	1994, 1995, 1997, 1998	4	152, 100

Table 2 continued.

Treatment				Reach and Creek	Year treatment put into place	Survey years	Number of cross-sections	Reach length (m)
Cattle eliminated	Cattle and Elk eliminated	Beaver influence	Control					
				beaver influence	since before 1991			
				White Mts, AZ				
	X			Hay Ck NEE	1994	1994, 1997	3	234/115[4]
X				Hay Creek NCE	1994	1994, 1997	3	319/115[4]
X				Home Creek NCE	1994	1994, 1997	2	663/113[4]
X				Lower Stinky NCE	1994	1994, 1997	5	1342/(57, 57, 152)[4]
			X	Hay Ck SEM area	1992	1994, 1997	3	150, 150
			X	Lower Burro Ck SEM area	1992	1994, 1997	5	100, 114, 137
			X	Mandan Ck SEM Area	1992	1994, 1997	6	152, 150

(1) Year that the Riparian Guidelines legally when into effect. However, it took a couple of years before the permittee was using the guidelines effectively.

(2) Johnson Creek and Trail Creek old cattle exclosures both had additional cross-sections added in 1996. The other cross-sections in those exclosures were not resurveyed at that time.

(3) 1992 was the year that the new elk exclosure and new cattle exclosure on Price Creek were built. However, the treatment of interest is the beaver dam influence.

(4) 1950/500[4] = Length of exclosure/Length of stream surveyed

Beaver dams were observed only on Price Creek. The beaver treatments focused on beaver-dam integrity, and dams were either intact or failing. Widespread dam failures occurred sometime between 1995 and 1997 because the dams were no longer being repaired and maintained due to the removal of beavers by a local trapper. As beaver influences were absent from the other study areas, three levels of beaver influence can be considered to have occurred: 1) none, 2) beavers present and dams maintained, and 3) beavers trapped out and dams failing. The "none" category is addressed by comparing the cross-section area responses in areas with and without beaver dams.

The ideal situation is to complete the baseline cross-section survey several years prior to the initiation of a new treatment. However, this timing requires considerable advanced planning on the part of the agencies. This is a difficult task given the current budget, time constraints, and focuses of the agencies. Therefore, the time interval between my baseline surveys and the initiation of new treatments varies from one year prior to the new treatment up to three years after a change in treatment. The three-year time difference occurs at Basin Creek for areas managed under the Riparian Guidelines. The guidelines went into effect in 1993 but it took about two years for the guidelines to be adjusted to the realities of the field and to mastered by the range riders (Dallas, 1997). Therefore, the time interval between treatment initiation and baseline survey is considered to be one year rather than three years and is stated as such in Table 2. The time interval between treatment initiation and baseline survey for the two old cattle exclosures is 28 to 30 years.

Channel Cross-section Selection

Different channel features provide distinct types of information about the influence of the treatments on channel cross-section area and the potential for cross-section area reductions for streams. Channel features fall into three general categories: straight sections, bends, and other.

Straight sections help separate out cattle and elk grazing pressure from fluvial processes as the cause of channel widening because they are expected to show minimal bank losses from stream erosion. In straight sections, the maximum stream velocity occurs in the middle of the channel rather than near the banks as in the case of bends. Thus the velocity gradient near the bank along straight sections, and consequently shear stress, is low compared to what exists at outside bends (Ashworth 1996; Knighton 1998). Therefore, the retreat of cohesive banks along straight sections of banks in small drainages grazed by cattle and/or elk is more likely related to a grazing-pressure influence. Rates of cross-section area reductions are expected to be slow.

Bends are more geomorphically dynamic than straight sections in both disturbed and non-disturbed conditions. In addition, the inside and outside banks of the bend are different in their sensitivity and response to cattle and elk grazing pressure and fluvial processes. When grazing pressure is high and banks are devoid of vegetation, outside bends are susceptible to erosion by both hoof action and fluvial processes. When outsides bends are well vegetated and grazing pressure minimal, they are much more resistant to instream erosion and can exhibit considerable stability. The appearance of the bank on the outside bend can to help separate out relative contributions of these influences. When cattle are contributing to outside bend retreat, small, discrete clods of bank are often found at the base of the bank having been sheared off by hooves (Trimble and Mendel 1995; Figure 7), giving the banks a pocked appearance. This observation also holds for straight sections of stream.

Figure 7. Example of bank erosion as a result of grazing pressure and hoof action. Note the discrete clods of bank along the water's edge and the pocked or scalloped appearance of the banks. Mandan Creek SEM area, cross-section 5, White Mountains, AZ (1994).

The point bars, or inside bends, are particularly valuable study sites. They provide information on the maximum potential for vegetative recovery and sediment accumulation in a reach because stream velocities are low. The bars provide sites where vegetation can become established in the channel (Hupp and Simon 1991; McKenney et al. 1995; Friedman et al. 1996; Hupp and Osterkamp 1996), setting in motion the vegetation-sediment deposition feedback loop. Therefore, if point bars show minimal change, then the potential for cross-section area reductions along the rest of the channel is limited.

The “other” category includes abandoned meander bends, straight sections with tension cracks, cattle crossing sites or well-vegetated straight sections or bends. These areas provide additional information on rates of sediment accumulation, cross-section area reductions, stream bank stability, as well as the contribution of fluvial processes versus treatment influences on the evolution of channel morphology.

Bank retreat as a result of cattle and elk grazing pressure can occur either by the shearing off of small blocks of banks by hoof action and/or through the development of tension cracks as cattle trail along the edge of a stream bank (Trimble and Mendel 1995; this study). A visual inspection of the banks and adjacent surfaces is needed to confirm the grazing pressure influence because bank retreat can occur even in the absence of grazing pressure through mass failure or as a result of hydraulic action that undercuts the lower banks (Knighton 1998). The sensitivity of the banks to stream erosion and grazing pressure varies as a function of bank composition and stratigraphy and increases with bank height, drainage area, and channel size (Thorne and Tovey 1981; Thorne 1982; Knighton 1998).

The cross-sections were located in each of the three channel-feature categories to capture maximum and minimum rates and directions of change and to determine whether fluvial processes or treatment were driving the changes in the channel cross-section area. In the areas with beaver dams, cross-sections were placed at various distances upstream of beaver dams to determine how the rates and directions of the changes varied with proximity to a dam and dam condition. As beaver dams effectively trap and store sediment (Naiman et al. 1988; Butler and Malanson 1995), examination of sediment accumulation rates in the ponds provides information on size, composition, and amount of sediment available for reductions in channel area in non-beaver dam-controlled reaches. A fluvial system in which only minimal amounts of sediment accumulate in the ponds indicates that the stream is indeed sediment starved. In such streams, reductions in channel cross-section area in reaches without beaver dams will occur, but slowly. When sediment accumulation does occur in the pond, the size of the sediment trapped provides information on the whether the sediment is likely to be moving as suspended or bed load in the non-beaver dam-controlled reaches. If the sediment type is silts and clays, then the sediment will move as suspended load in non-dam controlled reaches and cross-section area reductions in these reaches will be minimal. This information on sediment type helps identify the potential for cross-section area reductions in non-beaver dam-controlled reaches.

Channel Cross-sections Measurements

The cross-sections were surveyed using a Topcon AT-G7 auto level, and measurements were taken along a horizontal meter tape stretched out between two rebar pins. The rebar pins were used as the site benchmarks, as at least one pin and if possible both pins were placed in an area on the valley floor that was geomorphically stable. The pins were examined for stability at the start of each survey and the relative relationships of the tops and bottoms of the pins compared to prior surveys to verify the continued stability of the pins and surface around the pins. Cross-section data elevations were entered into spreadsheets and the cross-section graphs were generated (Appendix B). The composition and relative density of the vegetation were noted along each cross-section line in order to qualitatively evaluate the contribution of baseline vegetation to the cross-section area changes.

Stream Reach Measurements

Reaches were selected to capture representative sections of the stream. The reach boundaries were referenced to the cross-sections or exclosure boundaries so that reaches could be remeasured and future results compared. A variety of channel characteristics were measured to give a more complete picture of the reach (Appendices C and D). Reach lengths ranged from 58 m to 230 m, but most were 100 to 150 m long. The reach characteristics measured were channel-bed composition, sinuosity, thalweg depths, water surface slope, and hydrologic bankfull widths. Channel bed composition, water surface slope, sinuosity, and data from cross-sections were used to determine the Rosgen stream classification (Rosgen 1996) for cross-sections on straight sections that showed no change over the course of the study.

Reach and Cross-section Hydrologic Bankfull Widths

I used hydrologic bankfull stage indicators noted in the field (Harrelson et al. 1994) to measure hydrologic bankfull widths. The same stage indictors were used to identify hydrologic bankfull width at the cross-sections. Channel hydrologic bankfull widths were collected every 2.3 to 5 m depending on the reach length. Sample sizes ranged from 25 to more than 50 measurements (Appendix C). The reasons for measuring multiple reach widths were 1) to capture reach variability and 2) to determine how representative the cross-sections were of the reach. The reach hydrologic bankfull widths were collected at regularly spaced intervals, a form of random sampling (Shaw and Wheeler 1997) and allowed me to determine how well the non-randomly selected cross-sections represented the reach. With this comparison I was able to extend the cross-section changes up to the reach scale and demonstrate that the use of statistical tests to evaluate cross-section area change was appropriate.

A later analysis of the cross-section graphs showed, however, that the majority of the cross-sections had widened, incised, and/or aggraded over the course of the study. Of the 60 cross-sections located on straight sections of stream, only 27 cross-sections showed no change in their channel morphology. The dominant Rosgen stream type of these 27 cross-sections was an E type channel, with a few C and B type channels. However, the uncertainty in the hydrologic meaning of the hydrologic stage indicators identified in the field also applies to these 27 cross-sections, and in these altered and adjusting systems the use of the Rosgen stream classification does not appear to be appropriate.

The graphical evidence of channels in disequilibrium was supported by an analysis of the hydrologic bankfull cross-section areas calculated from the field-identified stage indicators. The degree of variability in the hydrologic bankfull areas indicates streams are continuing to adjust to current and historic land uses. The analysis revealed a serious lack of internal consistency in hydrologic bankfull area calculations within and between reaches and study areas (Appendix E). In some cases channels with smaller drainage areas had larger "hydrologic" bankfull areas than channels with larger drainage areas. The bankfull areas of cross-sections within the same reach were often dissimilar, streams with similar drainage area sizes had very different hydrologic bankfull areas, and in some cases the average hydrologic bankfull area for a reach or stream was greater than individual geomorphic cross-section areas.

Based on the above analysis, I concluded that the indicators of bankfull stage could not be used to determine hydrologic bankfull channel geometry in systems undergoing continuous change as a result of ongoing land use. Instead, the indicators reflected either relict features, left over from an earlier channel geometry that has recently altered through widening, incision and/or aggradation or, as Knighton (1998, p.164 citing Carson and Griffiths 1987) suggests, are reflecting "nothing more than the intensity of the most recent erosive flow event." Consequently, the indicators of bankfull stage could not be used to calculate channel enlargement. However, despite the uncertainty of the hydrologic meaning of the stage indicators identified in the field, the graphical and statistical comparison of the reach and cross-section "hydrologic bankfull" widths found in Appendix E remained valid because the same indicators were used to identify the "hydrologic bankfull" stage in the reach and at the cross-section. In the future, it would be more appropriate to collect the geomorphic channel widths rather than hydrologic bankfull widths in areas unless there is strong enough evidence that the streams have stabilized. The geomorphic channel is less transitory in systems that are continuing to undergo adjustment and is easier to identify consistently. Measurement of the geomorphic channel also allows reaches with and without beaver dams to be compared, something not possible when using the field stage indicators because the concept of hydrologic bankfull is not applicable to beaver ponds, even in stable systems

Channel Bed Composition

Channel-bed substrate for a reach was determined using the Wolman pebble count (Wolman 1954). A minimum of 100 counts was done. If the sediment was gravel size (2 mm) or larger, it was measured. If the sediment was sand size or smaller, it was hand textured to estimate if it were sand, silt, or clay. Substrate transects in 1993 were done at pre-determined intervals designed to sample an area around the cross-section. Substrate surveys done in 1994 and 1995 were more representative of the reach as pools, riffles, and runs within the reach were sampled. The sample size collected from each channel unit type was based on the percentage of each type in the reach. The assessment of channel bed substrate was used to identify the potential for channel bed incision and changes in bed topography over time in response to treatment.

Data Analysis

The geomorphic channel cross-section area is the variable of interest and the basis of the analysis. Annual rates, directions and trends of change in the geomorphic channel cross-sectional area were determined from the cross-section measurements and graphs.

Annual rates of change in channel area were determined through a two-step process. The channel cross-section area was determined for each survey, and that value was then subtracted from its baseline area to determine the net change in area. The net change between the baseline and final surveys was then divided by the number of years between the two surveys and an annual rate of change calculated. If more than two surveys took place (i.e. 1993, 1995, 1998), then the annual rate of change between each survey was calculated and used to determine trends in directions and rates of change.

The magnitude and directions of the annual rates of changes were first evaluated as a function of drainage area, baseline cross-section area, geomorphic channel width, and the geomorphic channel width/maximum depth ratio to determine if these physical features, rather than cattle and elk grazing pressure or beaver-dam integrity, were controlling channel response. Next the geomorphic significance of the annual rates was evaluated to determine 1) the importance of these rates for the evolution of the baseline geomorphic channel area and 2) the capability of the annual rate to hydrologically reconnect the stream and the valley floor over time.

Cross-section area changes were analyzed at two scales using dot plots and statistical tests: 1) the cross-section as the sample unit and 2) the reach as the sample unit. Both scales are required to accurately assess the influence of treatment. Cross-section graphs were also examined to determine where deposition and bank and channel erosion specifically occurred and the nature of the bank and bed changes (i.e. upper versus lower bank retreat; aggradation versus incision). This examination of the graphs allowed me to determine the relative contribution of fluvial processes versus treatment on the evolution of channel cross-section area. The number of years between the baseline and final survey ranged from one to five years. Net change, annual rates of cross-section area change, and annual percent change were calculated for each cross-section for the total time interval and for individual survey intervals (Appendix F).

Graphs, descriptive statistics and statistical tests were used to analyze the data for a treatment influence. The use of statistical tests generally requires that the data be randomly collected or in some other way that does not introduce operator bias (Underwood 1997). In this study the cross-sections (sample unit) could not be randomly selected because the study sought 1) to identify the range in rates and directions of channel change and 2) to separate out fluvial processes from treatment influences as mechanisms controlling the evolution of channel morphology. The nature of the research questions, therefore, required that I select the cross-section sites. However, I addressed the lack of randomly selected cross-sections by graphically and statistically comparing the distributions of the channel reach hydrologic bankfull widths, collected using a form of unbiased sampling, against the hydrologic bankfull widths at the operator-selected cross-sections. The graphical comparison between the two data sets was done at the reach, creek, and treatment levels.

Determining Annual Rates of Change in the Geomorphic Channel Cross-section Area

The calculation of channel cross-section area required identifying the boundaries of the geomorphic channel. In a general sense, the boundaries are where the valley floor meets the channel bank. The selection of the actual boundaries was, however, an iterative process because the elevation and abruptness of this meeting point often differed on the two sides of the channel due to local variability in topography or as a result of bank trampling on one side. Trial and error revealed that the boundary elevations on both sides of the channel had to be the same in order to avoid introducing error into the calculations. When an elevational difference existed between the two sides, the first choice for the upper boundary of the geomorphic channel was the bank with the most distinct break between the valley floor and channel bank (Figure 8, point A). When multiple valley floor surfaces existed at different elevations a decision had to be made as to which surface was the most recent active floodplain prior to channel enlargement. As Figure 8 shows, the surface selected as the recent active floodplain makes a difference in the channel cross-section area. Once a baseline channel-boundary elevation was selected, the location of the same elevation was calculated or identified on the other side of the channel. The cross-section areas were then calculated for each survey using Sigma Plot and then used to determine annual rates of change (Equation 1).

Equation 1: *(Geomorphic channel baseline XS area – Resurvey XS area) / years between surveys = Annual rate of XS area change*

Examining Annual Rates of Cross-section Area Change for Influences Other than the Study Treatments

Prior to analyzing the annual rates of change for a treatment response, the cross-section area data were examined for factors other than treatment that might be influencing the channel response. Seven potential confounding factors were identified. Five factors are quantifiable (drainage area, baseline geomorphic channel width, baseline geomorphic channel width/maximum depth ratio, baseline cross-section area), and their potential influence on determining annual rates of change was tested using linear regression. The last two, creek and geographic region, are categorical factors and represent the local variability in bank composition, vegetation type and distribution, and climate. These two categorical variables were assessed graphically and statistically using analysis of variance (ANOVA). Once the potential contributions of the seven factors were evaluated, the cross-section area changes were examined for a treatment effect.

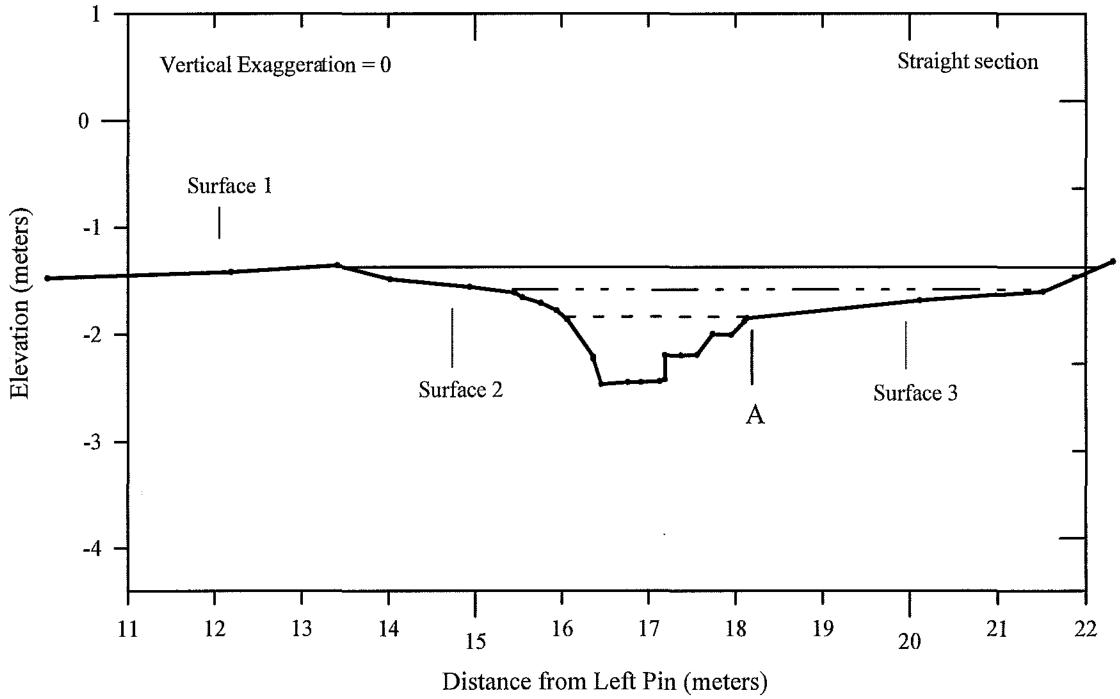


Figure 8. Example showing the variation in the elevation of the channel banks and the multiple valley-floor surfaces. In this case point A was used to define the upper elevation of the geomorphic channel boundary.

Evaluating Cross-section Area Changes Statistically as a Function of Study Treatments

Analysis of variance (ANOVA) was selected as the statistical test to use when evaluating the annual rates of change for a treatment influence. Three assumptions underlie the application of ANOVA: 1) independence, 2) normality, and 3) homogeneity of group variance (Underwood 1997). Each assumption was evaluated for validity before using ANOVA on the data sets.

The annual rates of cross-section area change were graphically assessed for independence. The distributions of these data sets were examined for normality four times. First, the annual rates as a function of treatment within a creek were tested for normality (12 tests). Second, the results from each of the four study watersheds were combined regardless of treatment and tested for normality (four tests). Third, like treatment results (e.g. all cattle exclosures) were combined regardless of geographic region or creek and tested for normality (seven tests). Finally, all results within a geographic region (i.e. east-central Arizona, southwestern Montana) were combined regardless of treatment and compared (two tests). The null hypothesis was that the data sets were normally distributed.

The final ANOVA test assumption, homogeneity of variances, was evaluated using Bartlett's test. The Bartlett's test was selected because most data sets were normally distributed but the sample sizes were unequal. While normality is not critical for the ANOVA test, it is critical for the selection of a homogeneity of variance test because the Bartlett's test is highly sensitive to non-normally distributed data (Underwood 1997). The null hypothesis was that the group variances were similar.

One challenge to using ANOVA, despite having met the underlying assumptions was that the sizes of the treatment cross-section data sets were unequal. Unequal sample size is not ideal but occurred because the exclosures were small and only captured a small portion of stream compared to the areas grazed by cattle and elk. The number of exclosures available for the study was also limited. While not an ideal case, the application of ANOVA to this study is not invalid because I am testing only a single factor (treatment) (Underwood 1997).

Once the validity of the assumptions had been determined, differences in the means of the data sets were ascertained using the Balanced ANOVA, when the data sets were balanced, and the General Linear Model when the data sets were unbalanced (Minitab Inc. 1997). Where the variances were not similar ($p < 0.05$), the data sets were still tested for differences in the means.

Evaluating the Geomorphic Significance of the Cross-section Area Changes

The statistical tests (ANOVA and homogeneity of variances) and descriptive statistics (means, median and standard deviation) were found to be insufficient to completely answer the research questions. The above-mentioned statistical tests and descriptive statistics do not incorporate the scale of the feature examined and therefore have no geomorphic context. To address the absence of a geomorphic context, I made two additional calculations to determine the "geomorphic significance" of the area changes: 1) percent change in baseline area and 2) estimated target rate of channel cross-section area reduction required to hydrologically reconnect the stream and valley floor in 10 years. The target rate was then compared with the annual rate.

The geomorphic significance of the annual rate involved converting the annual rate of change in baseline cross-section area into an annual percent change in baseline area (Equation 2). The percent change calculation is highly sensitive to baseline cross-section area. Therefore, small rates of change might result in large percent changes while in other cases larger rates of change resulted in small percent changes. This subtlety in the data had to be kept in mind when analyzing and interpreting the resulting percentages.

Equation 2: *(Annual XS area change/Baseline XS area) x 100 = Annual % change in XS area*

Determining the geomorphic significance of the annual rate of change with respect to the recovery of the stream and valley-floor hydrologic connection was a more complex procedure. An estimate of a pre-disturbance channel cross-section area was needed that could be compared against the current geomorphic channel area. In stable stream systems, the hydrologic bankfull channel area can serve as an estimate of the pre-disturbance or target channel area. However, the study streams were either continuing to experience grazing or were in the process of adjusting to reductions in grazing pressure and were not stable. Therefore, I selected my smallest geomorphic channel cross-section measured in drainage areas less than 15 km^2 and my smallest cross-section measured in drainage areas greater than 50 km^2 and used those values (0.1 and 0.53 m^2 respectively) as my estimates of pre-disturbance geomorphic channel areas. The pre-disturbance channel area for cross-sections downstream of tributaries was not adjusted because the individual and summed drainage areas of the tributary streams and their main stems were less than 15 km^2. Net area increases or decrease of 0.05 m^2 or less was considered essentially no change because changes this small (a 22 cm by 22 cm square) were thought to reflect area variations due to differences in points selected along the survey line from year to year rather than real change in cross-section area.

Estimates of a pre-disturbance channel area are conservative because even those cross-sections used as an estimate of pre-disturbance area had undergone some channel enlargement. In reaches with drainage areas less than 15 km^2, the heavy clay content of the stream banks and the frequent occurrence of mottled soils and low valley gradients suggest that some of these reaches may have been wet meadows or swales and had no channels prior to disturbance. This method is a modification of the method used by prior researchers to estimate the amount of historic channel enlargement. Bryan (1928a) and Schumm et al. (1984) used the channel dimensions mentioned in historical surveys as their basis for estimating a pre-disturbance channel area, information that was not available at my study sites.

Once the pre-disturbance channel area was selected, I determined the amount of channel enlargement that had occurred (Equation 3). These channel enlargement values were then used to estimate the amount of cross-section area reduction required in order to reconnect the stream hydrologically to its valley floor over some specified amount of time (Equation 4).

Equation 3: *Geomorphic Baseline XS area – Pre-disturbance estimate of channel area = amount of channel enlargement*

Equation 4: $A_{ECE} / Years = TR$

A_{ECE} = Estimated channel enlargement (m^2)
Years = Desired time frame to hydrologically reconnect stream to valley floor (yrs)
TR = Target annual rate of cross-section area reduction required to meet goal (m^2/yr)

In this chapter, 10 years was selected as the desired time frame for hydrologically reconnecting the stream and the valley floor because 10 years has cultural and economic significance. Ten years is the time frame in which a cattle grazing allotment management plan comes up, ideally, for review and modification. It is also an acceptable time frame for most people because it is long enough for change to occur, but short enough that initial changes are noted early on if the treatment is effective. This helps maintain the momentum and commitment towards recovery and allows early adjustments in the treatment if no change is noted. With the time interval selected, the target rate was calculated (Equation 4) and compared against the actual rates of change to determine if the desired future goal would be met.

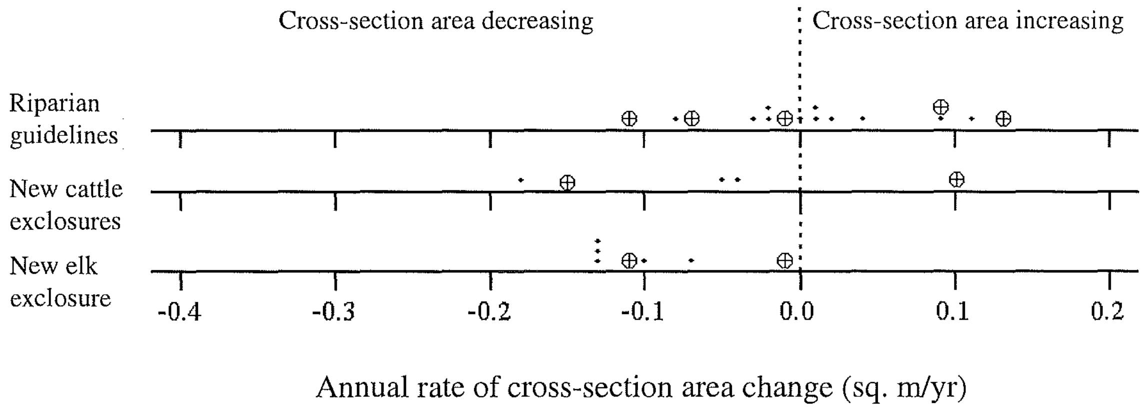
Results

The geomorphic variable of interest in this study is the geomorphic channel (Figure 8), not the hydrologic bankfull channel as defined by the 1.3 to 2.3 year frequent high flow event. The data used in this study to answer the research questions come from the channel cross-section graphs (Appendix B) and stream reach width measurements

(Appendix G). The cross-section graphs and resurveys provide the information necessary 1) to graphically evaluate channel changes, 2) to calculate the net change and then the annual rate of change in the cross-section areas, and 3) to determine trends in cross-section area changes. The cross-sections graphs, combined with field observations, help determine if the channel changes are being driven by fluvial process or treatment. The annual rates of change were used to examine the cross-sections for a treatment influence (Figure 9a) and to establish trends in channel change. The reach-level stream width measurements provided the information needed to determine 1) the range of variability within and between stream reaches and streams and 2) the degree to which the operator-selected cross-sections were representative of the reach (Figure 9b; Appendix G). This second point was important because the comparison determined whether it was appropriate to analyze the annual rates of change as a function of treatment using statistical tests that rely on an unbiased sampling procedure.

There are three study assumptions: 1) cattle grazing pressure and beaver-dam integrity are the dominant factors controlling channel response; 2) the data collected at monumented cross-sections is accurate and reproducible and is the appropriate methodology for determining rates and directions of channel change in response to treatments; and 3) the geomorphic channel, rather than the hydrologic bankfull channel, is the appropriate channel to measure when addressing questions related to the stream and valley-floor hydrologic connection and identifying requirements for restoration;

a)



b)

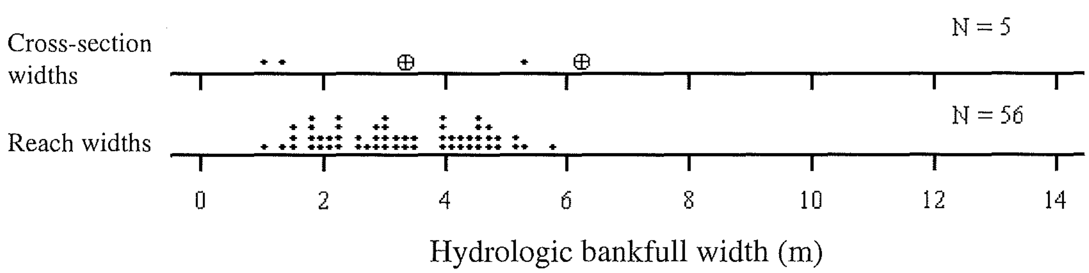


Figure 9. Examples from Basin Creek, Montana of the basic data used in this study to evaluate changes in cross-section area as a function of treatment. a) Annual rates of cross-section area changes as a function of treatment and channel segment. Open cirlcle = Cross-section on a bend, Solid dot = Cross-section on a Straight section. b) Example of reach bankfull and cross-section bankfull width comparisons for a given reach.

The results section is divided into five subsections. The first section presents the results of the stream reach and cross-section bankfull width comparison. The second section presents the results of the ANOVA assumption testing. The third section evaluates factors other than the study treatments for their possible influence on the annual rates of cross-section area change. The fourth section evaluates the annual rates of cross-section area change as a function of treatment. The fifth section evaluates the geomorphic significance of the annual rates of cross-section area change, and the final section evaluates the cross-section area data for trends. The annual rates of change for cross-sections on straight sections and bends are coded differently on the graphs and separated out in the tables to aid the analysis. Their different sensitivity to fluvial processes and treatment helps identify the relative contribution of fluvial processes versus treatment as mechanisms resulting in changes in the geomorphic channel.

Results of the Stream Reach and Cross-section Bankfull Width Comparisons

The stream reach and cross-section bankfull widths were compared graphically and statistically to determine if the operator-selected cross-sections were representative of the reach (Appendix G). This comparison ascertained if it was appropriate to use statistical tests and descriptive statistics that generally require randomly collected data, or some other method of unbiased data collection in the analysis of the annual rates of cross-section area change as a function of treatment. The graphical comparison of the two data sets was done at the reach, creek, and treatment levels. The statistical comparison was done only at the creek and treatment levels because the cross-section sample size at the reach scale was too small to be statistically analyzed. The graphical and statistical comparisons showed that the cross-sections selected captured the reach variability (Appendix G). Therefore, the use of statistical tests and descriptive statistics that require some method of unbiased data collection were appropriate to use in my analysis of the annual rates of cross-section area change as a function of treatment, provided the other assumptions inherent in the statistical tests were met.

Results of the ANOVA Assumption Testing

The ANOVA test has three assumptions that must be met in order for the results of the statistical test to have validity: 1) independence, 2) normality, and 3) homogeneity of group variance (Underwood 1997). Each assumption was examined individually prior to using ANOVA to determine if the sample unit (cross-sections) and the subsequent data set (annual rates of change) generated from the cross-sections met the assumptions.

The independence of data assumption was assessed graphically by examining plots of annual rates of cross-section area changes as a function of position within the watershed to determine 1) if changes at a given cross-section or reach influenced the magnitude or direction of change in its nearest upstream and downstream cross-section or reach and 2) if the upstream treatment type could be used to predict a downstream cross-section or reach response. Graphical evaluation of the annual cross-section area changes found no patterns in cross-section responses that suggested that channel response at one cross-section controlled what occurred at the nearest upstream or downstream cross-section. Nor did any patterns emerge that suggested that treatment upstream of a cross-section influenced the downstream cross-section response. Therefore, the sample unit and resulting data set met the assumption of independence.

Normality of the annual rates of change was tested using various combinations of the data. The data were first examined by creek and by treatment within a creek (15 tests). The data were normally distributed in 11 of the 15 tests. The non-normal distribution in two of the remaining four tests was the result of a single outlier, and in one of the remaining two was because all the annual rates clustered around zero. The data from like treatments (i.e. new cattle exclosures) were then combined, regardless of geographic region, and tested for normality. Of the seven treatments, only three had normally distributed data sets. When the outliers were temporarily removed from three of the four non-normally distributed data sets, these three data sets were normally distributed. The exception was the results from the new elk exclosures which remained non-normally distributed.

Although not all the data set combinations were normally distributed, or were so only after temporarily removing outliers, according to Underwood (1998, p. 194) the condition of normality is not critical for the ANOVA test, particularly in the case "where experiments are large (there are many treatments) and/or samples of each treatment are large. It is also the case when samples are balanced (Underwood 1997, p. 194)." Underwood defines many treatments as "having more than about five" and having a sample size per treatment of "more than about 6" (Underwood 1997, p. 193). I have a total of seven treatments, of which five are grazing treatments. At the cross-section scale, all grazing treatments have sample sizes greater than six. At the reach scale, three of the five grazing treatments have sample sizes greater than six. Therefore, the lack of normality of a couple of the data sets was not considered an impediment to using ANOVA to test for differences in the mean rates of cross-section area change as a function of treatment.

The data sets were tested for homogeneity of variance using Bartlett's test because the data sets were normally distributed but unequal in size (Underwood 1997). Most combinations of data had similar variances, but even those with dissimilar variances were analyzed using ANOVA. It is uncertain what conclusions that can be drawn from comparisons where the variances of the data sets are dissimilar but the means are similar. The variances may speak more to local variability in bank composition while the means address the overall net impact to the channel area. If this interpretation is correct, then those cases with similar means but dissimilar variances suggest that the net impact to the overall reach channel area (i.e. overall increase, overall decrease, or no change) is the same despite differences in the range of responses.

Confounding Factors

This section addresses the first research question: "What factors other than the study treatments may be controlling the direction and amount of change in the channel cross-section areas? Is the magnitude of their influence great enough to preclude identifying a treatment influence?" To answer this question, I considered five additional factors that might influence the annual rates of change. Three factors, baseline cross-section area, geomorphic channel width, and geomorphic width/maximum depth ratio explored the possible role of baseline channel characteristics on rates and directions of cross-section change. The other two factors concerned the role of drainage area size and creek on the rates and direction of channel change.

The annual rates were examined graphically as a function of creek and treatment for patterns that suggested a location influence (Figure 10). For example, were the new cattle exclosures in Basin Creek responding differently than the new cattle exclosures in the White Mountains? Figure 10 shows similar patterns of channel response as a function of treatment but different magnitudes in the range of response. Graphically, Basin Creek has the widest range in cross-section area reductions and increases. Price Creek shows essentially no change, while Muddy Creek and the White Mountain sites are graphically similar and fall between the two other groups in their distribution. As expected, the test for homogeneity of variances for annual rates in grazing treatments, as a function of the creek, found that the ranges in annual rates of change of the four creeks were statistically different ($p = 0.000$). However, the graphical patterns of change as a function of treatment and the means of the annual rates of change based on an ANOVA were not statistically different ($p = 0.159$). The similar pattern in channel response to grazing treatment allowed the data to be combined into groups of like treatments and analyzed while acknowledging variations in site characteristics. While differences in the range in the annual rates of change as a function of creek were noted, I did not consider the differences extreme enough to prevent like treatment results (i.e. annual rates from all new cattle exclosures) from being combined and analyzed.

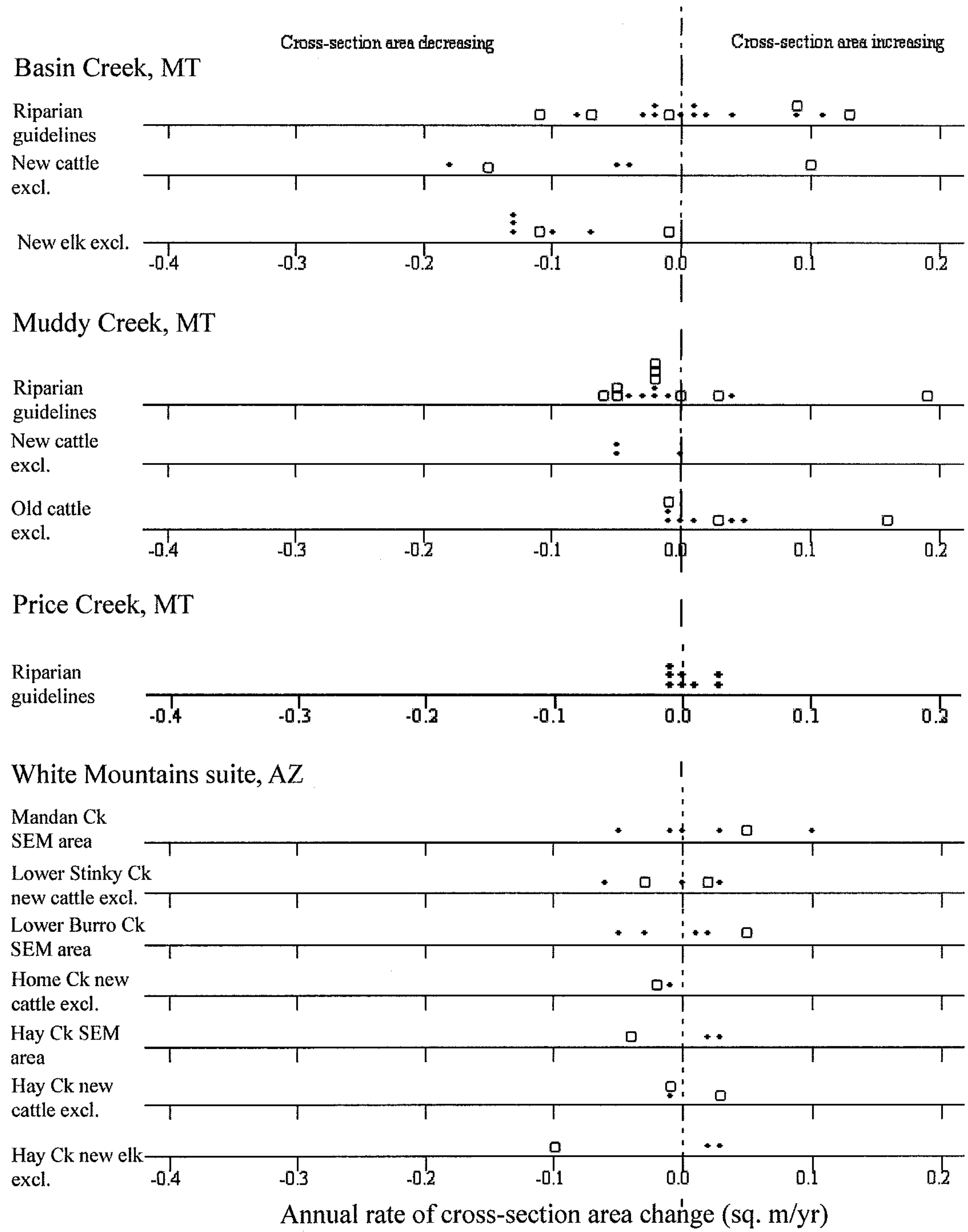


Figure 10. Annual rates of geomorphic cross-section area changes as a function of creek, treatment, and channel segment for grazing treatments. Open squares = Bends. Solid dots = Straight sections.

The possible influences of drainage area, geomorphic cross-section area, channel width, and width/depth ratio on the annual rates were examined using linear regression. Ninety-six linear regressions were run. The annual rates were grouped by creek and treatment and then further subdivided into bends and straight sections and reexamined when the sample size was greater than three data points. The significance level was set at $\alpha = 0.05$. The linear regressions showed no statistically significant influence from drainage area or baseline channel dimensions on the rates and directions of channel change ($p > 0.05$, Appendix H). Linear regressions were not run on the data from the beaver dam-controlled cross-sections because the dams exerted such a strong control on the annual rates of change that any influence as a function of channel geometry or drainage area would be inconsequential. In conclusion, none of the five factors examined exerted a strong influence on annual rates of change. This allowed the annual rates to be examined graphically and statistically for a treatment influence.

Annual Rates of Change as a Function of Grazing Pressure and Beaver-dam Integrity

This section addresses the second research question: "What is the response (rates, directions, and processes) of the channel cross-sections to reductions in cattle and elk grazing pressure and changes in beaver-dam integrity? Are the rates, directions, and processes similar or different? Why?" Evidence for a treatment influence on the channel response was sought 1) within each creek and 2) between treatments once like treatment results were combined. Results from the grazing treatments and beaver activity were examined first separately and then together for comparison. The cross-section graphs and dot plots of annual rates of change versus treatment were examined for evidence of treatment influences on rates and directions of channel change.

The annual rates were examined graphically and statistically. The annual rate is the summation of all the sediment gains and losses that occurred at a cross-section. As a single numeric value, the annual rate cannot reveal the respective contribution of fluvial processes and treatment to the changes and, therefore, its ability to predict trends is limited. Information on fluvial processes and treatment effects, however, is available from the cross-section graphs because these graphs show the specific locations and character of the sediment gains and losses (Appendix B). This information is important when evaluating some of the more subtle patterns observed in the dot plots. Cross-sections were used to make a qualitative assessment of the respective contribution of fluvial processes and treatment and to evaluate the potential long-term contribution of those gains and losses to the evolution of the channel cross-section. The annual rates of change are examined first.

Annual Rates as a Function of Grazing Pressure within a Creek

Annual rates of changes as a function of grazing pressure were first examined for patterns within the three streams that had more than one grazing treatment: Hay Creek in Arizona and Muddy and Basin Creeks in Montana. The other streams either had beaver activity on them (Price Creek) or involved only one grazing treatment (Home, Lower Burro, Lower Stinky and Mandan Creeks).

A graphical examination of treatment influence on rates and directions of cross-section area changes showed no strong treatment influence on Muddy Creek (Figure 10b) or on Hay Creek (Figure 10d). All treatments had a similar mix and range of increases and decreases in cross-section area. This graphical observation was supported by the statistical analysis. Muddy and Hay Creeks had similar variances and means in annual rates as a function of treatment, indicating the absence of a treatment influence over a two-to-five year period (Table 3).

Basin Creek, in contrast, graphically shows a greater range in annual rates of change and a possible treatment influence. All but one cross-section inside the new cattle and new elk exclosures showed some reduction in cross-section area while the cross-sections in the Riparian Guideline treatment recorded both increases and decreases in area (Figure 10a). A statistical analysis of the annual rates as a function of treatment on Basin Creek agreed with the graphical observations. The annual rates as a function of grazing treatment had similar variances but dissimilar means (Table 3). A series of paired comparisons on the Basin Creek showed that a difference in means occurs between the new elk exclosures and the Riparian Guidelines cross-section rates and directions (Table 4). The rates from the new cattle and the new elk exclosures had similar variances and means. The rates from the Riparian Guidelines and new cattle exclosure were not significantly different in variance or mean, but close to being significantly different in mean suggesting a continuum in channel response as a function of grazing pressure. The difference in channel response between the elk exclosure and Riparian Guidelines' cross-sections initially suggested a treatment influence. However, elk use in the Basin Creek study area is minimal because the elk tend to congregate at the higher elevations (USDA Forest Service 1992; P. Bengeyfield, USDA Forest Service pers. comm. 2000), and another explanation was sought to explain the differences between the elk exclosures and the other four grazing treatments.

Table 3: Results of the statistical tests comparing the variances (HOV) and means (General Linear Model) of annual rates of cross-section area change for grazing treatments within a given study area. The null hypotheses are that 1) variances are similar and 2) means are similar. The significance level is $\alpha = 0.05$. A negative annual rate indicates a reduction in cross-section area. RG = Riparian Guidelines, SEMA = Special Emphasis Management Area, EE = elk exclosure, CE = cattle exclosure. P-values that are significant (i.e. reject the Ho) are underlined.

Study Area	Treatments compared	Sample size	Homogeneity of Variance (HOV) Barlett's test (p-value)	General Linear Model Test (p-value)	Average annual rates of change (sq. m/yr)
Basin Creek, MT	RGs, New EE, New CEs	16, 7, 5	0.15	<u>.01</u>	0.01, -0.1, -0.06
Muddy Creek, MT	RGs, New CE, Old CEs	15, 3, 9	0.54	0.20	-0.005, -0.03, 0.03
Price Creek, MT	RGs only	8	N/A	N/A	0
Hay Creek, AZ (White Mts)	SEMAs, New EE, New CE	3, 3, 3	0.36	0.85	0, -0.02, 0

Table 4: Results of the statistical tests comparing the variances (HOV) and means (General Linear Model) of paired treatments within the Basin Creek study area. The null hypotheses are 1) variances are similar and 2) means are similar. Significance level is adjusted to $\alpha = 0.017$ using the Dunn-Sidak procedure (Underwood 1997). A negative annual rate indicates a reduction in cross-section area. RG = Riparian Guidelines, SEMA = Special Emphasis Management Areas, EE = elk exclosure, CE = cattle exclosure. P-values that are significant (i.e. reject the Ho) are underlined.

Study Area	Treatments compared	Sample size	Homogeneity of Variance (HOV) F-test (p-value)	General Linear Model (p-value)	Average annual rates of change (sq. m/yr)
Basin Creek, MT	RGs, New EE	16, 7	0.28	<u>≥ 0.01</u>	0.01, -0.1
	RGs, New CE	16, 5	0.16	0.08	0.01, -0.06
	New EE, New CE	7, 5	0.05	0.48	-0.1, -0.06

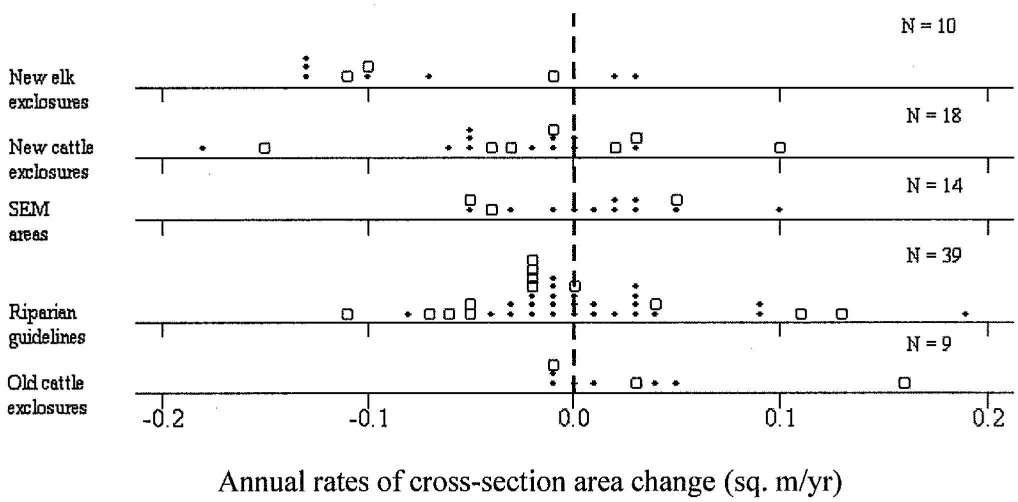
The elk exclosure contains two study reaches and six cross-sections. The upper reach has a number of low surfaces covered with sedges and rushes that are effectively capturing sediment from the eroding banks and channel bed upstream. The lower reach is downstream of the confluence between North and South Basin Creeks and downstream of the cattle exclosure fence on South Basin Creek. The position of cross-sections downstream of the confluence and cattle/elk fence, combined with an abrupt bend in the river's direction and tall willows along the channel's edge may be causing water to slow down and/or slightly pond in this lower elk exclosure reach. The result would be enhanced sediment deposition. Therefore, this apparent treatment response is more likely the result of site-specific characteristics, and the removal of cattle, rather than related to a reduction in cattle and elk grazing pressure. In the future it is probably more appropriate to analyze the data from the Basin Creek elk exclosure with the data from the other cattle exclosures because the absence of elk activity means that the only reduction in grazing pressure is coming from the removal of cattle.

In conclusion, Basin Creek was the only stream of the three that appeared to have a grazing-treatment influence. However, further investigation found that elk numbers are low in the Basin Creek study area, and though a real difference in channel response exists, the difference is more likely combination of local site characteristics and the absence of cattle grazing rather than the absence of elk and cattle grazing. The lack of a strong grazing treatment signal at these three streams led me to combine observations from like treatments. The goal was to see if an increase in sample size revealed patterns suggestive of a grazing-treatment influence not visible in the smaller sample size.

Annual Rates as a Function of Grazing Pressure – Like Treatment Observations from all Creeks Combined

Observations from like treatments were combined and examined graphically and statistically at the cross-section and reach scales to see if a grazing-pressure signature existed in the larger sample size. At the cross-section scale, Figure 11 shows a similarity in channel response between the new cattle exclosures, Riparian Guidelines, SEM areas and old cattle exclosures, at least in the early stages of a reduction in cattle grazing pressure. These four treatments all show a mix of increases and decreases in cross-section area, though variability exists in the relative abundance of cross-section area increases and decreases.

a. Cross-section as sample unit (N = 90)



b. Reach as sample unit (N = 36)

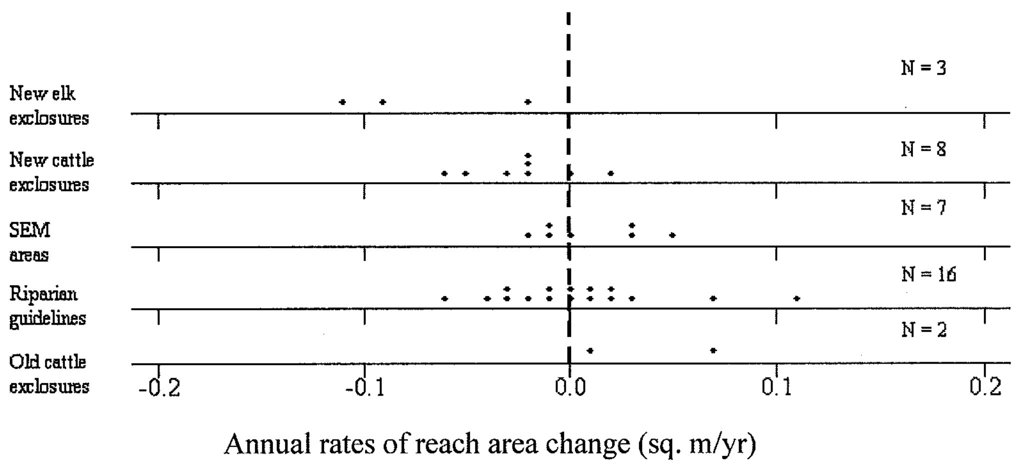


Figure 11. Annual rates of cross-section area changes (sq. m/yr) as a function of grazing treatments at the cross-section and reach scales. Open squares = Bends, Solid dots = Straight sections.

The annual rates at the bends and straight sections are combined and averaged at the reach scale to reflect the overall reach response (Figure 11b). Graphical examinations of the annual rates at the reach scale show patterns similar to the ones observed at the cross-section scale (Figure 11a), with two differences. The similarity between the new elk and new cattle exclosures is slightly more pronounced in Figure 11b, while the similarity between the new cattle exclosures and the Riparian Guidelines, SEM areas, and old cattle exclosures is not as strong as in Figure 11a. Statistical evaluation of the annual rates as a function of treatment at the cross-section and reach scales (Table 5), however, reveals that the variances between the four grazing treatments has remained about the same while the similarity in their means has slightly increased (p values = 0.086 to 0.114).

The apparent difference between the channel response inside the new elk exclosures compared to the other four grazing treatments can not simply be explained as a function of the cessation of all grazing pressure. As noted earlier, there are two important caveats when interpreting the meaning of the cross-section observations from the new elk exclosures. First, only two elk exclosures were available for sampling because beavers entered the third elk exclosure between the first and second survey. Therefore, the sample size is very small. Second, two of the three reaches in the new elk exclosures occur on Basin Creek. As mentioned earlier, the lack of elk in the study area (P. Benegyfield, USDA Forest Service, pers. comm. 2000) lends support to the suggestion that the consistent reductions in cross-section area at Basin Creek are reflecting site-specific characteristics and, possibly, the removal of cattle grazing pressure, rather than the removal of elk and cattle grazing pressure. Therefore, this particular data set is limited in its ability to conclusively link the complete removal of cattle and elk grazing with the higher rates of cross-section area reductions and should be considered only as a starting point for further research.

Table 5: Results of the statistical tests comparing the variances (HOV) and means (General Linear Model) of the annual rates of cross-section area change as a function of grazing treatment. All like treatment results combined. The null hypotheses (Ho) are 1) variances are similar and 2) means are similar. The significance level is $\alpha = 0.05$. RG = Riparian Guidelines, SEMA = Special Emphasis Management area, New CE = new cattle exclosure, New EE = new elk exclosure, Old CE = old cattle exclosure. P-values that reject the null hypothesis are underlined (i.e. the variances or means differ).

Treatment comparisons	Cross-section Sample size	HOV Bartlett's test (p value)	General Linear model test (p value)	Av. Annual rate of change (sq. m/yr)
RGs, SEMAs, New CEs, New EEs, Old CEs	39, 14, 18, 10, 9	0.68	> 0.01	0, 0.01, -0.03, -0.07, 0.03
RGs, SEMAs, New CEs, Old CEs	39, 14, 18, 9	0.55	0.09	0, 0.01, -0.03, 0.03
RGs, SEMAs, New CEs	39, 14, 18	0.35	0.13	0, 0.01, -0.03,
NCEs vs. NEEs	39, 10	0.97	0.08	
	Reach Sample size			Av. Annual rate of change (sq. m/yr)
RGs, SEMAs, New CEs, New EEs, Old CEs	16, 7, 8, 3, 2	0.56	> 0.01	0, 0.01, -0.02, -0.07, 0.04
RGs, SEMAs, New CEs, Old CEs (no elk exclosures)	16, 7, 8, 2	0.45	0.11	0, 0.01, -0.02, 0.04
RGs, SEMAs, New CEs, New EEs (no old cattle exclosures)	16, 7, 8, 3	0.38	> 0.01	0, 0.01, -0.02, -0.07
New CEs, New EEs	8, 3	0.18	0.04	-0.02, -0.07

The interpretation of the meaning of the cross-section area increases observed in the two old cattle exclosures on Muddy Creek should also be approached with caution. The sample size is small (two reaches) and restricted to a single creek. There is no theoretical basis for expecting channels inside cattle exclosures to increase in area. Therefore, these changes reflect adjustments to local channel characteristics, watershed conditions, and/or feedback loops that have been set in motion as a result of historical land use or random frequency events rather than current cattle grazing pressure in the reaches. These changes suggest that channel adjustments can continue long after cattle have been removed from the area (> 30 years).

The lack of a strong grazing treatment signal was unexpected and further complicated by the fact that the new elk exclosures and the old cattle exclosures tell conflicting stories (Figure 11). Explanations were sought for the lack of a strong signal and four possible explanations emerged: lack of time, lack of sediment, type of sediment in transport (bedload versus suspended sediment), and/or lack of a sediment trapping mechanism. These factors and their contribution to determining rates and directions of channel change are explored in the discussion section. Another possibility is that the annual rate measurement is not sensitive enough to pick up an grazing treatment signal after only two-to-five years. The annual rate is a single numeric number. As the sum of all sediment gains and losses at a cross-section, the annual rate cannot illuminate the long-term contribution of individual gains and losses to channel evolution. Therefore, differences in channel response to reductions in grazing pressure may be obscured in the annual rate as the channel undergoes a period of adjustment before stabilizing.

Annual Rates as a Function of Beaver-Dam Integrity

Beavers were present only at Price Creek, but a graphical examination of the annual rates of cross-section area change for the two beaver treatments shows the clear influence of dam integrity on rates and directions of cross-section change (Figure 12). Most cross-sections in reaches with intact beaver dams show large reductions in cross-section area, while most cross-sections in reaches with failing beaver dams show large increases in cross-section area. The next step was to calculate the annual rates for each survey interval and examine cross-section area response as a function of distance upstream of a beaver dam and dam integrity (Figure 13). It was necessary to calculate the annual rates for each survey interval (i.e. 1995 to 1997, 1997 to 1998) when analyzing the influence of distance upstream of a beaver dam on cross-section area because 1) the dams failed over the course of the study and 2) the changes were not linear over time.

Figure 13 shows the channel's sensitivity to changes in beaver-dam integrity. When the dams were structurally sound, channel bed aggradation was rapid at sites upstream and in close proximity to the dams. When the dams began to fail, the fine sediment trapped behind the dam rapidly eroded, revealing one of the fluvial processes by which channelization and drainage network expansion occurs. Cross-sections located 15 m or less upstream of a beaver dam responded rapidly to changes in beaver dam integrity, with the rates of change varying over time. Cross-sections located more than 15 m upstream of a dam showed a more variable response indicating that factors other than dam integrity and distance were also influencing rates and directions of cross-section

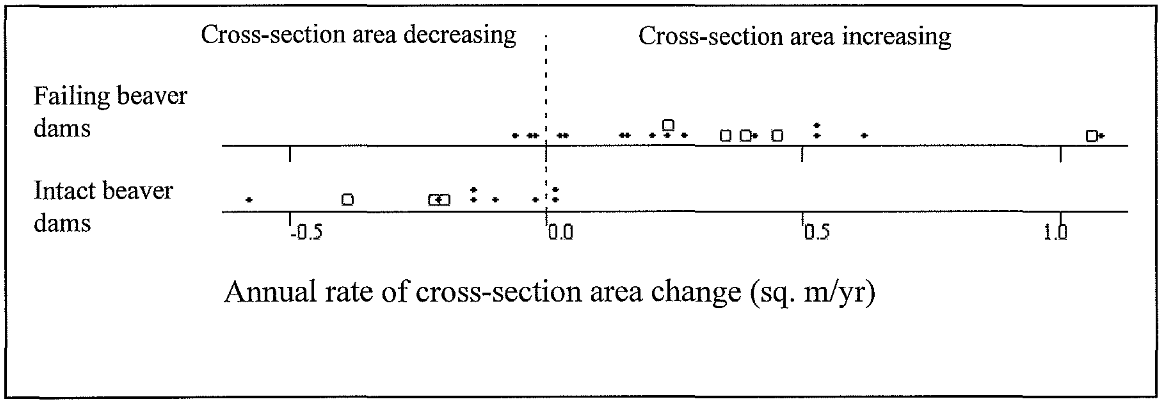


Figure 12. Annual rates of change in the geomorphic cross-section area as a function of beaver-dam integrity, Price Creek, Montana. Open squares = Bends. Solid dots = Straight sections.

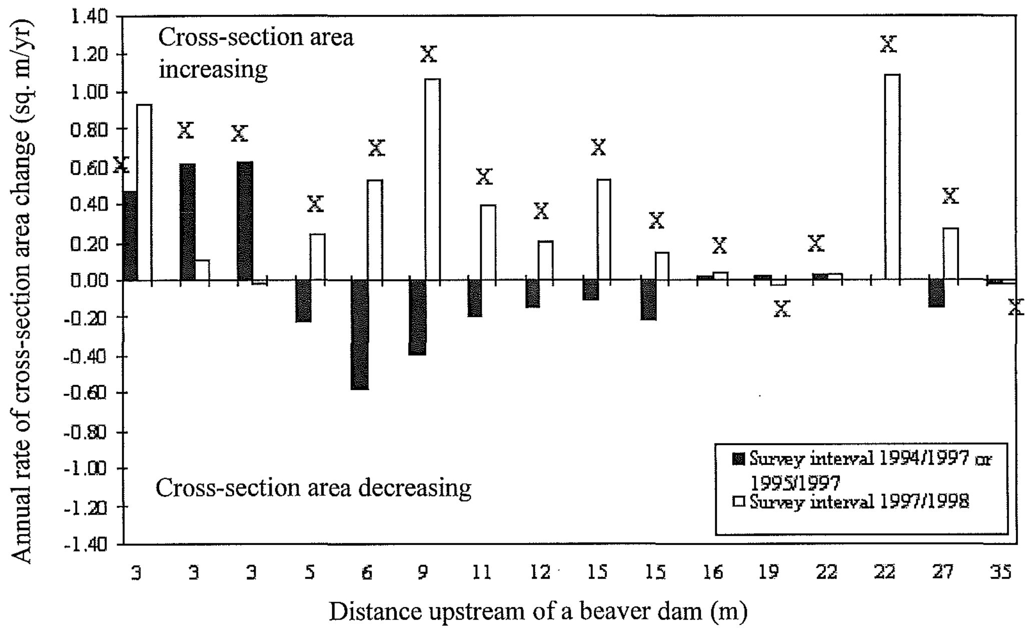


Figure 13. Annual rates of change as a function of distance upstream of an intact or failing beaver dam. Only cross-sections that had intact beaver dams at the time of their baseline survey are showns. 'X' indicates the survey interval during which the dam failed.

response. Other influential factors include 1) time since the dam was built or began failing, 2) the condition of the dam at the time of the baseline survey, 3) the rate and nature of the dam breach, 4) distance upstream of a dam, 5) the interaction between valley width and the particulars of the channel planform, and 6) availability of sediment.

The rapid rate of change as a function of beaver-dam integrity and proximity to a dam is clearly visible in cross-section and trend plots (Figure 14). The dam failures also provide information on the type of sediment in transport on Price Creek. Evaluation of the cross-section graphs for 17 and 18, located downstream of the dam controlled reaches on Price Creek, showed no changes in cross-section area between 1995 and 1998 despite the remobilization of large amounts of trapped sediment upstream once the dams failed (Figure 14). This lack of change at cross-section 17 and 18 indicates that the sediment moving through Price Creek was traveling most likely as suspended load.

Comparison of Annual Rates as a Function of Grazing Treatments versus Beaver-Dam Integrity

A comparison of the annual rates of cross-section area change as a function of treatment found that the rates were greater in the beaver-dam-controlled reaches than in reaches under the various grazing treatments (Figure 15a). The same result was observed when annual rates were examined at the reach scale though the distinction between the new elk exclosures and intact beaver-dam cross-sections is less pronounced (Figure 15b). A statistical analysis using ANOVA and homogeneity of variance tests found that the annual rates of cross-section area change in the new elk exclosures and the intact beaver-

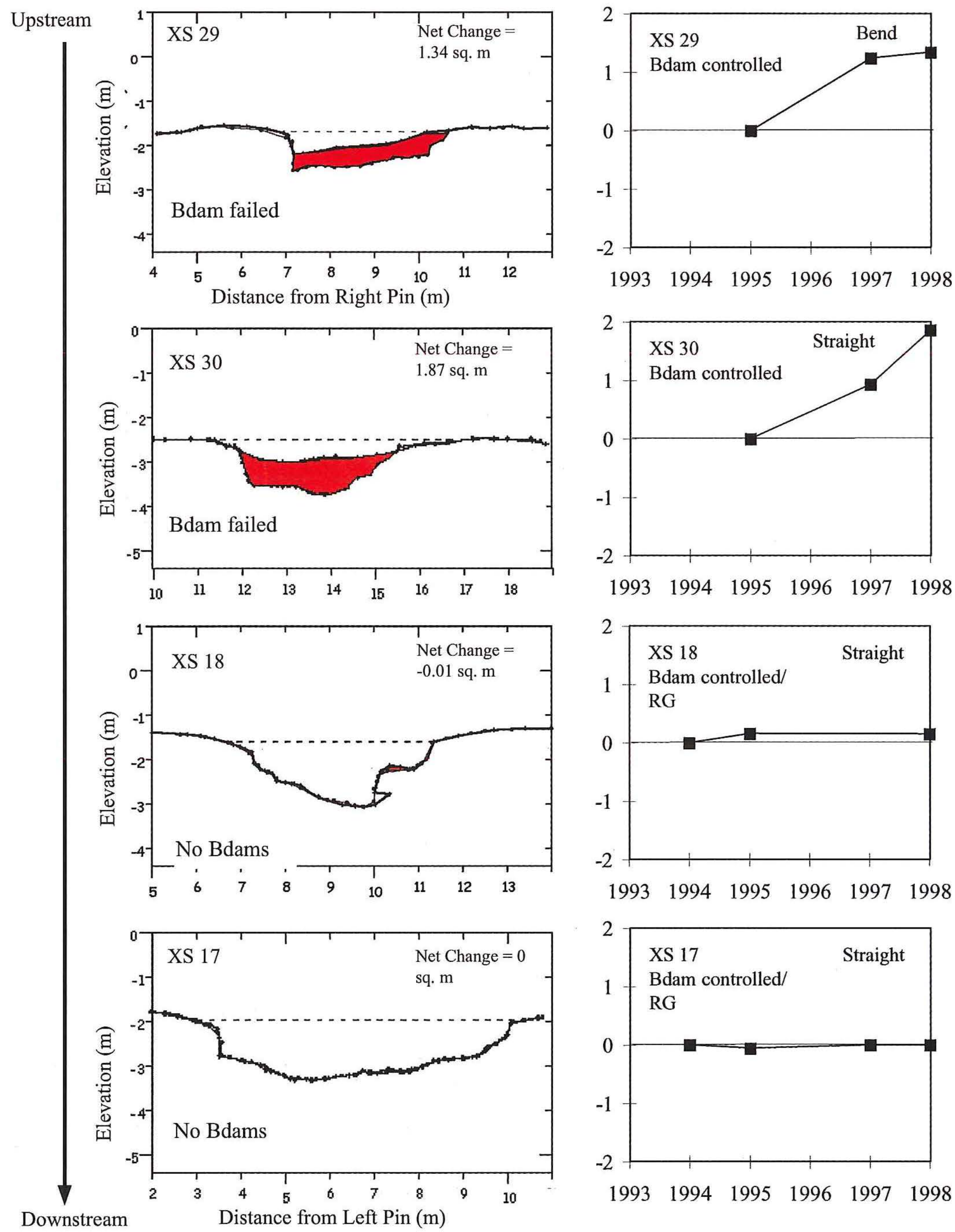
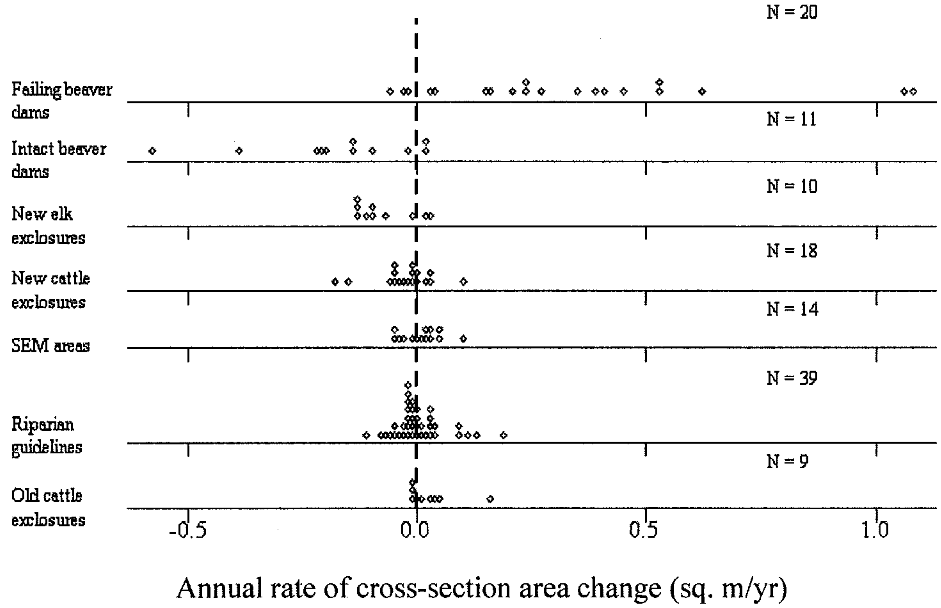


Figure 14. Comparison of cross-section area changes as a result of beaver-dam failures (cross-sections 29 and 30) versus cross-section area changes downstream of the failures (cross-sections 17 and 18), Price Creek Montana. Comparison between 1995 and 1998. BLACK = erosion. DASHED line = baseline geomorphic channel width.

a. Cross-section as sample unit (N = 121)



b. Reach as sample unit (N = 46)

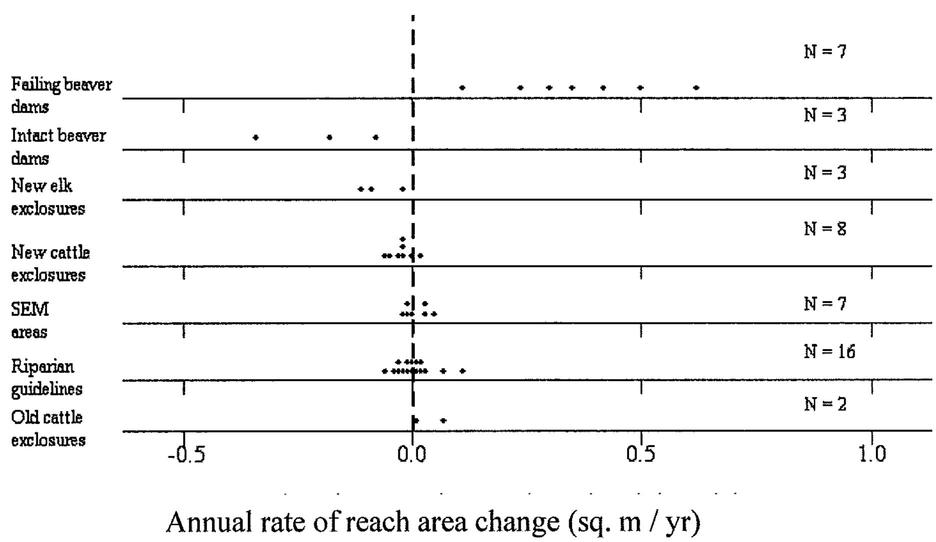


Figure 15. Comparison of annual rates of cross-section area change as a function of the different treatments. a) at the cross-section scale and b) at the reach scale.

dam reaches had means (p = 0.23) and variances (p = 0.19) that were not significantly different. Whether this similarity would have continued over time is unclear and cannot be tested as all beaver dams had failed or were breaching by the final survey in 1998.

Evidence Suggesting a Grazing Pressure Influence

The lack of a clear signal in the annual rates as a function of cattle and elk grazing pressure was unexpected, as was the absence of any consistent pattern in direction or magnitude of the annual rates as a function of cross-section location on a bend or straight section (Figures 10 and 11a). However, one difference is noticeable that bears further scrutiny: fewer straight sections in the new cattle exclosures (1 in 11), new elk exclosures (2 in 7), and old cattle exclosures (2 in 6) increased in cross-section area compared to the cross-sections in the Riparian Guidelines (11 in 25) and SEM (7 in 11) areas (Figure 11a). The magnitude of these increases ranged from 0.01 m^2 to 0.29 m^2 with the largest increases occurring in the Riparian Guidelines and SEM areas. This difference in the number of cross-sections increasing in area is not simply a function of different sample sizes. Even when the observations are normalized, more cross-sections in straight sections in the areas managed under the Riparian Guidelines (44%) and as SEM areas (64%) increased than did the cross-sections in the new cattle exclosures (1%), new exclosures (29%), and old cattle exclosures (33%). This greater frequency of cross-section area increases on straight sections in reaches grazed by cattle and elk suggests a grazing-pressure signature because straight sections are expected to be stable in these small systems. This observation was, therefore, examined further.

Prior to drawing any conclusions about the above observation, it is important to remember that the cross-sections were not randomly selected. I selected cross-sections to provide specific information on change and stability. I tried to select similar types of cross-sections in the different grazing treatments, but some variability existed in what was available in the different reaches. This lack of random selection of the cross-sections, combined with reach variability, means that one must proceed with caution when drawing conclusions from this observation. First, the cause of the increase in net cross-section area may be processes other than grazing pressure. Second, a lack of change, or even a reduction, in cross-section area does not necessarily negate the possible presence of a grazing pressure influence. The annual rate is a sum of all sediment gains and losses and cannot reveal cross-section specific changes that have long-term implications for channel evolution. I therefore examined all 60 cross-section graphs from straight sections in order to identify the location of bank erosion and deposition – information that might illuminate if and how grazing pressure was affecting the evolution of the channel. Evaluation of the causes of channel changes observed on the graphs was supplemented by field observations.

The upper and lower bank losses were evaluated separately for change. Lower bank changes were considered the result of fluvial processes (Thorne and Tovey 1981; Lawler 1992) while upper bank retreat, if observed in the field to be the result of hoof shearing action, was the result of grazing pressure. Bank retreats from rotational slumping, planar sliding, or tension crack failure had to be evaluated individually because these processes can be triggered either by fluvial processes (Thorne and Tovey 1981;

Knighton 1998) or cattle grazing (Trimble and Mendel 1995; Knighton 1998). Increases in cross-section area over the study period due to channel incision were not considered the direct result of current cattle-grazing pressure in the same way that upper bank retreat was considered a direct consequence of current grazing pressure. However historical livestock-grazing impacts on riparian and upland vegetation contributed to base-level drops by removing stabilizing bank vegetation and increasing discharge, and current grazing pressure and livestock-related activities may be contributing to further base-level drops.

Close examination of the 60 cross-section graphs and field notes found that the evidence for bank trampling as the cause of cross-section area increases was inconclusive. While 23 cross-sections increased in area (Figure 11a), only 14 out of the 60 cross-section graphs showed stream bank retreat occurring (Table 6). All 14 cross-section graphs were located in the Riparian Guidelines and SEM areas (Appendix B). In two of the 14 cases, the cross-sections showed a net reduction in area, underscoring the importance of examining both the annual rates and the cross-section graphs.

Table 6: Cross-sections with bank retreat related to grazing in areas managed under the Riparian Guidelines and as SEM areas. The cross-sections in BOLD show a net decrease in cross-section area despite bank losses. Negative net changes = cross-section area reduction. RG = Riparian Guidelines, SEMA = Special Emphasis Management areas.

Treatment	Creek	XS No.	Net XS area change (sq. m)	Amount of bank lost (sq. m)	Amount of bank retreat (m)	Cause of bank retreat
RG	N. Basin	17	0.21	0.2	0.31	Trampling?
RG	N. Basin	18	0.07	0.06	0.12	Trampling
RG	N. Basin	19	0.19	0.08	0.1	Block failure
RG	N. Basin	22	> 0.01	0.03	0.19	Trampling
RG	S. Basin	11	-0.16	0.08	0.14	Trampling?
RG	S. Basin	12	-0.06	0.22	0.24	Tension crack failure (trampling?)
RG	S. Basin	13	0.05	0.05	0.19	Trampling?
RG	Muddy	16	0.17	0.11	0.58	Rotational slump
RG	W. Fk Price	5	0.11	0.06	0.14	Trampling
RG	W. Fk Price	31	0.05	0.04	0.12	Trampling
SEMA	Hay	1	0.1	0.05	0.48	Trampling
SEMA	Lower Burro	5	0.14	0.03	0.17	Trampling?
SEMA	Mandan	5	0.31	0.36	0.67	Tension crack failure (trampling)
SEMA	Mandan	6	0.08	0.07	0.62	Trampling

The amount of retreat ranged from 0.1 to 0.67 m (Table 6) or 0.05 to 0.22 m/yr, and the location, spatial extent, and amount of stream bank retreat varied. In some cases the entire bank retreated, while in other cases only a portion of the bank retreated. Two of the 14 cross-sections had considerable upper bank erosion, but the erosion was not attributed to the direct effects of cattle or elk trampling. At one site the erosion was the result of a rotational slump, and at the second site it was the result of a downward shift in a block of bank, possibly related to channel incision (Table 6).

Both the channel incision and the rotational slump suggest a system still undergoing channel adjustments possibly related to past grazing impacts and land use, even though changes could not be attributed to present grazing pressure. The remaining

12 cross-section graphs had changes suggestive of a grazing-pressure influence (Table 6). While the bank erosion amounts were small in cross-section area, with most less than 0.1 m^2, the linear amount of bank retreat ranged from 0.12 to 0.67 m. The cause of bank retreat, based on field observations, was predominantly trampling which sheared off small portions of the bank (Figure 7). Tension cracks failed in two places. The cause of their eventual failure (i.e. grazing pressure or fluvial processes) is unknown. These observations regarding changes in cross-sections on straight sections in the Riparian Guidelines and SEM areas suggest that the greater grazing pressure in these areas is impacting the channel. While the amount of bank retreat was small (most $< 0.1\ m^2$), these are small headwater streams. Therefore, even small amounts of bank retreat are important and can greatly influence the stream and valley floor hydrologic connection.

Geomorphic Significance of the Cross-section Area Changes

This section answers the third research question: "What is the geomorphic significance of the cross-section area change as it relates to reconnecting the stream hydrologically to its valley floor?" The geomorphic significance of the cross-section area changes was evaluated by examining the degree to which the available channel capacity decreased. Reductions in available channel capacity and the resultant improved stream and valley-floor hydrologic connection can occur either through sediment deposition or by the maintenance of higher water levels in the channel (i.e. backwater effects of beaver dams). Therefore, three aspects of the data were analyzed. First, the annual rates were evaluated in terms of their annual percent change in baseline cross-section area. Second, the annual rate of change was compared against the target reduction in cross-section area required to hydrologically reconnect the stream and the valley floor. Finally, the percent reduction in the available channel capacity of the geomorphic channel was calculated for a point in time as a result of the amount of water present in the channel. This last calculation highlighted the ability of intact beaver dams to reduce available channel capacity as a result of ponding water behind the dams and is discussed in depth in the discussion section.

Annual Percent Change in Cross-section Area

The annual rates of change were expressed as a percent of baseline cross-section area in order to place the rates in their geomorphic context (Figure 16). The percent change calculation is highly sensitive to baseline area (Figure 16) and demonstrates the importance of examining the percent change and the actual rate of change simultaneously. Only three grazing cross-sections (three percent) had changes greater than 10 percent per year, and of the three, two had very small baseline cross-section areas (less than 0.5 m^2). In contrast, the 16 beaver-dam cross-sections (53 percent) had changes in their baseline area greater than 10 percent.

The examination of the data graphically and statistically prevents overestimating or underestimating the significance of the changes as they apply to the variable of interest – in this case channel cross-section area. The summary presented in Table 7 supports the earlier statistical tests and graphical plots that showed minimal difference between the

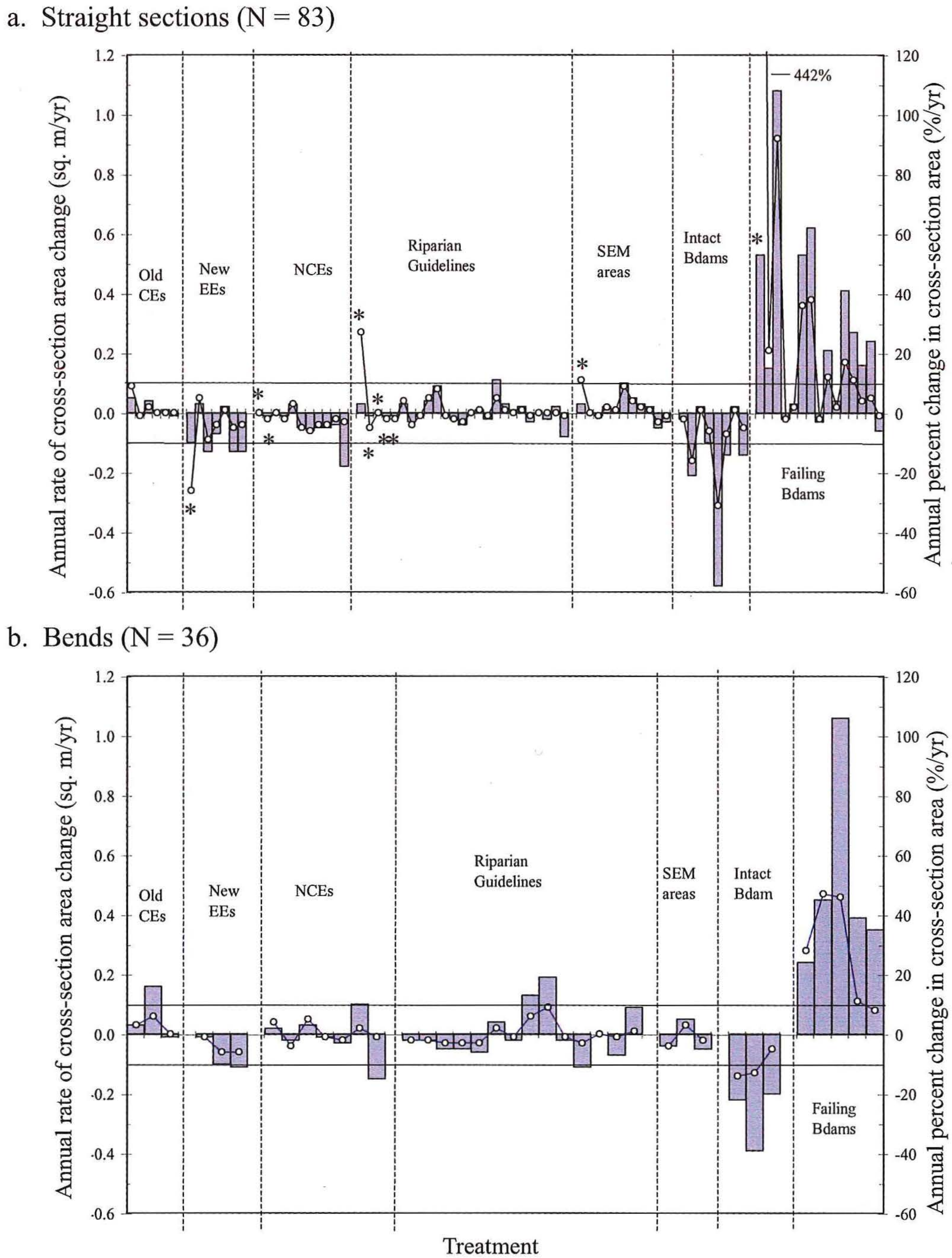


Figure 16. Annual rates, directions and percent change in baseline cross-section areas as a function of treatment. Bar = annual cross-section area change (sq.m/yr), Circles = Annual percent change in cross-section area. Cross-sections within a treatment are in order of increasing basline area. An (*) above a bar indicates that the cross-section area is less than 0.5 sq. m.

grazing treatments, at least in the initial years of a reduction in grazing pressure. Therefore, the annual rates of change for the grazing treatments are combined in the following section when evaluating the geomorphic significance of the various treatments. As mentioned earlier, the difference in annual rates between the new elk exclosures and the other four grazing treatments may be site-specific rather than treatment-specific, a question that can only be answered with further surveys.

Table 7: Summary of annual percent change in baseline cross-section area as a function of treatment at the cross-section scale. (^) = Baseline cross-section area < 0.5 m^2. (↑) = cross-section area increases, (↓) = cross-section area decreases

Treatment	Sample Size	No change	$\|X\| \leq 10\%$	$10\% < \|X\| \leq 20\%$	$20\% < \|X\| \leq 30\%$	$\|X\| > 30\%$
Non-dam controlled	90	14	87 (97%)	1 (1%)	2 (2%)	0
New Elk Exclosures	10	0	2 (↑) 7(↓)	0	1^ (↓)	0
New Cattle Exclosures	18	2	4 (↑) 12 (↓)	0	0	0
Old Cattle Exclosures	9	4	4 (↑) 1 (↓)	0	0	0
Riparian Guidelines	39	7	11 (↑) 20 (↓)	0	1^ (↑)	0
SEMAs	14	1	7 (↑) 5 (↓)	1 (↑)	0	0
Dam controlled	31		15 (48%)	7 (23%)	2 (6%)	7 (23%)
Intact Bdams	11	0	2 (↑) 5 (↓)	3 (↓)	0	1 (↓)
Failing Bdams	20	0	5 (↑) 3 (↓)	4 (↑)	2 (↑)	6^ (↑)

Geomorphic Significance of the Annual Rates of Channel Change

I examined the net cross-section area changes, the annual rates, and the calculated target rates to determine the "geomorphic significance" of the annual rates of cross-section area change. A channel change is defined as "geomorphically significant" if it increases or decreases the degree to which the stream and valley floor are hydrologically connected. The target annual rate of cross-section area change is defined as the annual rate of decrease in cross-section area required to return the cross-section to its pre-disturbance area in 10 years and hydrologically reconnect the stream and valley floor. The target rates were then compared against their corresponding annual rates to determine whether the annual rate would meet the desired reduction in cross-section area in 10 years or less (Figure 17). The pre-disturbance cross-section areas selected for my cross-sections were 0.1 m^2 for cross-sections with drainage areas less than 15 km^2 and 0.53 m^2 for cross-sections with drainage areas greater than 50 km^2. The values were the smallest geomorphic cross-section area measured in their respective drainage area categories.

The first step was to examine the net changes to determine which cross-sections had no net change in cross-section area. As mentioned earlier, a net area increase or decrease of 0.05 m^2 or less was considered essentially no change. This value is so small (a 22 cm by 22 cm square) that it more likely reflects variations in the location of the survey points between years rather than real change in cross-section area. Once the cross-sections with "no net change" were identified, the annual rates of change for the remaining cross-sections were examined. All cases in which the cross-section area increased were considered significant because the stream is beginning to, or continuing to, disconnect hydrologically from its valley floor. Decreases in cross-section area were separated into two categories, "positive" decrease and "significant" decrease, depending on whether the annual rate did or did not met the target rate. I identified six categories of geomorphic significance (Table 8). Two categories applied to cases where the channel enlargement was less than or equal to 0.2 m^2, and four categories applied to cases where the channel enlargement was greater than 0.2 m^2. A channel enlargement of less than or equal to 0.2 m^2 over its estimated pre-disturbance channel area was not considered enough to disconnect the stream hydrologically from its valley floor.

The majority of the cross-sections, and therefore the reaches, did not meet or exceed the annual rate of change required to hydrologically reconnect the streams to their valley floors in 10 years (Figure 17, Table 8, Appendix I). About a third of the cross-sections in the grazing treatments were improving. The remaining two-thirds either increased in area, and thus available channel capacity, or showed no change but had streams that were already hydrologically disconnected from their valley floors.

Cross-sections in the area of failing beaver dams showed annual increases in cross-section area up to 1.08 m^2/yr (Figure 13). The magnitude of these changes revealed the magnitude of sediment that had been trapped behind the dams and the speed at which a stream can shift from processes of aggradation to erosion. However, these initial high rates of erosion are expected to be short-term and drop abruptly once the stream has eroded through the fine sediments down to a more resistant layer in the channel bed. In terms of the recovery of the hydrologic connection, the intact beaver dams were very effective. The annual rates of cross-section area reductions at eight of the 11 intact beaver-dam cross-sections met or exceeded the target rate. Initial cross-section area reductions were as high as 0.58 m^2/year for sites in close proximity to intact beaver dams.

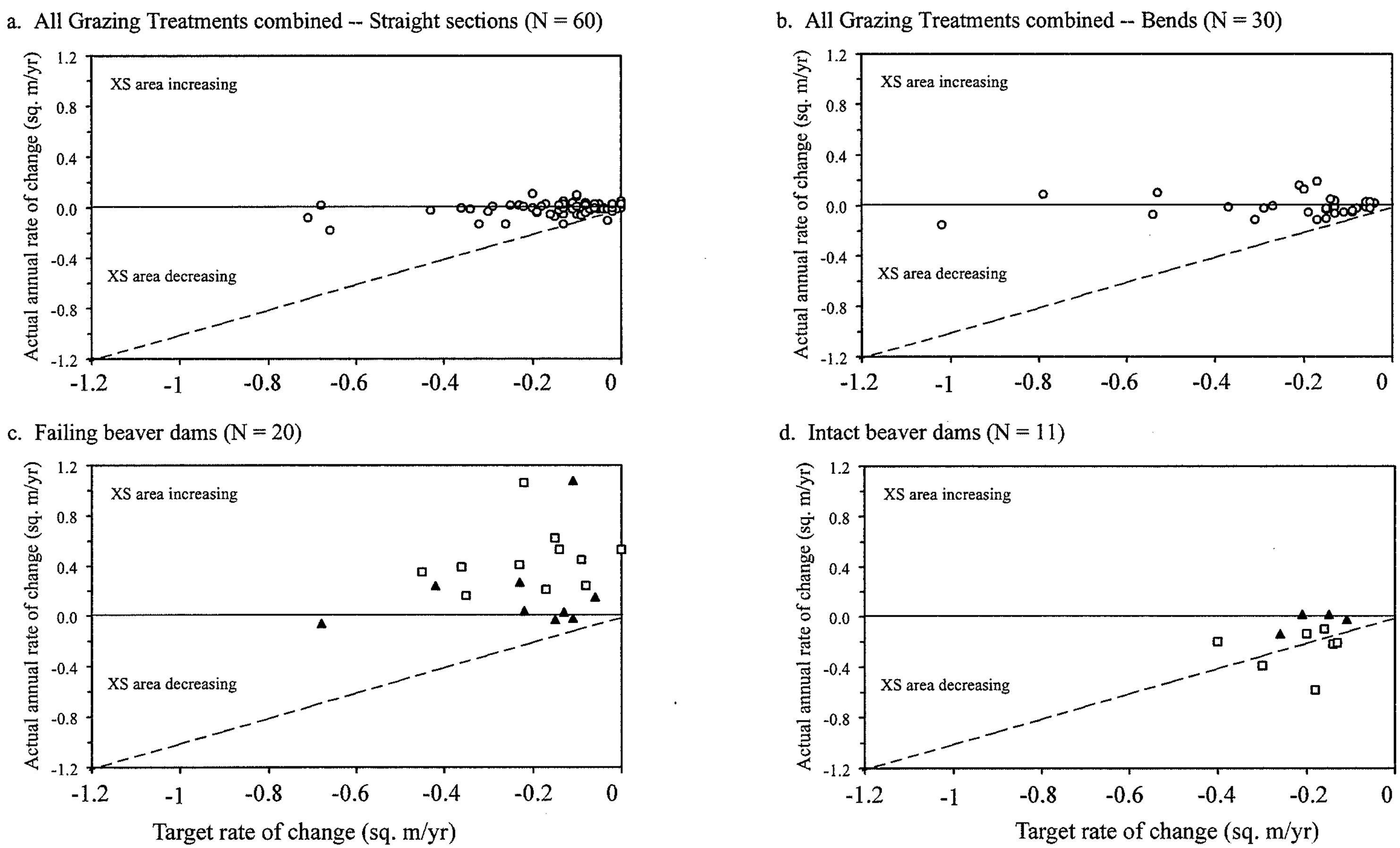


Figure 17. A comparison of the actual rates of geomorphic cross-section area change with the target rate required to reduce the geomorphic cross-section area to its pre-distubance cross-section area in 10 years. The DASHED line is target rate. The area below the DASHED line is the zone where the annual rate of change meets or exceeds the target rate. Squares = cross-sections < or = 15 meters upstream of a beaver dam. Triangles = cross-sections > 15 meters upstream of a beaver dam.

Table 8. Geomorphic significance and implications of the cross-section responses as they pertain to hydrologically reconnecting the stream and the valley floor in 10 years. Channel enlargement is defined as the amount that the geomorphic channel cross-section area has increased over the pre-disturbance channel area.

Cross-section area change	Criteria	Stream and Valley-Floor Hydrologic Connection	System Condition	Grazing Treatments N = 90	Failing Bdams N = 20	Intact Bdams N = 11
Channel enlargement < 0.2 m^2						
No real change in cross-section area occurred	|Net change in XS area change| $\leq 0.05\ m^2$	Hydrologically connected	Stable and Functioning	2 (2%)	0	0
An increase occurred in the cross-section area	Net XS area increases > 0.05 m^2	Becoming hydrologically disconnected	Degrading	3 (3.5%)	1 (5%)	0
Channel enlargement ≥ 0.2 m^2						
No real change in cross-section area occurred	|Net XS area change| $\leq 0.05\ m^2$	Hydrologically disconnected	Stable but in degraded condition	31 (34.5%)	3 (15%)	3 (27%)
An increase occurred in the cross-section area	Net XS area increases > 0.05 m^2	Hydrologic disconnection increasing	Degrading	21 (23%)	15 (75%)	0
A positive reduction occurred in the cross-section area	1. Net XS area decreases by more than 0.05 m^2 2. Annual rate < Target rate	Hydrologic connection is improving BUT will not reach the desired goal in 10 years at current rate.	Improving	30 (33.5%)	1 (5%)	4 (36.5%)
A significant reduction occurred in the cross-section area	1. Net XS area decreases by more than 0.05 m^2 2. Annual rate ≥ Target rate	Hydrologic connection is improving AND will reach or exceed the desired goal in 10 years at current rate.	Rapidly Improving	3 (3.5%)	0	4 (36.5%)

Water Levels and Available Channel Capacity as a Function of Grazing Pressure and Beaver-dam Integrity

Most cross-sections in reaches controlled by beaver dams had annual rates of cross-section area reductions as a result of sediment deposition equal to or greater than the target rates in contrast to the low reductions in area for the grazing treatments (Figure 17). The large difference between rates of reduction in area for the dam-controlled and non-dam controlled sites is the result of the beaver dams effectively trapping the fine suspended load that would have otherwise been transported out of the reaches. However, even when sedimentation rates were low in the dam-controlled reaches, as it was at some cross-sections (Figure 13), the hydrologic reconnection between the stream and valley floor still occurred because the elevated water levels in the beaver ponds reduced the available channel capacity. The effectiveness of intact beaver dams and ponds towards reducing available channel capacity and maintaining the surface hydrologic connection between the stream and valley floor during the summer low-flow months is visible when comparing the percent reduction in the available channel capacity for the three Montana streams (Figure 18; Appendix J). The impact of this reduction in available channel capacity on flood frequencies will be examined later in the discussion section of this chapter and again in Chapter 3.

Percent reductions in available channel capacity for the three streams as a result of water levels in the channels were compared for the 1995 surveys as a function of the geomorphic cross-section area. The surveys took place from mid-July to late August. In the dam-controlled reaches on Price Creek, one cross-section had a 100 percent reduction in available channel capacity, being completely filled with water, while another cross-section had water extending onto the valley floor as result of the top of the dam being higher than the top of the bank. In addition, a number of the Price Creek cross-sections had reductions in available channel capacity of 50 percent or more due to water ponding behind the dams. Reductions in available channel capacity in the dam-controlled reaches less than 50 percent occurred where the dams were not being maintained. The lack of maintenance led to lower water levels as water leaked through the dams or spilled over the breaches in the dams.

In contrast to the dam-controlled reaches, water occupied less channel area for similar geomorphic channel areas in the non-dam-controlled reaches. Reductions in available channel capacity were less than 40 percent for the majority of the non dam-controlled cross-sections. The two non-dam-controlled Price Creek cross-sections demonstrate that the percent reductions in available channel capacity as a function of the amount of water occupying the channel in the dam-controlled and non-dam-controlled cross-sections was not a function of creek and/or variations in discharge. The two cross-sections are identified in Figure 18 by open circles. Their percent reductions in available channel capacity are similar to the percent reductions calculated for the non-dam-controlled cross-sections at Muddy and Basin Creeks.

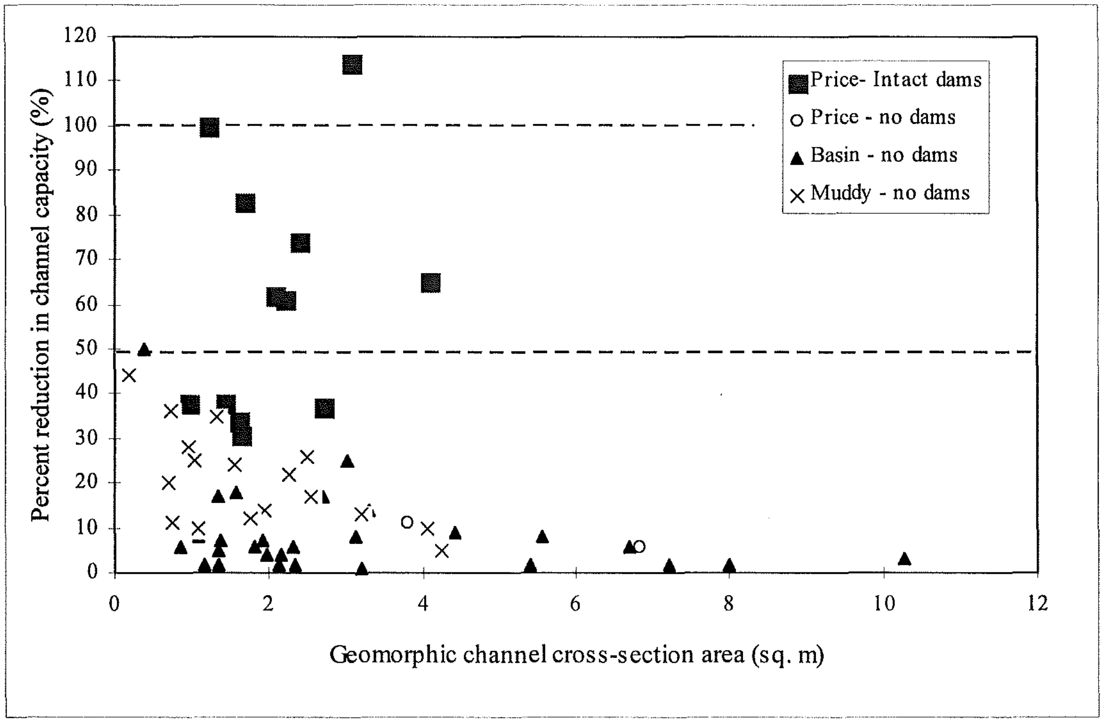


Figure 18: Percent reductions in available channel capacity in streams with and without beaver dams. All streams in southwest Montana and all data were collected between mid-July and late August 1995.

The effectiveness of beaver ponds as a mechanism for reducing available channel capacity becomes even clearer when comparing the available channel capacity at Price Creek in 1995 (dams intact) and in 1998 (dams failing or failed) are compared (Figure 19). All cross-sections inside the dam-controlled areas show a significant increase in available channel capacity in 1998 as a result of dam failures and pond drainage. The difference between the two survey years cannot be attributed to variations in discharge because the water levels at cross-sections 17 and 18 did not vary between 1995 and 1998. Cross-sections 17 and 18 are located downstream of the beaver dam-controlled reaches and downstream of the confluence between Price Creek and the West Fork of Price Creek. The changes in available channel capacity between 1995 and 1998 demonstrate the speed at which a hydrologic disconnection can occur as well as a means to its restoration.

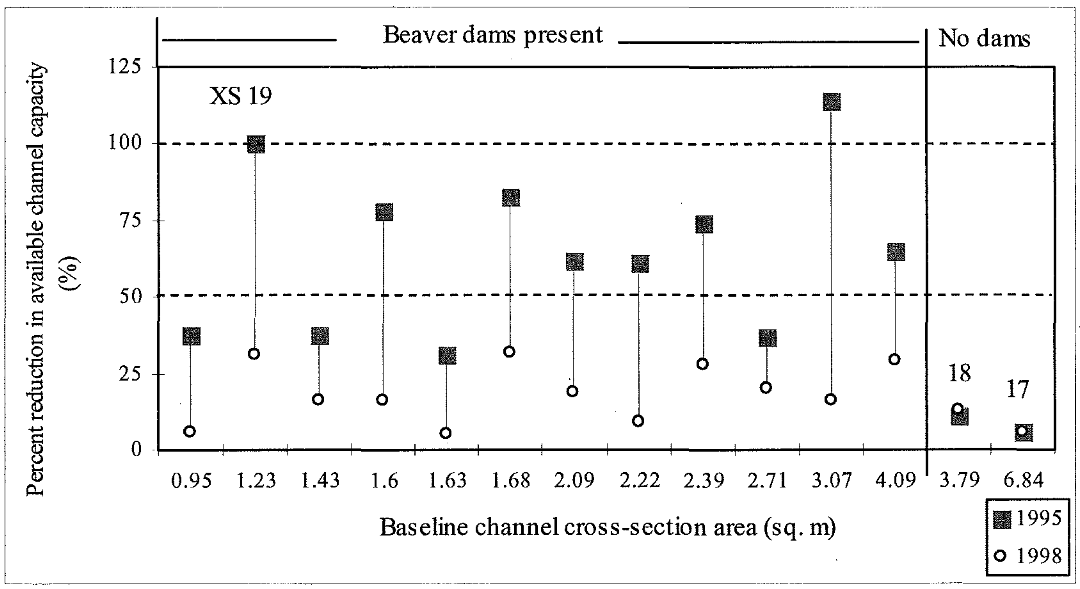


Figure 19: Percent reductions in available channel capacity as a function of beaver-dam integrity, Price Creek, Montana. The dams were intact in 1995, though some were not being maintained. Dams had completely failed or were breaching in 1998. Cross-sections 17 and 18 are downstream of the beaver dam-controlled reaches.

Identifying Trends in the Cross-section Area Changes

This final section examines changes in the cross-section area as a function of time to answer the fourth research question: "What are the time scales of channel change, potential trends, and the effectiveness of the different study treatments as strategies for restoring the stream and valley flood hydrologic connection?" A combination of cross-section graphs, trend plots, and annual rates were used in the analysis.

Multiple resurveys were essential for understanding the long-term response of streams to reductions in cattle and elk grazing pressure and changes in beaver-dam integrity. The resurveys documented the complex nature of fluvial adjustments, revealing non-linear rates and, in some cases, abrupt reversals in the direction and magnitude of cross-section area change. Four causes were identified from the cross-section graphs as responsible for variations in rates and directions of change: 1) close proximity to a beaver-dam failure, 2) close proximity to an intact beaver dam, 3) the completion of an episodic event such as a bend failure, and 4) changes over time in the amount of sediment deposited relative to the amount of sediment eroded. A fifth cause, not yet visible at my cross-sections in beaver-dam controlled reaches, is the situation whereby a knickpoint generated at a failing beaver dam migrates upstream and at some later date results in a sudden increase in area at a cross-section distant from a dam. The amount of increase in a cross-section area will vary depending on the amount of sediment deposited at the site prior to dam failure.

Several examples demonstrate this variability and complexity in response and underscore the limitations in relying solely on a single repeat survey and an annual rate to predict future trends. The first example examines trend plots from Muddy and Price Creeks. All four trend plots from Muddy Creek show variation in trend predictability (Figure 20a). The most noticeable changes occur for cross-sections 12 and 17 and are the result of the completion of bend failures. In contrast, Muddy Creek cross-sections 16 and

5, both on straight sections, show very little change in trend. Of the four Price Creek trend plots, three show changes in the magnitude and an abrupt reversal in the direction of channel change as a result of beaver-dam failures (Figure 20b). Price Creek 17, located downstream of the beaver dam-controlled reaches, also shows a change in trend, though the change is minor compared to the beaver dam-controlled cross-sections. The ability to predict future trends and channel changes at individual cross-sections is thus poor, if only the first survey interval rate was used (Figure 20). An examination of all the Muddy Creek and Price Creek trend plots showed no evidence for any linear trends as a function of treatment (Figures 21 and 22). In the case of Price Creek, the lack of trend in the beaver-dam reaches is because the dams failed part way through the study due to lack of dam maintenance as a result of beaver trapping, an event nicely captured by the plots (Figure 22).

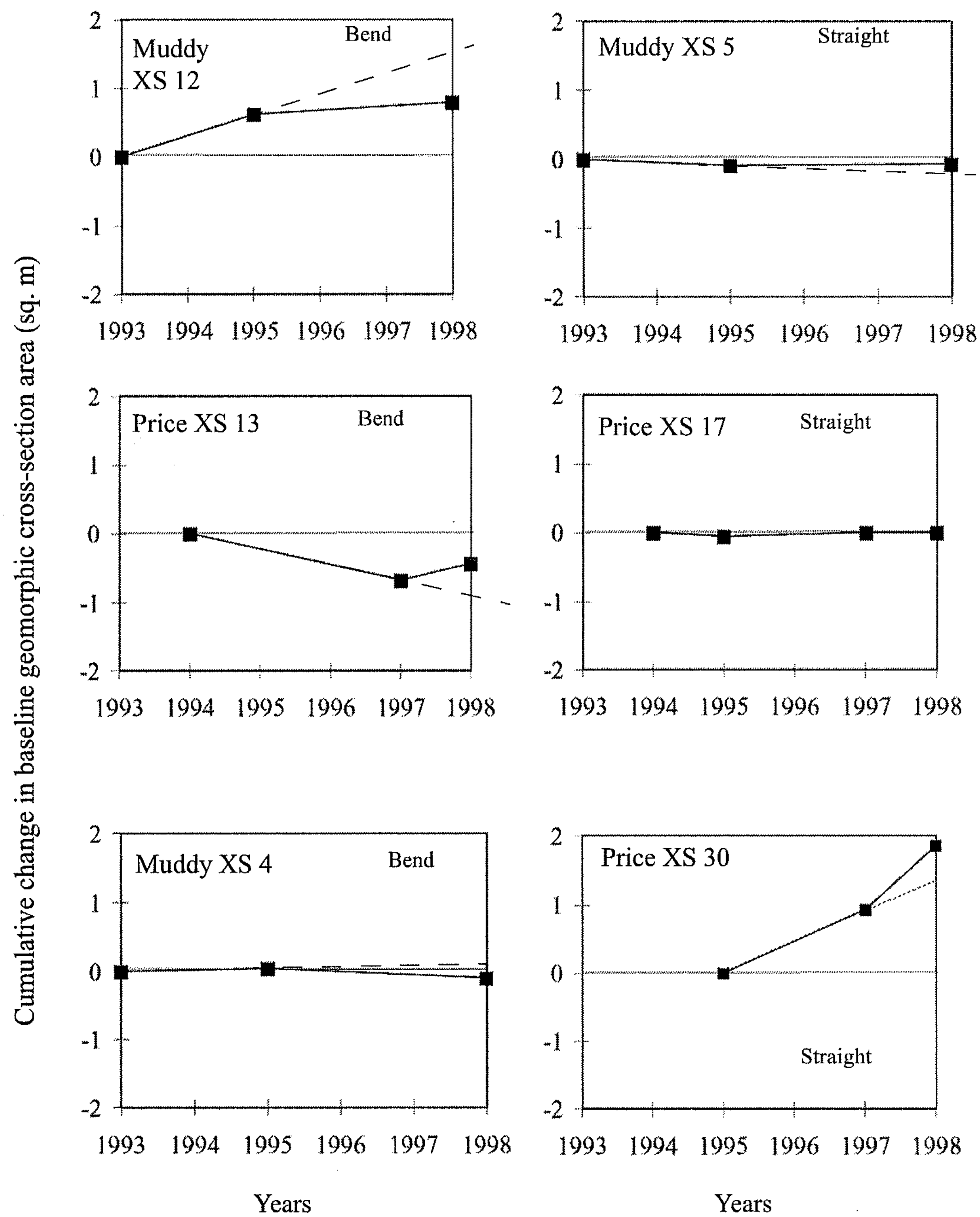


Figure 20. Examples of changes in cross-section area trend over time. The dashed line reflects the predicted trend based on the first survey interval. ‘0’ = baseline area reference point.

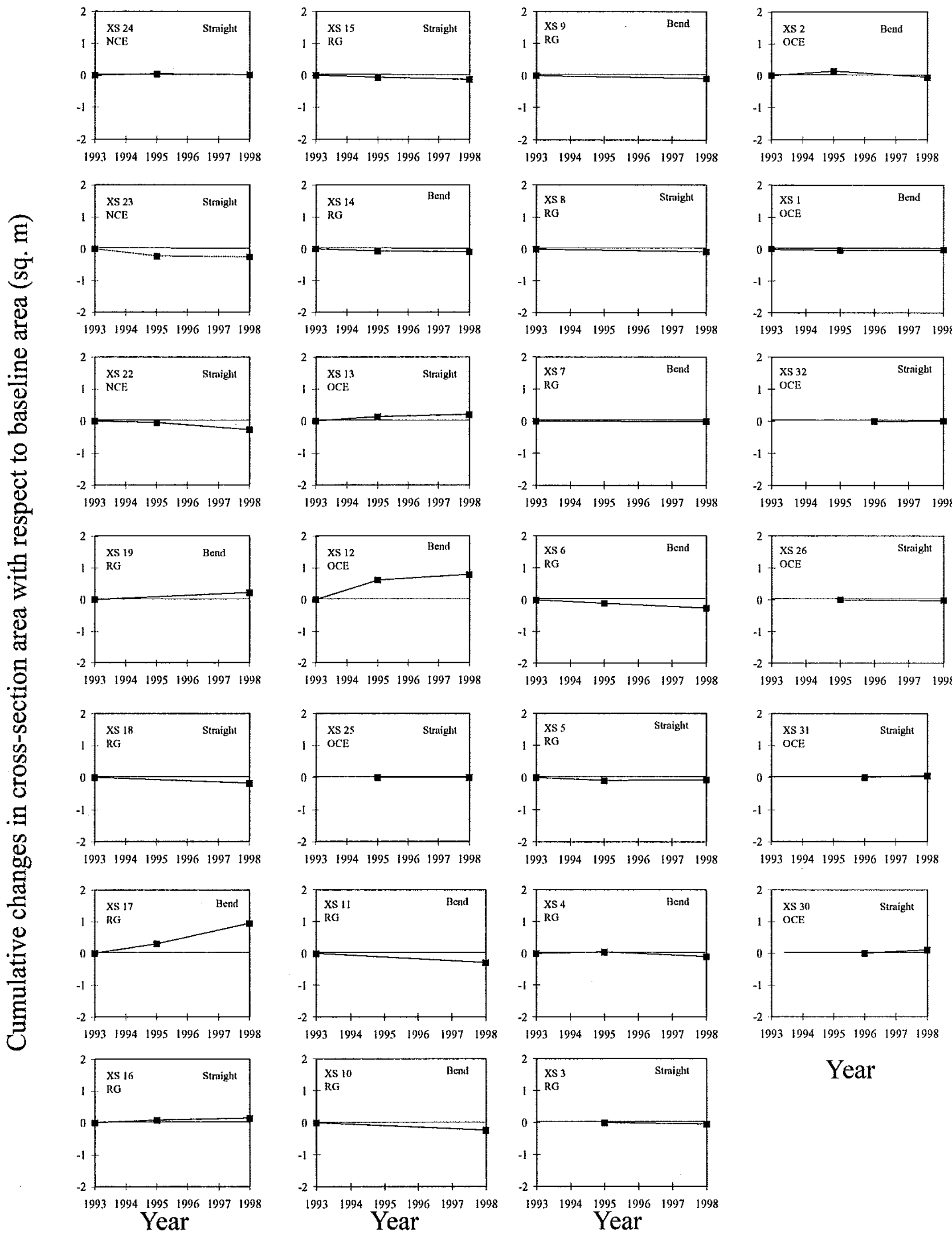


Figure 21. Changes in cross-section area over time with respect to baseline cross-section area, Muddy Creek, Montana. '0' = baseline area. Plots start at the upstream end and head downstream. OCE = Old cattle exclosure, NCE = New cattle exlclosure, RG = Riparian guidelines.

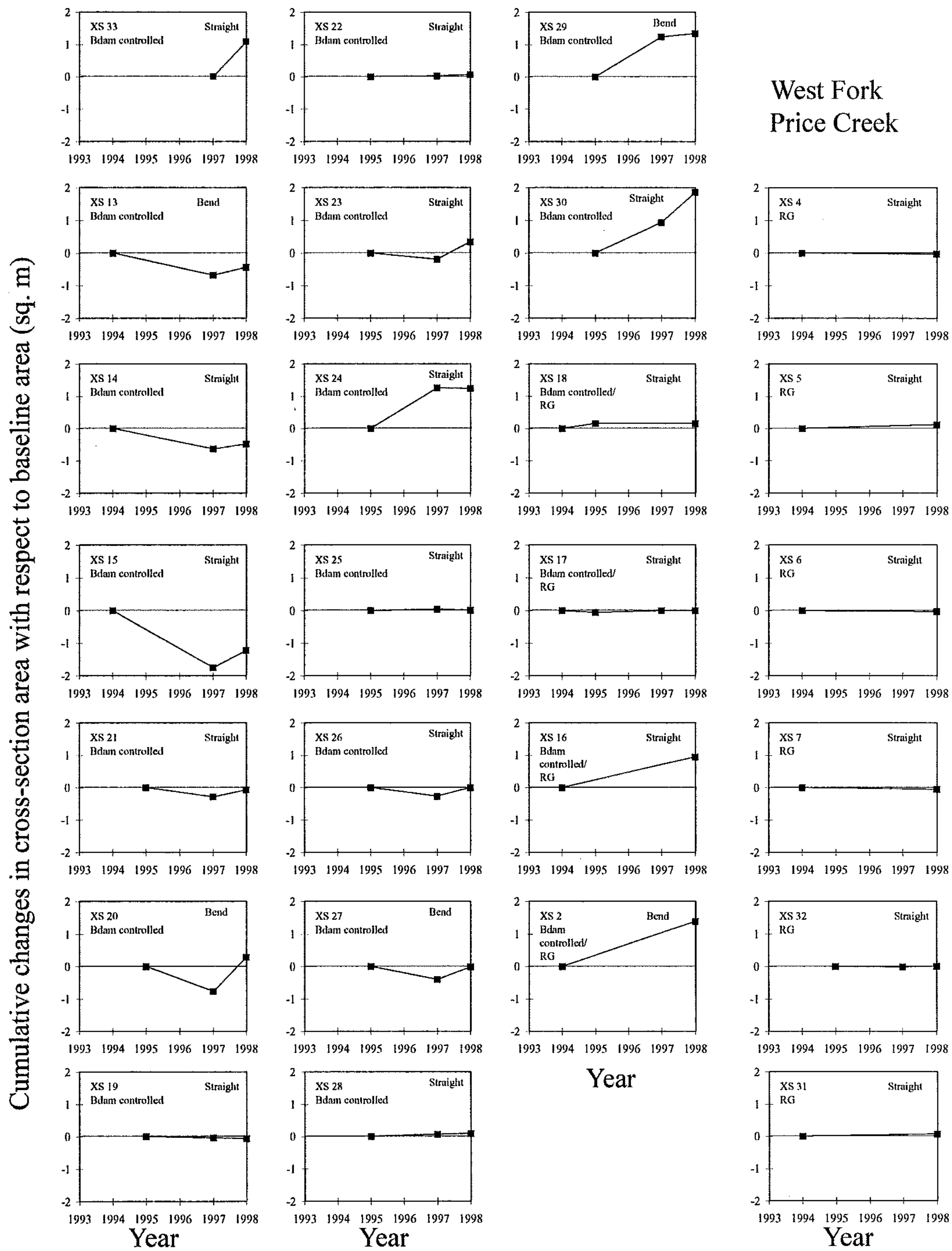


Figure 22. Changes in cross-section area over time with respect to baseline cross-section area, Price Creek, Montana. '0' = baseline area. Plots start at the upstream end and head downstream. Bdam controlled = beaver dam influence, RG = Riparian guidelines, Bdam controlled/RG = Treatment shifted over study.

In some cases, both the annual rates and trend plots show minimal change in baseline cross-section area, and it is only by examining the cross-section graphs and field notes that the existence of change becomes visible. West Fork of Price Creek cross-section 32 is an excellent example. The reach section represented by cross-section 32 is still hydrologically connected to its valley floor, but the potential for a hydrologic disconnect in the future is high. The cross-section was resurveyed twice. The annual rates of change were low, only -0.01 m^2 between 1995 and 1997 and 0.02 m^2 between 1997 and 1998, and its trend plot showed little change (Figure 22). However, field observations noted high levels of bank trampling, an impact that was captured in its graph (Figure 23). The graph suggests that higher rates of change will occur in the future. Site-specific change at the cross-section as a result of bank trampling will be compounded as knickpoints observed in the reach migrate upstream beyond the cross-section. Therefore, in addition to channel widening, channel incision is expected to occur at the cross-section, the combination of events shifting the stream from being hydrologically connected to its valley floor to being disconnected. Again, the importance of using all the data available when attempting to predict channel change and identify impacts is highlighted as well as the importance of long-term surveys.

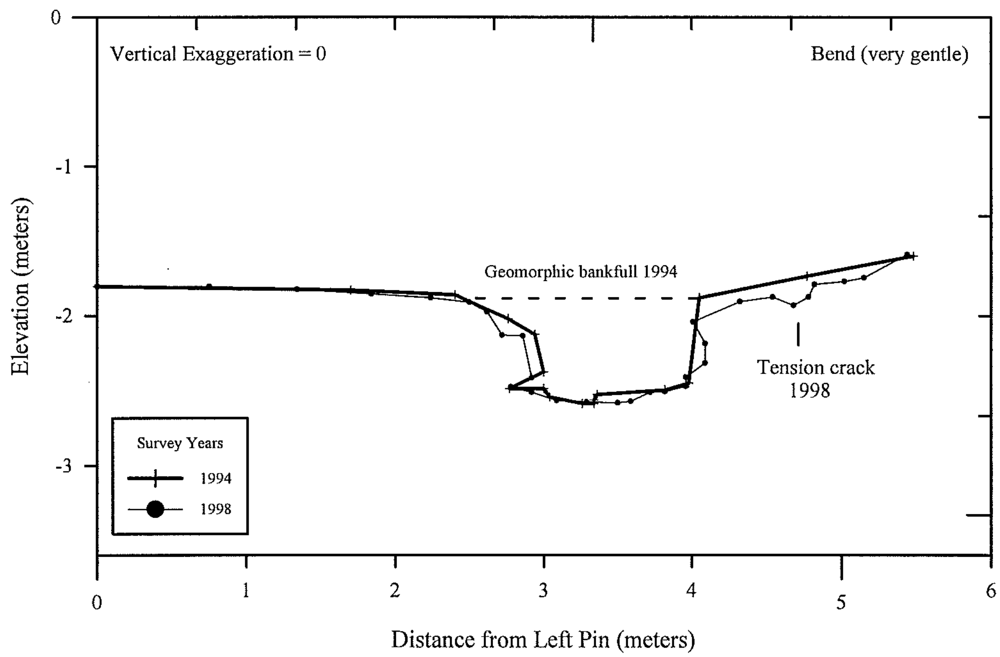
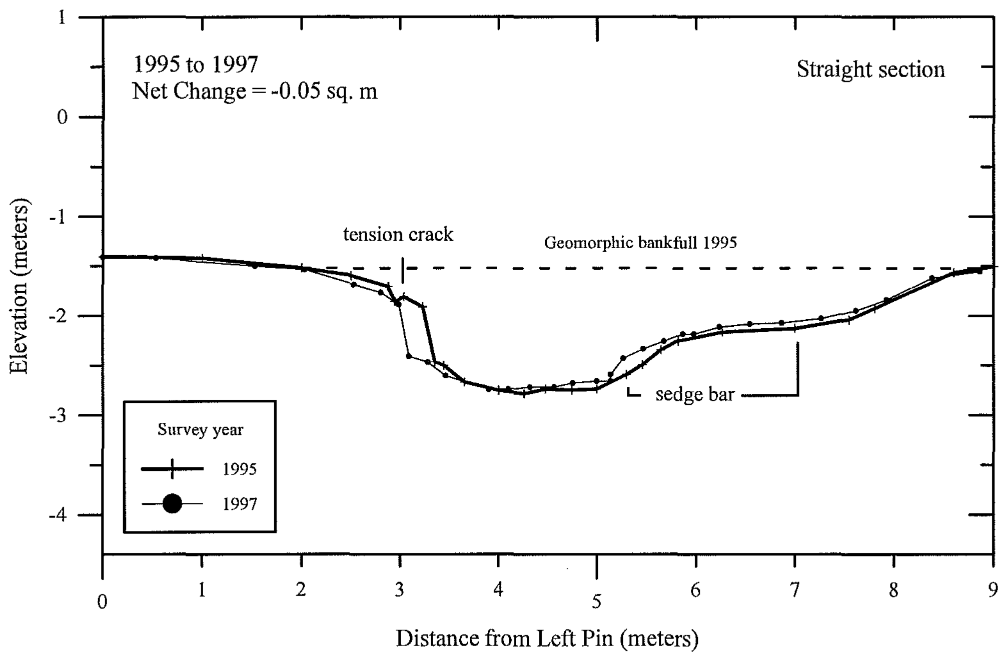


Figure 23. Cross-section showing changes to the channel banks as a result of bank trampling. West Fork Price Creek 5, Montana. DASHED line = Baseline geomorphic bankfull channel width.

Another example demonstrating the contribution made by the cross-section graphs shows how cross-sections can have similar net changes in area but for different reasons and with different implications for the stream and valley-floor hydrologic connection. In the case of Basin Creek 12, the net change was minimal (-0.05 m^2) because the amount of bank that eroded was about equal to the amount of sediment that was deposited (Figure 24a). The long-term contributions of the gains and losses to the evolution of the channel morphology at Basin Creek 12 differ sharply. The left bank failure at Basin 12 is a permanent change while the sediment deposited on the bar may be temporary unless vegetation becomes well established. In the case of Mandan Creek 2, the net change was also minimal (-0.02 m^2), but in this case it was because only a small amount of sediment was deposited (Figure 24b). As the Basin Creek and White Mountains sites were only surveyed twice, trends at cross-sections or as a function of treatment could not be determined.

The location, amount, and complexity of cross-section change over time were distinctly different for grazing treatments versus beaver treatments (Figures 14 and 15; Appendix B). These differences are qualitatively summarized in Table 9. The complexity of channel response underscores the importance of using cross-section graphs, trend plots and annual rates of change when interpreting results and predicting future changes. The results also underscore the value of having more than two surveys when attempting to draw interpret the data. While the annual rates of change are an effective means of comparing cross-sections and determining trends, they do not reveal the spatial and temporal composition

a) Basin Creek 12 (Riparian Guidelines)



b) Mandan Creek 2 (Special Emphasis Management area)

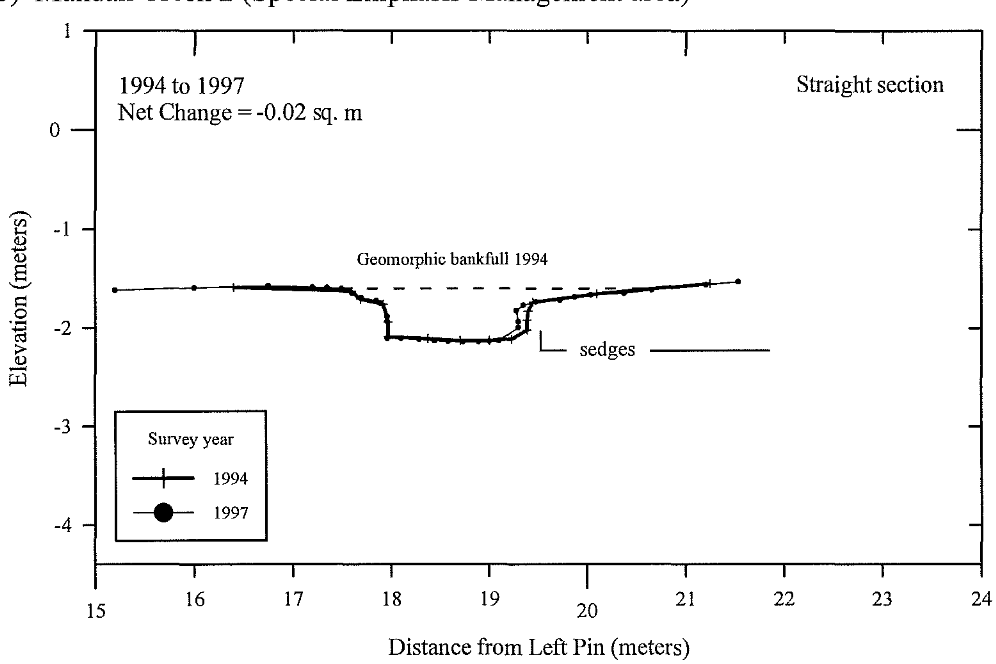


Figure 24. Comparison of cross-sections with similar net changes in area, but with different geomorphic significance to the channel. Dashed line = baseline geomorphic channel width. Vertical exaggeration = 0. Graphs at same scale for direct comparison.

of those changes. This information is critical for interpreting trends in channel evolution and the potential for reconnecting the stream hydrologically to its valley floor.

Table 9. Differences in cross-section response as a function of grazing pressure and beaver-dam integrity as observed on the cross-section graphs.

Sediment gained and lost	*Grazing Treatment XS response*	*Beaver Treatment XS responses*
Amount	Usually about equal amounts.	Not equal. A gain or a loss dominates in close proximity to beaver dams. At sites more distant to beaver dams, the results are more similar to the patterns noted in the grazing treatment areas.
Spatial Distribution	Spatially diverse and complex.	Little spatial diversity.
Magnitude of Change	Varies, but usually small. The occasional large net gain or loss occurs on both straight sections and bends.	Large in close proximity to a beaver dam, decreasing with distance upstream of a dam.
Bend or Straight section influence	Most of the largest gains and losses occur at bends.	No clear influence. Dam proximity is the control.
Ability to predict location, direction and relative magnitude of future XS change	Low	High

Discussion

The results show distinctly different cross-section area responses between the grazing treatments and the beaver treatments. The beaver dam-controlled reaches showed large magnitude increases or decreases in cross-section area depending on the integrity of the beaver dams and proximity to a dam. A similar strong signal, however, did not emerge in the annual rates as a function of the grazing treatments (Figure 15). Large reductions in grazing pressure due to exclosures did not result in a corresponding pattern of large reductions in cross-section area. Of the 90 cross-sections located in grazing treatments, 87 (97%) had annual percent changes in their baseline area less than or equal to 10 percent (Figure 16). And except in the case of cross-sections with areas less than 0.5 m^2 the annual rates were well below the target rates required to hydrologically reconnect the stream and the valley floor within a 10-year period (Figure 17). While the statistics and the dot plots indicate some differences between the new elk exclosures and the other four grazing treatments, the differences are small.

Explanations for the Similarity in Annual Rates of Cross-section Area Change Despite Differences in Grazing Pressure

The lack of variation in the annual rates of cross-section area change as a function of grazing treatment was unexpected. Three factors were considered as possible causes of the minimal contrast: 1) lack of time, 2) lack of sediment or absence of bedload, and 3) lack of an effective sediment trapping mechanism. The examination of these factors addressed the final research question: "What factors limit the ability of streams to hydrologically reconnect with their valley floors?"

Lack of Time

My study examined channel changes over a two-to-five year period in the early years of a reduction of grazing pressure. Thus one possible explanation of the minimal difference is that not enough time has passed. Therefore, I examined the results from other exclosure studies to determine if additional time resulted in 1) greater differences in channel morphology inside and outside exclosures and 2) a consistent pattern of difference. Only those exclosure studies that measured changes in the geomorphic or hydrologic bankfull width and/or area were considered in the analysis in order to compare my results with like features. Exclosure studies that used wetted width as their channel-width parameter were not considered in the analysis because of their sensitivity to discharge (e.g. Platts and Nelson 1985; Stuber 1985; Myers and Swanson 1996; Clary 1999). My decision to restrict exclosure comparisons to those with information on the geomorphic or hydrologic bankfull widths narrowed the number of exclosure studies that could be evaluated to five studies (Winegar 1977; Clifton 1987; Medina and Martin 1988; Kondolf 1993; Magilligan and McDowell 1997). All five of these studies considered the contribution of cattle only and did not mention whether elk were or were not contributing to channel change. Two of these exclosure studies used the space-for-time substitution method (Kondolf 1993; Magilligan and McDowell 1997). The other three studies used either repeat surveys (Winegar 1977; Medina and Martin 1988) or combined historic photographs with a later survey (Clifton 1987) to evaluate change.

No consistent patterns in channel morphology inside and outside the exclosures emerged from these five studies, and therefore they were unable to help identify the role of time in my results. Kondolf (1993) measured channel widths inside and outside a 24-year-old exclosure in the White Mountains in California and found minimal differences in width despite greater vegetation inside the exclosures. Magilligan and McDowell

(1997) measured bankfull channel width inside and outside four exclosures in eastern Oregon. The exclosures ranged in age from 14 to 30 years. Bankfull channel widths inside the four exclosures averaged 0.9 to 1.2 m narrower than in the adjacent grazed reaches in all but one case where the difference was even greater (Magillian and McDowell 1997). They suggest that the channels inside the exclosures have narrowed. However, the space-for-time substitution method makes it difficult to determine process and direction of change in the absence of baseline data. An alternative explanation for the differences inside and outside the exclosure fences is that over the last 14 to 30 years continued bank trampling outside the exclosures has caused these reaches to widen. The cross-sections were resurveyed six years later in three of their study areas. The limited resolution of the initial cross-section surveys prevented identifying the directions and rates of channel change over the intervening six years except at Camp Creek. At Camp Creek the channel widening outside the exclosure was pronounced enough that it was visible on the cross-sections (Mowry 2003). One cross-section inside the Camp Creek exclosure also increased in width. The remaining four exclosure cross-sections appeared stable based on the limited resolution of the initial survey (Mowry 2003).

Medina and Martin (1988) resurveyed cross-sections over a nine-year period (1977 to 1985) in exclosed and lightly grazed reaches in southwest New Mexico. They found that all cross-sections increased in channel width. They attributed the increases in channel widths to a large fire in 1951 that occurred in the headwaters, followed by a series of subsequent storms that led to channel adjustments as a sediment pulse moved downstream. They did not considered cattle grazing pressure an influence as it was negligible over the study period and the allotment had been rested four out of the seven years prior to the study (Medina and Martin 1988). No information was provided on the potential elk grazing pressure. Finally, Clifton (1987) and Winegar (1977) found high rates of bed aggradation and rapid vegetative recovery inside their exclosures compared to outside their exclosures. Beavers, however, were present in both exclosures and, based on the results from Price Creek and other studies (Apple et al. 1984; Johnston and Naiman 1990), beavers were probably responsible for the accelerated rates of cross-section area reductions and vegetative recovery.

While these five studies do not answer the time question, they provide lines of inquiry that may partially explain the minimal response and lack of variation in channel response despite reductions in cattle grazing pressure. For example, it is entirely possible that the differences in the channel width patterns found by Kondolf (1993) and Magilligan and McDowell (1997) reflect pre-exclosure conditions only and have no treatment implications. Under this scenario, these channels are stable under the current cattle-grazing pressure. Their current channel area and morphology reflect channel adjustments made during the late 1800s through the 1940s when grazing pressure was much higher than it is today. It is also possible that site-specific variability, such as the cohesiveness of the banks, bank height, the composition and amount of sediment input into the channels, and the type and distribution of vegetation are controlling how the channels respond to reductions in grazing pressure. In reaches with composite and/or non-cohesive banks, grazing pressure outside the exclosures will facilitate channel widening through bank trampling and vegetation reductions (Trimble and Mendel 1995;

Knighton 1998), in addition to widening occurring through instream erosion. In contrast, the banks inside exclosures should eventually stabilize narrow as vegetation becomes established on the bars and banks, and in time possibly narrow if sufficient sediment is available.

Differences in bank vegetation and bank stability in grazed and rested reaches were noted on the Rio de las Vacas in northern New Mexico (Rinne 1988). Banks inside the two exclosures were totally stable while 64 percent of the banks in the downstream grazed reaches were unstable. Stream-bank vegetation and overhanging vegetation were also greater inside the exclosure (Rinne 1988). Gunderson (1968) found a similar pattern in Rock Creek in Montana and Wyoming. Again, greater channel widths in the grazed versus rested reaches were accompanied by lower vegetative cover in the grazed reaches. He attributed the difference in widths to bank instability in the grazed reaches. Kondolf (1993) observed greater vegetation inside the exclosure, but found no difference in channel widths. This lends support to the suggestion that factors in addition to grazing pressure are contributing to his results.

The varying results of the five exclosure studies, combined with my cross-sections, suggests that time is not the key factor determining rates and directions of channel change inside the exclosures. The two other factors suggested at the beginning of this section – lack of sediment and lack of a sediment trapping mechanism -- may be more important and are discussed below.

Lack of Sediment

While the channel responses to reductions in grazing pressure were mixed, the impact of beavers on the channel cross-section areas was not. Beavers clearly accelerated bed aggradation and cross-section area reduction in the Price Creek exclosures (this study). Beavers are also implicated in the rapid rates of bed aggradation and vegetative recovery noted at Camp Creek (Winegar 1977) and Wickiup Creek (Clifton 1987) – changes that have been observed in other places in the presence of beavers (Bailey 1936; Apple et al. 1984; Johnston and Naiman 1990). The presence of beavers in these four exclosures helped answer the question regarding whether my sites were sediment starved or not.

A comparison of changes at some of the Price Creek beaver-dam-controlled cross-sections and non-beaver-dam-controlled cross-sections located downstream showed noticeable differences in the amount of sediment deposited at each site. Cross-sections in close proximity to intact beaver dams had high annual reductions in cross-section area (-0.58, -0.39, -0.22 m^2/yr, Figure 13), while cross-sections in the non-dam controlled reaches were minimal (most less than -0.01 m^2/yr) (Figure 11). This difference in annual rates of cross-section area reductions between the dam-controlled and the non-dam controlled reaches was not simply a matter of cross-section location. Evaluation of the cross-section graphs for 17 and 18 (non-dam controlled sites) showed no change in cross-section area between 1995 and 1998 despite the remobilization of large amounts of trapped sediment upstream once the dams failed (Figure 14). This lack of change at cross-section 17 and 18 means that the sediment moving through Price Creek as suspended load, and in the absence of a trapping mechanism was transported through the system leaving the impression that the system was sediment starved.

Suspended sediment or bedload samples were not taken at my study sites. However, at Price Creek, the beaver dams provide information on both sediment availability and its mode of travel. The availability of sediment could not be addressed as directly at my other three streams, but the results from Price Creek, along with knowledge of the bank composition and presence of bank failures at my study streams, means that sediment is entering these streams and moving as suspended load. The repeat surveys on Price Creek provide strong evidence that the lack of difference in annual rates as a function of grazing treatment is, at least in part, the result of sediment moving as suspended load.

Evidence for a beaver influence in the exclosures on Wickiup Creek and Camp Creek is more circumstantial than the repeat surveys on Price Creek. The Wickiup Creek exclosure was built in 1938. By 1948 old photographs document that the channel banks and the meadow inside the exclosure had revegetated and that the channel bed had aggraded approximately 0.6 m. After about 50 years the bed had aggraded one meter and the channel had narrowed inside the exclosure from a mean width of 5.25 m to 3.5 m (Clifton 1987). Clifton (1987) suggested that bed aggradation occurred as the result of cattle removal and rapid vegetative recovery on the banks and valley floor. She noted, however, that a portion of the exclosure was being affected by beaver activity at the time of the 1986 survey. Beavers were identified as being in part responsible for bed aggradation though their current effect was localized, affecting only a 100-meter reach within the exclosure (Clifton 1987). This information however when coupled with the rapid revegetation of the valley floor from 1938 to 1948, suggests that beavers may have been more influential in the bed aggradation and vegetative recovery than previously thought.

A review of Forest Service files revealed that in 1935 willows were planted and a male and female beaver released in the Wickiup Creek exclosure, or close by, based on an old photograph and a section/township/range location (Edwards 1939). The colony disappeared sometime during winter 1937 and spring 1938, apparently due to a food shortage. Sometime between 1938 and 1947, beavers re-entered the upper watershed of Wickiup Creek. The colony was small and having a problem with inadequate water supply during the summer (USDA Forest Service 1947). A recommendation was made for removal, but no information was located indicating whether the recommendation was carried out.

The documented presence of beavers during the period of 1935 to 1948 provides an explanation for the rapid reduction of channel area and expansion of the valley-floor riparian vegetation noted by Clifton (1987). The magnitude of the changes noted by Clifton (1987) are similar to those documented by other researchers when beavers reentered drainages (Bailey 1936; Apple et al.1984; Johnston and Naiman 1990), a magnitude and speed of cross-section area reductions that is absent in exclosures where the only change has been the removal of grazing pressure.

The Camp Creek cattle exclosure was built in stages, beginning in 1965. By 1974 about four miles of stream had been fenced off from cattle (Winegar 1977). The regrowth of native vegetation was rapid. Reductions in sediment loads of 48 to 79 percent were measured in 1972 and 1973 as the stream passed through the exclosure. The channel bed was measured at one location and found to have aggraded 0.9 m (36 inches) between 1966 and 1975 (Winegar 1977). Winegar (1977) attributed the reductions in suspended sediment load and bed aggradation to the development of riparian vegetation in the channel, but the timing of his measurements also coincided with the arrival of beavers inside the exclosure, suggesting a more than one contributing factor. Beavers were first noted in 1971 when they constructed a dam at the upstream end of the exclosure having been absent from the area since at least 1963 (Winegar 1977). By 1973 they had eight dams within 3.5 miles of fenced channel. The presence of the dams prior to the measurement of sediment deposition in 1975 and the reductions in suspended sediment strongly suggests that the dams played a key role in accelerating the rates of channel bed aggradation and riparian vegetation recovery and aided in the reduction of the suspended sediment load.

The contribution of beavers to the channel changes in the exclosures on Wickiup and Camp Creeks and in the two exclosures on Price Creek does not negate the importance of removing cattle grazing pressure, but underscore the important contribution of beavers and beaver dams toward stream restoration. The presence of bed aggradation inside the exclosures with beavers, but not upstream or downstream of the four exclosures, indicates that sediment was indeed present in these systems but traveling through the non-beaver dam-controlled reaches as suspended rather than bed load. The consistently higher rates of bed aggradation in these beaver-dominated exclosures compared to exclosures that do not contain beavers indicate that beavers are key to accelerating the hydrologic reconnection of the stream and valley floor and improving water quality by reducing suspended sediment loads.

The evaluation of sediment availability as a factor limiting cross-section area reductions at Basin Creek, Muddy Creek and the White Mountains' streams could only be addressed qualitatively because there were no beaver dams. Instead I used information about the sources and composition of the sediment input into the channel, their likely mode of transport (suspended or bedload) and the magnitude of the sediment input required to reduce the channel cross-section area. All streams showed minimal bed aggradation or sediment deposition on channel bars. My study streams are small headwater streams that flow through gentle topography. Bank erosion, channel incision, and at Muddy Creek some hillslope gullying, are the primary sources of sediment inputs into these channels. The banks in all three areas are composed primarily of silts, clays and fine sands. Therefore, when sediment enters the stream, it is largely transported as suspended load. The potential for large-scale channel area reductions in my small headwater streams, even with additional time, will be small in the absence of mechanisms capable of trapping the suspended load.

Lack of Effective Sediment Trapping Mechanism

The presence or absence of an effective sediment trapping mechanism determines the rate, direction, and stability of the changes. Beaver ponds were very effective on Price Creek at trapping suspended sediment but are not the only mechanism capable of trapping this sediment. Vegetation can be very effective depending on its location, composition, and abundance. Its most effective locations are on the channel bed or on bars in close elevational proximity to the stream (Schumm and Lichty 1963; Burkham 1972; Winegar 1977; Pizzuto 1994; McKenney et al. 1995; Friedman et al. 1996; Scott et al. 1996 Zierholz et al. 2001). Therefore, channel geometry is important because it partially determines if bars and/or secondary channels are present or if the channel bed is exposed at low flow. In my non-beaver-dam-controlled reaches, most of the riparian vegetation occurs along the upper edge of the stream bank or along the valley-floor and stream-bank edge, locations that do not facilitate bank, bar, or bed accretion and aggradation. Channel bars exist in all of the study areas and most show some aggradation and accretion. However, at the time of the surveys, the bars were largely unvegetated, and so the contribution of the bar sediment towards long-term channel area reductions is uncertain because the bar stability is questionable.

The above three subsections examined the factors that might be limiting the ability of streams to hydrologically reconnect with their valley floors (lack of time, sediment, sediment trapping mechanism). Examination of the different exclosure studies and the minimal changes observed in this study under the different grazing pressures suggest that the role of time or lack of time is the least important of the factors controlling the rates and directions of channel change, thought its contribution remains uncertain until additional long-term repeat surveys are completed. However, the data do suggest that the lack of a grazing treatment signal in the study is partly driven by a lack of sediment and the lack of sediment trapping-mechanisms. The results in the Price Creek beaver dam-controlled reaches demonstrate that sediment is entering the system and moving through it but as suspended sediment. Documented bank failures on the study streams also demonstrate that sediment is entering the streams. However, whether there is enough sediment available to the watersheds to hydrologically reconnect the stream and valley floor along their entire lengths, even if a trapping mechanism was in place, needs to be examined. This question required estimating the amount of sediment that has been eroded from stream channels and determining the amount of sediment needed to reduce the geomorphic channels to their pre-disturbance channel areas.

Predicting Future Channel Changes in Areas Under Different Grazing Treatments

Basin, Price and Muddy Creeks and in the White Mountains are small headwater streams. The majority of the stream reaches studied have drainage areas less than 15 km^2 and their geomorphic channel widths and depths are less than 10 m wide and 1.5 m deep. The total length of stream examined in this study was about 5.4 km. A rough estimate of the cubic meters of sediment that has been eroded and removed from the system is about 8862 m^3 or about 1.6 football fields piled one meter deep with sediment (Appendix K). These streams reflect only a small fraction of stream length in the West, yet even in these headwater streams the amount of sediment required to reduce the current geomorphic channel reaches to their pre-disturbance channel area is substantial.

The challenges inherent in recovering the stream and valley-floor hydrologic connections on a large-scale become even more obvious when reviewing the published literature. Bryan (1928a) estimates that the Rio Puerco in New Mexico (15,540 km^2) had lost 487,144,150 m^3 of sediment over a 42-year period as a result of channel incision and widening. This volume is the equivalent of 90, 379 football fields piled 1 meter deep with sediment. Douglas Creek in Colorado (1, 070 km^2) incised 10 m and widened considerably between 1882 and 1961 (Womack and Schumm 1977), the Cimarron River in southwestern Kansas (7407 to 16,589 km^2) widened from an average of 15 to 366 m along more than 200 km of river between 1874 and 1939 (Schumm and Lichty 1963, Figure 25), and the Gila River in the Safford Valley near Safford, Arizona (20,450 km^2) widened from an average of 43 to 610 m between 1875 and 1916 (Burkham 1972). These examples of historic channel widening underscore the magnitude of the sediment that has been removed from stream channels and transported downstream over the last 170 years. Other studies on arroyos in the American Southwest have documented additional places where extensive channel incision and widening have occurred since the early 1800s (Gregory 1917; Gregory and Moore 1931; Bryan 1927, 1928a; Colton 1937; Bull 1964; Cooke and Reeves 1976).

In some cases, channel reaches will decrease in cross-section area after a period of channel widening and incision. In those cases, it is important to examine these channel reductions within their larger watershed contexts. For example, the portion of the Cimarron River studied by Schumm and Lichty (1963) decreased in channel widths between 1939 and 1954 (Figure 25), and the Gila River in the Safford Valley narrowed from an average of 610 m wide to an average of 122 m between 1918 and 1970 (Burkham 1972). Reductions in channel width of this magnitude require large inputs of sediment. The source of that sediment would have been erosion occurring in tributary streams and upstream riverbanks and/or hillslope erosion. Therefore, while portions of the Cimarron and Gila Rivers decreased in channel width, they likely did so at the expense of upstream portions of their drainage networks that widened and incised, or as a result of considerable hillslope erosion and/or mass wasting. Consequently, the ability to restore the stream and valley floor hydrologic connection at the watershed, rather than reach, scale solely through the fluvial processes of sediment aggradation and accretion is unlikely to occur. The recovery process is hampered both by the lack of sediment trapping mechanisms along many miles of stream and because the amount of sediment required to accomplish this task does not, at present, exist.

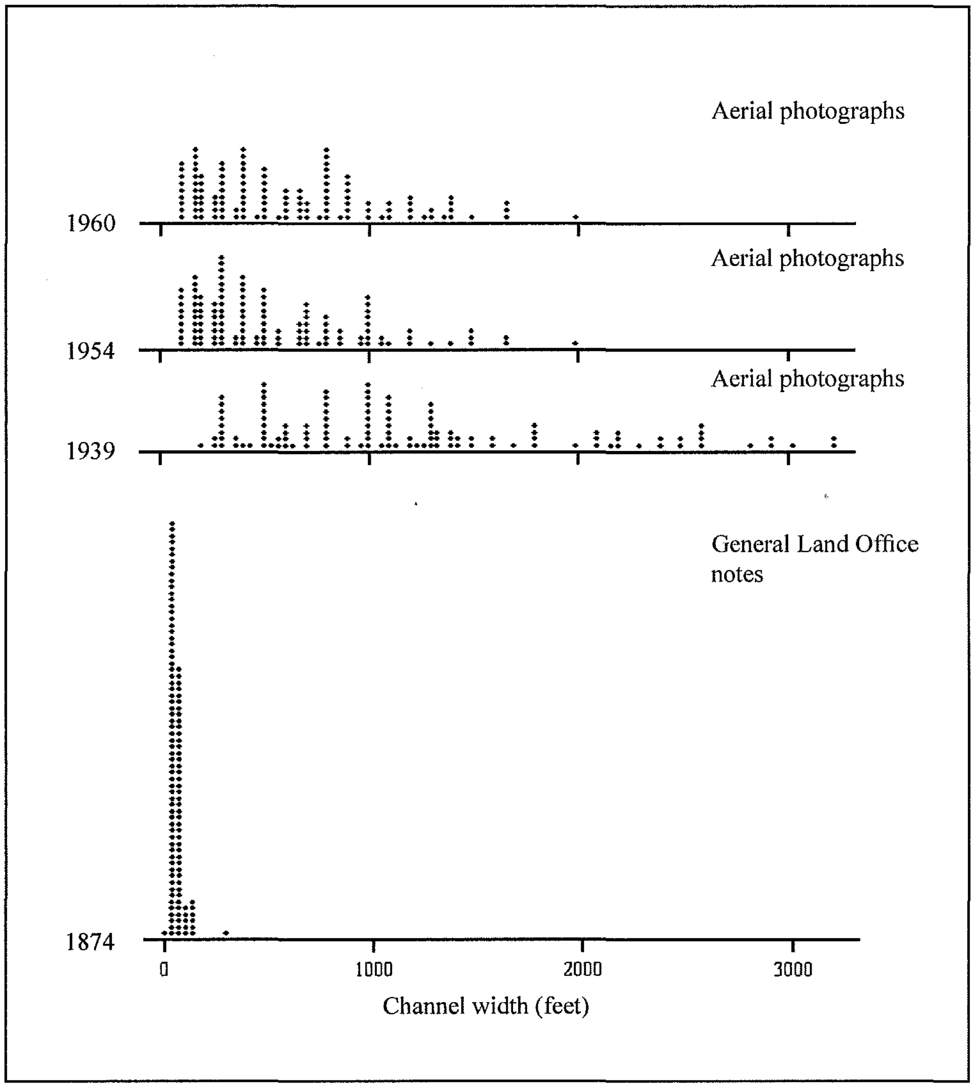


Figure 25. Changes in the channel widths of the Cimarron River in southwestern Kansas over time (N = 120). Figure generated using data presented in Schumm and Lichty (1963).

Beaver Dams as a Mechanism for Accelerating Restoration of the Stream and Valley-Floor Hydrologic Connection

The results from Price Creek and other exclosure studies in small drainages with and without beavers indicate that there are a number of factors limiting the ability of streams to hydrologically reconnect to their valley floors. The removal or reduction of grazing pressure from the riparian zone and stream banks is a critical first step because it allows for vegetative recovery along the stream banks and the cessation of bank trampling. The results are increased bank stability and the development of riparian vegetative communities. However, reduction of grazing pressure in these lower-order streams alone will not be sufficient to achieve the hydrologic reconnection within 10 years, or perhaps even longer. Many of these small streams lack sufficient sediment inputs and the sediment trapping mechanisms needed in order to reduce the geomorphic channel capacity to its pre-disturbance capacity. Instead, restoration of the hydrologic connection in many lower-order streams will require the reestablishment of healthy beaver populations and their extensive dam networks. Beaver dams create ponds that store water and trap suspended sediment and bedload, reducing both the geomorphic channel capacity (deposited sediment) and the available channel capacity (ponded water and deposited sediment). It is the available channel capacity that is key in achieving hydrologic reconnection between the stream and valley floor. Therefore, even when sediment is limited, the ponds circumvent this limitation by keeping available channel capacity low via elevated water levels in the channel (Figure 19). The ponds influence both flood frequency and water table levels in several ways. First, the decrease in available channel capacity due to ponds combined with the hydraulic effects of the dams are expected to cause the streams to overflow their banks at lower discharges and therefore more frequently. An increase in the frequency of valley-floor flooding increases recharge volumes and frequencies leading to a rise in the valley-water table and an increase the moisture content of the valley sediments. Second, the ponds maintain and stabilize the elevated water tables (Apple et al. 1984), probably by decreasing or reversing the elevational difference (or hydraulic gradient) between the water surface in the stream and the valley water table.

The increased storage of water in the valley sediments throughout watersheds would eliminate two of three factors hindering the expansion of riparian vegetation and riparian ecosystems: low soil moisture and low water tables. The third factor is heavy grazing by cattle, and in some places elk. The lack of sufficient sediment inputs and the complexity and time-intensive nature of the sediment-vegetation feedback loops suggest that beavers may be the only way to hydrologically reconnect many lower-order and low gradient streams to their valley floors in a timely and cost-effective manner. Beavers build and maintain their dams for free (Naiman et al. 1986, 1988; Butler and Malanson 1995; Apple et al. 1984) or, one might say, in exchange for abundant cottonwoods, willows and aspen. The alternative to beaver dams is check dams built and maintained by humans at great initial and continuing financial costs (Heede 1966; Gellis et al. 1995; Shields et al. 1995), an expenditure of capital that is unlikely to occur at the watershed or region scale.

Beavers are the ideal ecological and economical agents for actively restoring stream-riparian systems in many first through fourth-order streams. At present, however, their ability to aid in restoring stream and riparian systems is severely restricted for two reasons. First, riparian vegetation is limited after decades of cattle and sheep grazing and farming and continues to be impacted by those activities. Beavers prefer to use willow, aspen, and cottonwoods as a food source and building material (Hall 1960; Apple et al. 1984; Olsen and Hubert 1994). Cattle and wild ungulates also prefer to consume these riparian species (Case and Kauffman 1997; Keigley 1997). The continued grazing of riparian vegetation types by cattle, and sometimes elk, that are needed by beavers to build and maintain their dams restricts the beavers' ability to restore the stream and valley-floor hydrologic connections and the complexity and stability of stream-riparian ecosystems. Thus the lack of abundant riparian vegetation is one of the key roadblocks to stabilizing and then restoring stream systems. The only way to solve this roadblock is to decrease livestock and wild ungulate use in these areas.

In the case of cattle, the solution to reducing cattle use of the riparian zone comes from land management agencies who must either decrease use levels in this zone or exclude them by fencing or complete removal from a watershed. In the case of wild ungulates, the solution appears to be the reintroduction of the wolf. Some researchers in Yellowstone National Park are seeing reductions in the amount of elk use of the riparian zones as a result of wolf reintroductions, and willows and aspen appear to be responding (Ripple and Larsen 2000). Wolf reintroductions represent the return of a key player essential for maintaining ecological balance and are an area worthy of considerable study.

At present, studies are still in their infancy. But even if the wolf were to return, in many places the magnitude of the loss of riparian vegetation is so great that even with reductions in ungulate use of the riparian zone, some vegetative assistance will be needed to jumpstart the process. This jumpstart may be in the form of supplying beavers with willows, cottonwoods and aspen until the system stabilizes (Apple et al. 1984) and/or deliberately planting the desired vegetation types.

There is, however, a second impediment to the recovery of beavers and their ability to be active agents of widespread stream/riparian restoration. This second obstacle is the social perceptions of many in ranching communities that beavers serve no purpose or are even detrimental to their operations. This attitude results in continued beaver trapping. As beavers are trapped and their dams fail or are deliberately destroyed, water levels rapidly drop in the stream (Figure 19) and sediment behind the dams erodes (Figure 13). The result is 1) the rapid loss of the hydrologic reconnection as the available channel capacity increases, and 2) lowered water tables as the hydraulic gradient between the stream and the valley water table once again increases. The result is a shift on the valley floor from wet meadows to dry meadows (Bryan 1928b; Bailey 1936; Schaffer 1941). The speed of these changes and their consequences for the quality of the stream and valley-floor hydrologic connection were well documented in the Price Creek cattle and elk exclosures.

Conclusions

Expansion and extensive restoration of stream-riparian ecosystems requires that streams and their valley floors become hydrologically reconnected and that the valley floors once again become the active floodplain. For this to occur, the geomorphic channel cross-section area must decrease to pre-disturbance dimensions. Reductions in channel area can occur through bank accretion, bed aggradation, and/or elevated water levels. The magnitude of historical channel enlargements, the extension and channelization of many drainage networks, and the removal of sediment trapping mechanisms (e.g. dense riparian vegetation, beaver ponds), however, places limits on the amount of large-scale reductions that can occur in the geomorphic channel area at the watershed scale via sediment deposition. Historical land uses have set in motion fluvial processes that continue to define the current stream conditions and trends throughout the West. Current cattle grazing, though much less than in the 1800s, continues to widen channels via bank trampling and impede the recovery of the riparian vegetation. The result is that the available channel capacity has continued to increase in areas grazed by cattle, and in some places elk.

Reductions or the removal of grazing pressure from the riparian zone and stream banks is a critical first step in the restoration of stream and riparian ecosystems because it allows for the recovery of riparian vegetation and the cessation of bank trampling. The recovery and expansion of riparian vegetation on the stream banks and channel bars is necessary to increase stream-bank/bar resistance to instream erosion. This minimizes further increases in available channel capacity via fluvial processes and halts the processes contributing to the stream-valley floor hydrologic disconnection. Expanded riparian vegetation also provides critical habitat to a variety of wild species and the necessary food and building materials for beavers. The cessation of bank trampling is equally important as it eliminates another mechanism by which streams widen and increase in their available channel capacity.

Restoration of stream and riparian ecosystems is a complex process. While reducing or eliminating grazing pressure from this zone is critical, this is not the only step that must be taken. In many places the amount of sediment being contributed to streams is less than the amounts needed to reduce channel area on the watershed scale even if vegetation were abundant along the banks and in the channel. Fortunately, beavers and beaver ponds can effectively circumvent the sediment and sediment trapping limitations in lower-order streams (< 5^{th} order). The ponded water rapidly reduces the available channel capacity. The result is that valley floors flood at lower discharges and therefore more frequently reestablishing the stream and valley floor hydrologic connection. Unfortunately, in larger-order streams, removing or reducing grazing pressure may be the only restoration option available because the streams are too large to have beaver dams. While the amount of channel narrowing will be small, and will occur at much slower rates compared to ponded systems, the cessation of grazing will allow vegetation to become established on the banks and channel bars. In addition to stabilizing the banks and bars and increasing their resistance to erosion, the riparian vegetation captures what sediment is flowing through the system. Therefore, the restoration of upper and lower watershed stream and riparian systems will require multiple approaches, and results and rates of recovery will be varied. However, in all cases, the first step is the removal or reduction of grazing pressure from the stream and riparian zone. Only then can the first step in the restoration process, vegetation reestablishment, begin.

In my study, the ability of the small headwater study streams to reconnect hydrologically to their valley floors has been severely compromised by the amount of sediment lost from the cross-sections, the type of sediment input into the stream (largely suspended sediment), and the limited sources of sediment (largely stream banks). In addition, when sediment inputs are the result of upstream bank failures, the result is a net increase in geomorphic channel capacity upstream. The failure of the dams at Price Creek, due to beaver trapping, severed the stream and valley-floor hydrologic connection and removed the sediment trapping mechanism in those reaches. The silt bars, exposed in these reaches upon dam failure and pond drainage, were unvegetated in 1998, and their long-term stability and contribution to cross-section area reductions is uncertain. Channel bars in the five grazing treatments were also largely unvegetated, and it is too soon to determine how quickly reductions in cattle and elk grazing pressure will result in stream-bank stabilization and riparian vegetation recovery on the banks. My study only captured the initial response to reductions in grazing pressure and changes in beaver activity and more surveys will be needed to capture longer-term trends.

The absence of sufficient sediment and/or effective trapping mechanisms to aid in the reduction of the channel cross-section area is ubiquitous throughout the West. Examination of the magnitude of the historical changes reveals enormous amounts of bank and bed erosion and large increase in channel cross-section. The magnitude of these increases suggests that further large-scale widening and incision is unlikely under the current climate regime, except in small headwater streams. Cattle grazing pressure remains a significant and direct influence on the evolution of channel morphology in these small streams as trampling shears off sections of fine-grained, relatively cohesive bank. In larger streams (> 5^{th} order), bank composition is often more heterogeneous than in small meadow streams. The heterogeneous bank composition, combined with the magnitude of the increases in available channel capacity, results in fluvial processes having a more important role in the evolution of these larger stream channels. These does not discount the importance of cattle grazing pressure on these larger systems, but reflects a shift in how cattle influence the continued evolution of channel morphology and the drainage network. In those stream systems where cattle grazing occurs, grazing continues to impede the recovery and the expansion of riparian zones by continually removing the woody plants and sedges. The loss of this vegetation limits the potential for beaver-dam building, sediment trapping, bank stabilization, cross-section area reductions and the eventual hydrologic reconnection of streams to their valley floors. The relative contribution of elk towards limiting vegetative recovery in these larger streams varies but in some places is substantial (Singer et al. 1994; Keigley 1997).

In addition to the increasing our understanding of how streams respond to reductions in cattle and elk grazing pressure and changes in beaver-dam integrity, the study highlighted some deficiencies in our current research approach. Often studies are short-term, one or two surveys at most. However, as this study shows, without multiple repeat surveys, the ability to estimate recovery times and identify processes is limited. A rate calculated from two surveys cannot be assumed to continue into the future. In addition, repeat surveys determine if the changes occurring reflect linear trends, episodic events or just transitory changes with no long-term influence on channel area. The study also underscores the importance of examining the data from multiple angles. In this study I used cross-section graphs and trend plots and analyzed the annual rates of change statistically and graphically. Statistical tests and descriptive statistics provided one method of evaluating the significance of the response, but these measures can overstate and obscure important processes and relationships if used exclusively because they reduce the complex changes visible on the graphs to a single numeric value. Therefore, the statistical tests and descriptive statistics need to be supplemented by methods that place the response of the "variable of interest" in a larger context that references the scale and feature being examined and the requirements of the system or species being studied. Therefore, future studies would benefit by using both statistical tests, descriptive statistics, and employing some form of the geomorphic significance concept when evaluating study results.

In conclusion, this study sheds light on how current and historical human land uses and natural processes continue to hinder the ability of streams to hydrologically reconnect with their valley floors. The study also provides methods for improving our understanding of those processes as well as accelerating the restoration process. In the end, true restoration, rather than technological fixes, requires shifts in our perceptions about flooding and a recognition and appreciation of the contributions made to human communities by wild communities (e.g. beavers and wolves, both targets of human predation) and natural disturbance regimes (e.g. overbank flooding). This requires a shift in our values, an expansion of our worldview, and a larger historical perspective when evaluating the impact of long-term and chronic disturbance by humans.

The restoration of the ecological function of stream-riparian ecosystems becomes ever more urgent as our concerns over water quality and quantity, declining fisheries and climate change increase and become increasingly politically volatile. The ongoing bank retreat visible on the graphs and in the field in areas grazed by cattle (and by default accessible to elk), indicates that the reduction of grazing pressure is a critical first step in the stabilization of stream systems and their eventual recovery. However, this is but the first step. Reductions in channel area and vegetation recovery are expected to be slow to non-existent and may often be spatially limited. This does not discount the importance of reducing grazing pressure in the riparian zone, but simply underscores that the magnitude of historical changes to channels has left us with a more complex restoration challenge. The return of beavers to our upper watersheds in many places is an essential ingredient and capable of accelerating the stream and valley floor hydrologic reconnection. The combination of beavers with reductions in ungulate use of the riparian zones can produce rapid recovery of sustainable stream and riparian ecosystems capable of supporting humans, wildlife, fisheries, and plants for the long-term.

CHAPTER III

THE INFLUENCE OF BEAVERS AND BEAVER TRAPPING ON WATERSHED HYDROLOGY, CHANNEL MORPHOLOGY, VEGETATION, AND DRAINAGE NETWORK CHARACTERISTICS: A CONCEPTUAL MODEL

Introduction

Beavers are a keystone species in stream-riparian ecosystems (Naiman et al. 1988). Their numbers on the North American continent are currently estimated at 6 to 12 million, a sharp reduction from the 60 to 400 million estimated to have existed prior to Euro-American trapping (Naiman et al. 1988), but an increase over the trapping era when beavers were driven close to extinction (Phillips 1961; Ray 1975; Naiman et al. 1988). Trapping was systematic and temporally concentrated within individual watersheds and regions, beginning in the 1600s on the East Coast and along the Mississippi and Missouri Rivers, early 1700s on the West Coast, and moving into the Interior United States in the late 1700s and early 1800s (Phillips 1961; Figure 26). As examples of the numbers of beavers trapped, the Hudson Bay Company in Vancouver, Washington received 405,472 beaver pelts between 1834 and 1837 (USDA Forest Service 1937) while its office in California took 10,860 beavers from the San Francisco Bay area alone between 1830 and 1839 (Phillips 1961).

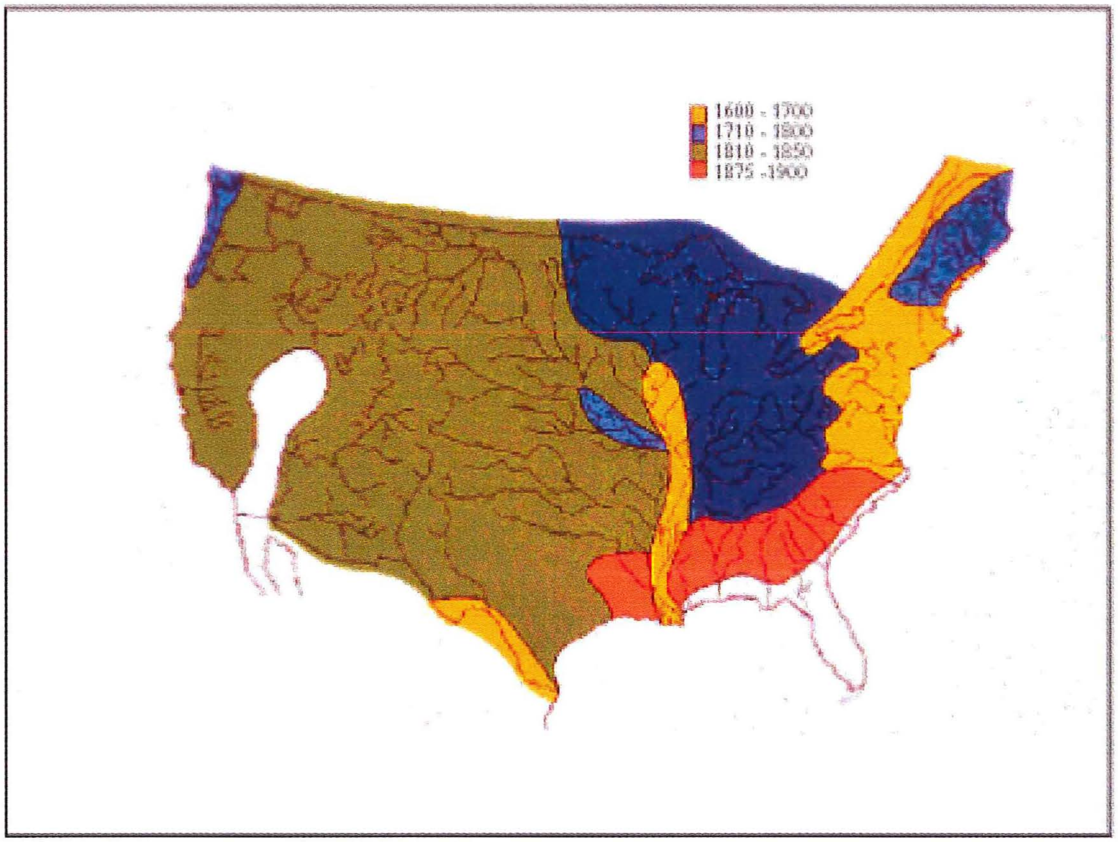


Figure 26. Timing of beaver trapping in the lower 48 states. Map courtesy of Jim Sedell (2001).

Trapping occurred prior to Euro-American settlement in all but the East Coast, resulting in a limited amount of information on how watersheds responded to the wholesale removal of beavers. Some researchers have argued that the long-term presence of beavers on the landscape, and their rapid removal by Euro-American and Native American trappers in response to the demand for beaver pelts by the European market, had enormous impacts on stream ecosystems hydrologically and ecologically (Ives 1942; Dobyns 1981; Parker et al. 1985; Naiman et al. 1986, 1988; Johnston and Naiman 1990; Fouty 1996). These researchers have suggested that beaver trapping was a major Euro-American disturbance of watersheds and that beavers and beaver trapping need to be integrated into our discussions and studies of fluvial processes and the evolution of current stream-riparian systems.

Several studies have examined portions of the beaver story (Dobyns 1981; Parker et al. 1985; Naiman et al. 1986, 1988; Johnston and Naiman 1990), but an overriding, integrated conceptual framework of how beavers and beaver trapping influence stream channel morphology, local hydrology (water tables), and flood hydrology (flood magnitudes and frequency) does not exist. This chapter, therefore, presents a conceptual model of the fluvial processes and the geomorphic and hydrologic responses of streams to beaver colonization and beaver trapping or abandonment of a drainage. The chapter also examines why historic beaver trapping as a watershed-scale disturbance has been ignored in the fluvial geomorphic literature and how that omission has affected the discipline.

The conceptual model presented in this chapter is similar in structure to Cooke and Reeve's (1976) deductive model of arroyo formation in the Southwest in that both models examine the hydrologic and geomorphic response of streams to Euro-American disturbances. The disturbances examined, however, are different. Cooke and Reeves (1976) focused on post-settlement Euro-American disturbances such as livestock grazing, logging, agriculture, and road building while I focus on a pre-settlement Euro-American disturbance, namely beaver trapping. My model predicts the hydrologic and geomorphic changes that accompanied beavers entering and beavers abandoning or being removed from a drainage. The model is based on the scientific literature and my own research. The model is presented in two parts. The first half of the model (beavers enter a drainage and establish a long-term presence) provides the snapshot of the geomorphic appearance and hydrologic behavior of a watershed prior to trapping and the drainage network that evolves. It is only with this backdrop firmly in place that the impact of trapping can be explored. The second half of the conceptual model presents the hydrologic and geomorphic changes that occur as beaver numbers rapidly decrease in a watershed and the resultant drainage networks that develops. A drainage network in which beavers have become established will be referred to in the text as a "beaver-dominated system." A drainage network in which beavers have been trapped out of, or have abandoned the area, will be referred to in the text as "channel-dominated system."

The model presented here explains the discontinuous arroyo, the active tributary incisions, and the relative abundance of wetlands and ponds observed by early expeditions and General Land Office surveys that post-date trapping but pre-date Euro-

American settlement and grazing. I will discuss the importance of placing our conceptual models, hydraulic geometry relationships, and studies of past changes in a broader historical and disturbance context and what have been the ramifications of not placing them within this context. I will discuss the implications of including beavers and beaver trapping in our studies of fluvial processes and how that alters our interpretation of pre-historic landscapes and our understanding of the evolution of stream and riparian ecosystems and their sensitivity of climatic variability. I will close this chapter with suggestions for future research.

Background

The development of a conceptual model of stream morphologic and hydrologic response to a long-term beaver presence, and subsequent beaver trapping, was based on five observations. First, observations of modern-day stream reaches with beaver dams are striking in their abundance of water and riparian vegetation compared to reaches without beaver dams, even when separated only by a fence line. This difference is particularly striking during times of drought and the summer low-flow season. Second, the journals from the beaver trappers (Pattie 1831; Work 1945; Ogden 1950) and the Lewis and Clark expedition (Burroughs 1961; Lewis and Clark 1970) describe complex, multi-channeled streams with dense riparian vegetation along the channels and wetlands and marshes on the valley floor, even in the Intermountain West and Southwest. These descriptions are in sharp contrast to current conditions in which most streams in these areas are single-thread and entrenched or braided and entrenched, with their valley floors covered in drought-tolerant species.

Third, prior to Euro-American trapping, beavers are estimated at 60 to 400 million on the North American continent. Yet by the early 1900s, they were nearly extinct (Naiman et al. 1988). The extend of beaver influence on local hydrology and vegetation suggests that so concentrated a removal of this number of beavers must have impacted watersheds as thousands of beaver dams failed and were not repaired. Thousands of dam failures would create thousands of localized base-level drops for points upstream of the failed dams (Dobyns 1981; Parker et al. 1985; Chapter 2). The result should be the development of a channelized drainage network as streams eroded the fine sediment trapped behind the dams, causing rapid increases in channel capacities as ponds drained and the sediment was remobilized. Numerous examples exist documenting the speed at which channel incision, widening and headward migration can occur (Cooke and Reeve 1976), suggesting that the transformation of the drainage networks could have happened within a couple of decades.

Fourth, early military and scientific expeditions to the Southwest and Colorado Plateau in the 1840s through 1870s noted the existence of discontinuous arroyos, often terminating at wetlands or unincised reaches (Bryan 1928a; Bull 1964; Cooke and Reeves 1976), as well as actively incising tributaries (Dellenbaugh 1912). An explanation for these early observations has remained elusive. The general consensus is that the channelization was a watershed response to recent a climate shift and/or random frequency-magnitude variations because these observation pre-date Euro-American settlement and grazing in the area (Bryan 1928a; Bull 1964; Cooke and Reeve 1976). However, all of these areas had been systematically trapped 10 to more than 30 years prior to these expeditions. Finally, discussions of the influence of beavers and beaver trapping on fluvial systems are completely missing from the discipline of fluvial geomorphology, making it an intriguing area for study (Dunne and Leopold 1978; Knighton 1998).

These observations led me to conclude that Euro-American beaver trapping was a major Euro-American disturbance, one that occurred on a regional and watershed scale across the North American continent. In most places trapping precedes all other Euro-American disturbances to watersheds, riparian areas, and stream systems. The absence of abundant documentation showing how watersheds responded to this rapid depopulation of beavers provides a challenge when attempting to reconstruct historic stream ecosystem response to early Euro-American beaver trapping. Trapping predates Euro- American settlement, General Land Office surveys, and the early scientific and military expeditions by at least a couple of decades in most places, and so observations are few. The one exception is New England in the 1600s where settlement and trapping co-existed in time. Journals from New England during this period provide intriguing but limited references to vegetative and ecological changes as a result of beaver removal (Cronon 1983).

Research exploring how beavers in the present day alter channel morphology, hydrology and vegetation characteristics is increasing. Beedle (1991) and Burns and McDonnell (1998) examined storm hydrographs for small headwater streams (≤ 6.2 km^2) in southeast Alaska and in New York respectively. They found varying levels of reductions in flood magnitudes from no reductions for a single pond to an increasing amount of reduction in flood magnitude as the number of ponds in series increased. Johnston and Naiman (1990) documented large increases in open water and wetlands as a result of beavers reentering a drainage basin in Minnesota. Naiman et al. (1986) examined the impact of beavers on the structure and dynamics of aquatic and terrestrial ecosystems in two nearly pristine watersheds in Quebec (i.e. largely untrapped, logged, grazed or mined), and discussed a conceptual model of a stream-river continuum that is not exclusively a channelized system but incorporates the presences of ponds and wetlands. Chapter 2 documented rapid reductions in channel-water levels and an increase in available channel capacity as beaver dams failed, ponds drained, and previously trapped sediment eroded in Montana (this study). Chapter 2 also quantified rates and directions of change in channel cross-section area and depths of channel incision as dams failed and sediment was remobilized. Other researchers have documented channel scour downstream of beaver-dam failures (Hillman 1998; Kondolf et al. 1991). These studies are beginning to provide the empirical data needed to verify long-standing assumptions about the ability of beaver ponds to effectively trap sediment and reduce flood magnitudes -- assumptions that have been "based primarily on qualitative observations in the literature from the first half of the century (Meentemeyer and Butler 1999, p. 437)." The studies also underscore the speed and magnitude of the channel morphologic and hydrologic changes that occur in response to changes in beaver-dam integrity.

Conceptual Models of Fluvial Systems in Drainages without Beavers

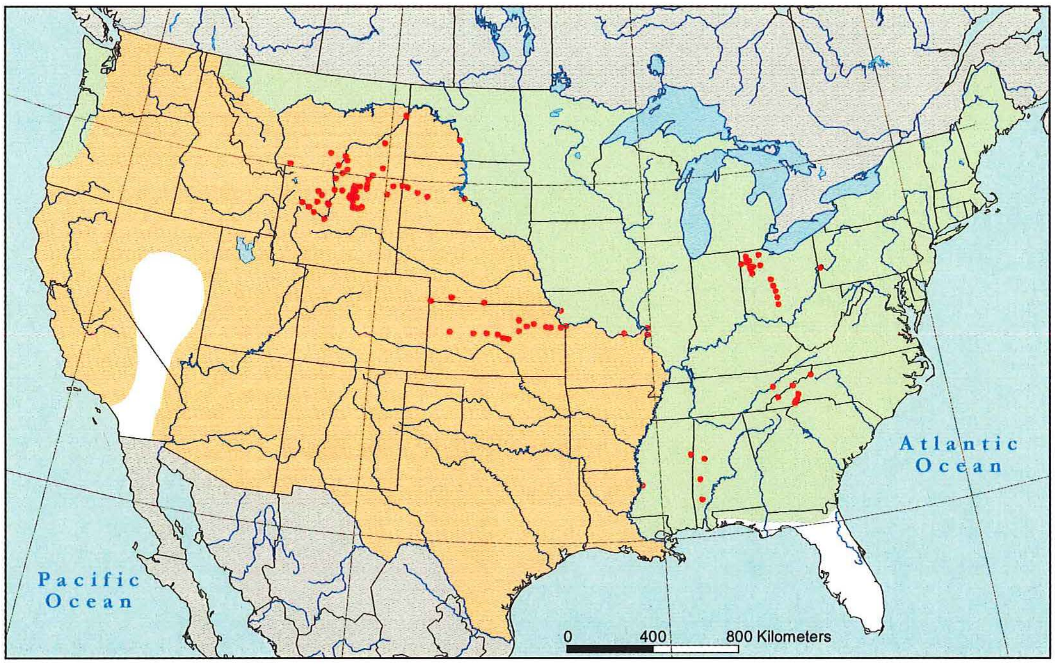
The majority of our current conceptual models for fluvial systems and the hydraulic geometry relationships focus on channel-dominated systems. Examples of conceptual models and predictive relationships include Cooke and Reeves' (1976) deductive model of arroyo formation in the Southwest, Knighton's (1998) model of the interrelationships in fluvial systems, Leopold and Maddock's (1953) hydraulic geometry relationships, and Love's (1979) conceptual model of the causes and time scales of fluvial adjustments in Chaco Canyon. Cooke and Reeves' (1976) deductive model and Leopold and Maddock's (1953) hydraulic geometry relationships are of particular interest to this paper and are discussed in more detail below and later in the chapter.

Cooke and Reeves' (1976) deductive model shows how land use, climatic events and random-frequency events (e.g. a 100-year precipitation event) can decrease vegetation, increase runoff, decrease the resistance of valley-floor soils to erosion, increase local channel instability, and lead to arroyo formation. Yet Euro-American beaver trapping, the earliest Euro-American disturbance, is missing from their model. With the loss of beavers, dams would have failed and not been repaired, making stream-riparian systems less stable and more sensitive to alteration from later random-frequency events, climatic variability, and other Euro-American land uses. The specifics of these changes will be discussed in the conceptual model portion of the chapter.

Leopold and Maddock's (1953) hydraulic geometry relationships are an excellent example of how the timing of historical events influenced the development of conceptual models and empirical relationships of fluvial systems. Their hydraulic geometry relationships were based on stream-gage data collected over a period of seventy years from gaging stations all over the United States (Figure 27a). Leopold and Maddock (1953) deliberately chose rivers from a diversity of geographic locations and physiographic and geologic types and sizes because their intent was to examine the channel morphology, stream velocity, suspended sediment loads, and discharge information for general trends. Their resulting hydraulic geometry relationships have become integral to the study of fluvial geomorphology. These relationships formed the basis for our current understanding and interpretation of the shape of "natural" stream channels and how width, depth, velocity, and suspended sediment loads vary with discharge.

Subsequent researchers have refined Leopold and Maddock's (1953) relationships by sorting their data based on bank cohesion, bank composition (e.g. coarse versus fine), abundance of vegetation, or amount of suspended load. This has resulted in the development of hydraulic geometry relationships or exponents that are more site and feature-specific (see Knighton 1998, p. 173, 184). However, all of the studies are determining hydraulic relationships using data collected from watersheds that have been greatly altered by historical and on-going large-scale human land uses. When the stream data are placed in the context of historical Euro-American disturbances (Figure 27), it becomes clear that the hydraulic geometry relationships developed represent neither healthy, functioning streams in which the valley floors are the active floodplains nor pre-beaver trapping relationships.

a)



b)

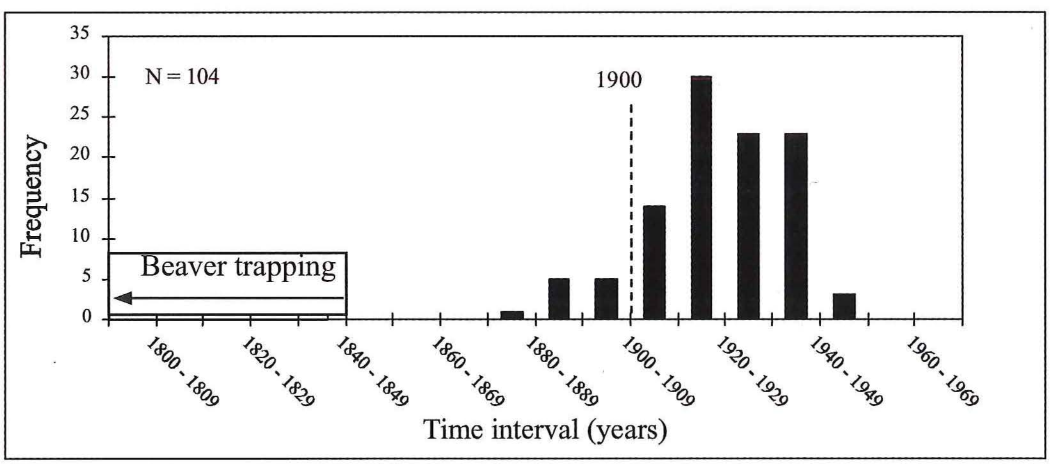


Figure 27. Spatial and temporal distribution of the stream gages used by Leopold and Maddock (1953) and the generalized timing of beaver trapping in the lower 48 states. a) Spatial distribution of the stream gages. Gages are represented by RED dots (N = 104), GREEN = Beaver trapping from mid-1500s to 1785, ORANGE = Beaver trapping from 1810 to 1850, WHITE = No trapping. b) Installation dates for stream gages. Source of installation dates is the U.S. Geological Survey website (http://water.usgs.gov). Eight of the gages listed in Leopold and Maddock (1953) were not listed on the web site. Source of beaver trapping dates is Phillips (1961). Map by author.

The majority of the stream gage data evaluated by Leopold and Maddock (1953), and therefore those used by later researchers, were installed after 1900 (Figure 27b) and post-date trapping, grazing, logging, and other Euro-American settlement activities. These land uses reduced upland, valley-floor and stream-bank vegetation, increasing storm runoff while at the same time reduced the resistance of the valley floors and stream banks to erosion. The land uses directly and indirectly led to channel incision, widening, and straightening. With the increase in available channel capacity, overbank flooding decreased and valley-floor detention storage was lost. The loss of valley-floor detention storage resulted in an increase in flood magnitude and a decrease in flood duration for a given storm. It also resulted in an increase in the frequency of large magnitude floods. The timing of the land uses and the stream gage installations means that what Leopold and Maddock (1953), and others, have captured in their data sets are the hydraulic geometry relationships of altered, highly disturbed watersheds. These relationships do not reflect fluvial systems with abundant beaver ponds and wetlands in the upper watersheds. The relationships also do not reflect fluvial systems containing streams with pre-disturbance channel capacities, well-vegetated stream banks, and excellent hydrologic connections between the streams and their valley floors in the lower watersheds. Consequently, by not placing these data sets in their historical context, we have misinterpreted the meaning of these relationships and missed the magnitude of the change that has occurred over the last 200 to 300 years since Euro-Americans arrived on the North American continent.

Conceptual Models of Fluvial Systems in Drainages with Beavers

Five conceptual models exist that present different aspects of the influence of beavers and beaver trapping on fluvial systems. Naiman et al. (1988) and Johnston and Naiman (1990) examined changes in the vegetation communities and local hydrology on the Kabetogama Peninsula, Minnesota, as beavers returned to the area and expanded their range. Their studies quantified complex and dynamic shifts in vegetation patterns and local hydrology, increased abundance of different ecological units (e.g. wetlands, wet meadows, bogs), and increased surface and subsurface water over 46-year period as the drainage network changed from a channel-dominated to a beaver-dominated system.

Naiman et al. (1988) also provides a conceptual model showing the ways a section of stream can evolve as a result of changes in beaver-dam integrity. The section of stream moves from a channelized stream to a pond and then either into a meadow or back to a channelized stream depending on whether the dams fail or remain intact. While Naiman et al. (1988) and Johnston and Naiman (1990) explicitly state that beaver trapping altered stream ecosystems, their work records and analyzes only the vegetative and local hydrologic changes in response to beavers re-entering the drainages of the Kabetogama Peninsula.

Naiman et al. (1986) presented a conceptual model of a stream-river continuum based on work in two nearly pristine watersheds that had intact beaver populations. The Matamek (673 km^2) and Moisie River (19,871 km^2) watersheds, both located in Quebec, Canada, experienced only minimal historic trapping and no logging or road building. Naiman et al. (1986) suggest that when beavers are present, our characterization of small streams needs to be modified to include numerous zones of open canopy and increased wetland areas, as well as other biogeochemical differences and changes in the size of the detritus that accumulates. In terms of the drainage network pattern, a key difference is the interruption of the channelized system with ponds and wetlands that develop as a result of dam building across the channel. In contrast to the beaver-dominated network, the conceptual model of a channelized drainage network is a visualized as a set of interconnected channels "where physical variables present a continuous gradient of physical conditions from the headwaters to the mouth (Naiman et al. 1986, p. 1267)." This conceptual model of a watershed of interconnected channels is implied in hydraulic geometry relationships of Leopold and Maddock's (1953) and other researchers (Knighton 1998), and is an assumption in the discharge-drainage area relationship.

In middle-order streams (fifth through eighth-order), beavers continue to alter stream systems, but their influence on the drainage system changes from direct channel alterations due to dam building across the channel to augmenting local inputs of woody debris. These accumulations of large amounts of woody debris contribute to the storage of sediment and detritus in the mainstream channel and frequently result in the formation of small islands (Naiman et al. 1986). On very large streams (stream orders ≥ 9) the influence of beavers on the stream-riparian ecosystem shifts to the floodplains and backwaters area (Naiman et al. 1986) and the control of beavers on the characteristics of the drainage network is minimal.

While the above studies examined the influence of beavers re-entering a drainage, Dobyns (1981) and Parker et al. (1985) discussed the impact of dam failures on stream channels. Parker et al. (1985) sought to quantify the ability of beaver dams to resist erosional perturbation and the conditions whereby the perturbation was too great and the dams failed. Parker et al. (1985) relied on thermodynamic and mechanistic principles and focused on the relationships between discharge, stream velocity, and the potential for bank or dam failure. They viewed the beaver dam, when beavers were present, as a "continuously renewed, erosionally resistant substrate" capable of resisting a shift in watershed conditions. They discussed the potential significance of beavers in decreasing channel sensitivity to erosion, but the bulk of their work focused on the erosional potential of the dam and was more theoretically based rather than empirical.

Finally Dobyns (1981), in his discussion of historic changes to the Gila River watershed in southern Arizona and New Mexico, briefly described the processes by which trapping in the headwaters of the Gila River watershed would have set in motion channel changes that contributed to increases in downstream flood magnitudes. He linked greater flood magnitudes in the lower watershed to channelization in the upper watershed and a loss of pond storage as dams failed in the upper watershed. Dobyns (1981) did not, however, consider how channelization would have decreased the stream and valley-floor hydrologic connection and limited access to the valley floor during high flow events. The loss of all the flood storage potential on the valley floor storage would have further amplified downstream flood magnitudes.

Development of Drainage Networks – An Overview

The pattern and character of the drainage network exerts a great influence on the hydrologic response of a watershed to a given climatic event. Evolution of the drainage network is controlled by climate, valley slope, vegetation, drainage area, geology (both lithology and structure), the infiltration capacity of exposed bedrock and sediments, topography, and the erosivity of the sediments (Knighton 1998), and beavers. A tension exists between erosion and resistance-to-erosion. This tension influences the final character of the network and the hydrologic responsiveness of the drainage to storm events as reflected in the stream hydrographs. As the factors controlling the evolution of the drainage network vary from place to place so will the final patterns of the drainage networks vary. The result is differences in flood magnitudes, durations, and frequencies of large magnitude floods for similar precipitation events. The size of the contributing drainage area and the resistance of the bed and bank material to channelized erosion are of particular relevance to natural systems when attempting to predict the possible rates of channelization and drainage network development (McLane 1978 in Schumm et al. 1984) and the final drainage-network pattern.

The depth and extent to which a channel incises into the fine sediments, migrates headward, widens, and develops tributary gullies depends on the valley slope and composition of the sediment (Morisawa 1964), the composition of the valley-floor vegetation, and the presence of resistant bodies (e.g. wetlands, intact beaver dams) or buried layers (e.g. bedrock, dense clay, cobbles) upstream or downstream of the point of incision. Examples taken from the published literature document the speed at which channelization can occur and the magnitude of the corresponding dimensions and character of that channelization (Table 10). Causes that lead to the rapid channelization include reductions in the resistance of the valley-floor sediment to incision, as a result of grazing, roads, and agriculture, and the creation of localized areas of flow convergence such as irrigation ditch, dam failures, roads, and cattle trails (Cooke and Reeves 1976).

Table 10. Examples of the speed at which channelization occurs, and the depth, width, and length of the channelization. The values in parenthesis are the units used in the original text if other than meters or kilometers.

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Location	Dates	Event	Amount of change	Time interval	Source
Rio Salado, NM	Between 1882 and 1918	Channel widens	From 3.6 to 14.9 m wide to 100.6 to 167.6 m wide	< 36 years	Bryan 1927
Felipe Gilbert Creek, NM	One storm event	Channel headcuts	Channel headcuts for a distance of 12 to 23 m	1 day	Bryan 1927
Whitewater Draw, AZ	One rainy season	Channel headcuts	Channel headcuts for a distance of 402 m	Up to a couple of months	Cooke and Reeves 1976
Kanab Creek, UT	Between 1883 and 1885	Channel incises, widens and headcuts	Channel incises 18 m and widens nearly 21 m for a distance of 25 km	2 years	Gregory 1917
Walker Creek, AZ	Between 1894 and 1913	Channel incises	Channel incises 24 m deep	< 19 years	Gregory 1917
Chinle Creek, AZ	Between 1894 and 1913	Channel incises	Channel incises 30 m deep	< 19 years	Gregory 1917
Mountain Meadows, UT	1884 – in one series of storms	Channel incises.	No numbers given but channel incises into what was once a wet meadow during a series of storms and continues to widen since 1884. Gullies fingering out to nearly all parts of meadow.	Up to one month for initial incisions	Cottam and Stewart 1940
Crane Creek, OR	Between 1925 and 1935	Channel incises	Channel incises to a depth of 7.6 m. Length of headcutting and amount of widening not stated.	10 years	Schaffer 1941
Santa Cruz River near Tucson, AZ	Between 1880 and 1928	Channel incises	Channel incises 4.5 m	48 years	Bryan 1928b
Sonoita Creek, AZ	Between 1891 and 1912	Channel incises and widens	Channel incises 5.4 to 6 m deep deep and widens to 76 m	21 years	Bryan 1928b
Santa Cruz River near Tucson, AZ	Between Aug 5 and 9, 1890	Channel incises and headcuts	Channel incises some unknown depth for 2.5 km. Between August 7 and 9 channel begins to fork and headcut in multiple directions	4 days	Cooke and Reeves 1976
Gila River near Safford, AZ	Between 1905 and 1917	Channel widens	Channel widens from an average of less than 91 m to about 610 m for about 75 km of river	12 years or less	Burkham 1972
Cimarron River in	Between 1874 and	Channel widens	Channel widens from average of 15.2 meters to 365.8 meters	65 years or less	Schumm and Lichty

Table 10 continued.

Location	Dates	Event	Amount of change	Time interval	Source
southwestern Kansas	1939				1963
Rio Puerco, NM	Between about 1885 and 1892	Channel incises and headcuts	Channel incises and the incision migrates upstream for 183 km. Discontinuous incision existed prior to 1885 and this may have facilitated rapid headward migration of the incision.	7 years	Bryan 1928a
Douglas Creek, CO	Between 1882 and 1900	Channel incises	Channel has incised 5 meters	18 years or less	Womack and Schumm 1977
Wolf River near Memphis, TN	Between 1964 and 1999	Channel incises and headcuts	Channel incises and the incision migrates upstream for 17 km. Headcutting is episodic in nature with an average rate of headward migration of 0.6 km/yr. Some areas have had a 6 m drop in bed level and the channel has widened to twice its original width.	35 years or less	Wiens 2001
Price Creek, MT	1995 and 1998	Channel incises and cross-section area increase	Channel incises 0 to 0.8 m deep and cross-section area increases between 0.21 sq. m/yr and 1.08 sq. m/yr for sites less than 15 meters upstream of beaver dams as a result of dam failures	1 to 3 years	This study
Obion River, TN	Since 1960s	Channel incises and widens	Channel has undergone headward migration of knickpoints as much as 1 km per year and channel widening as much as 1 m/yr	1 year	Shankman and Pugh 1992

The study by Schumm and Lichty (1963) of changes in the channel widths on the Cimarron River is a dramatic example of the magnitude and speed by which many western stream channels have changed since Euro-American settlement. The Cimarron River in southwestern Kansas (7407 to 16,589 km^2) widened from an average of 15 m to an average of 366 m wide along more than 200 kilometer of river between 1874 and 1939 (Schumm and Lichty 1963). The channel changes were, however, not uniform. The range and the amount of variability in the channel widths also increased (Figure 28). The range in widths increased from 3 to 93 m in 1874 to 61 to 975 m in 1939. The increase in variability reflects, in part, local variations in bank composition and stratigraphy. These features play a dominant role in determining the potential for, and type of, bank retreat once vegetation is removed (Smith 1976; Thorne and Tovey 1981; Thorne 1982; Pizzuto 1984; Lawler 1992; Beeson and Doyle 1995; Knighton 1998).

Other sources of information on the processes and speed of drainage-network development are a laboratory-flume study (McLane 1978 in Schumm et al. 1984) and a rare field study (Morisawa 1964). The flume study examined the development of the channel network under two different scenarios (McLane 1978 in Schumm et al. 1984). In the first case the evolution of the drainage network occurred on an undissected, unvegetated surface causing the network development to respond only to topography:

> Surface configuration of the model basin was designed to direct runoff toward the longitudinal centerline of the basin, where it would collect and flow to the basin outlet. Channel erosion progressed rapidly headward along this centerline to form a wide, main channel with vertical banks. Water was concentrated in depressions on the surface, and points at which interconnected pond systems drained over the banks became sites of tributary nickpoint initiation. As these nickpoints migrated headward into the pond systems, major tributary channels were formed (Schumm et al. 1984, p. 34).

The base level of the flume was then lowered and the response of the channels was again observed (McLane 1978 in Schumm et al. 1984). A lag in channel response was documented between the downstream drop in base level and the upstream response. The main channel incised first. As the main channel incision crossed a tributary junction, the tributary experienced a base-level drop and a knickpoint formed at the mouth of the

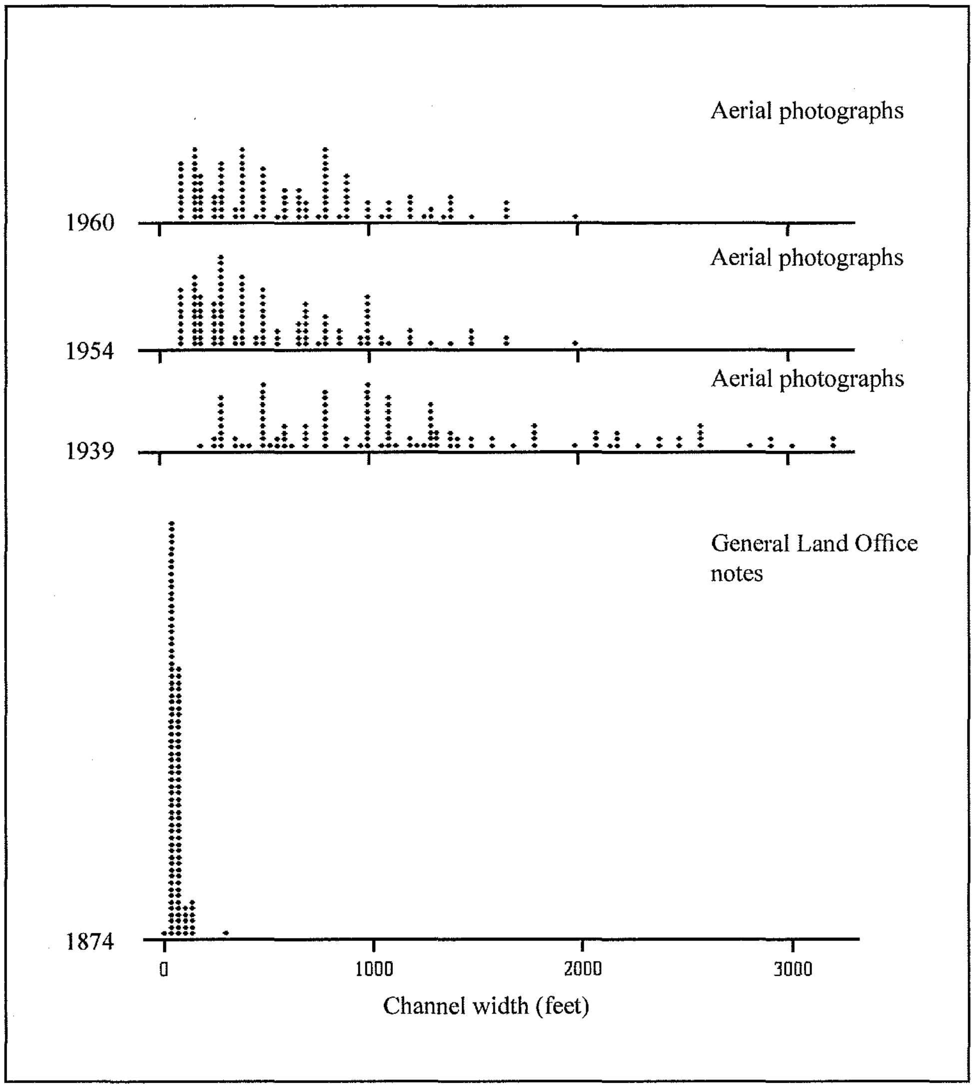


Figure 28. Changes in the channel widths of the Cimarron River in southwestern Kansas over time (N = 120). Figure generated using data presented in Schumm and Lichty (1963).

tributary and began migrating headward. The time lag resulted in the channel adjustments on the tributaries and on the main channel being out-of-phase.

Morisawa (1964) captured drainage-network development over a two-year period on a newly raised lake bed in Montana. She found that the slope and the bed material determined the character of the drainage network and the channel configuration that developed. Where the lake bed was sandy and steep, stream networks were straighter and simpler than those that developed on flat, silty surfaces. Streams on sandy beaches with high infiltration rates developed a V-shaped cross-section while streams on flat surfaces with silty material developed wide, shallow vertically walled valleys or an arroyo-type profile. The development of the drainage network on the unvegetated lake sediments was initially rapid in both sediment types with subsequent changes being more minor (Morisawa 1964). The limited quantitative data (Morisawa 1964; McLane 1978 in Schumm et al. 1984), when combined with field observations (Table 10), suggest that drainage basins can undergo rapid transformations from low to high channel-drainage density, and that the transformations can be exponential in form (Knighton 1998).

Method Used in Constructing a Conceptual Model of Watershed Response to Beavers and Beaver Trapping

My beaver-dominated conceptual model integrates and expands on the information contained in each of the conceptual models discussed earlier. Furthermore, the model traces the fluvial processes that occur, and geomorphic and hydrologic responses of stream systems, as beavers enter a drainage area and remain for long periods of time and then are suddenly gone. In developing the model I drew from a wide spectrum of literature. I examined articles for information on 1) the speed and types of vegetative, geomorphic, and hydrologic response as beavers re-enter or abandon a drainage, 2) the controls on the development of channelized drainage networks, 3) the speed and extent that channels incise and knickpoints migrate headward, and 4) the influence of channelization on storm hydrographs, water tables, and vegetation.

I restricted the spatial and temporal scope of the model because the impact of beavers on fluvial systems varies considerably depending on stream size and antecedent conditions (Naiman et al. 1986; 1988). Spatially I restricted my model to first through fourth-order streams because beavers are able to successfully build and maintain their dams across this range of stream sizes (Naiman et al. 1986; 1988). As a result of the dam placement, beavers have a direct effect on the physical character of the drainage network.

Temporally, I considered four events important for understanding how beavers influence the evolution of the drainage network morphology and watershed hydrology in the upper watershed. They are: 1) beavers enter a channel-dominated drainage network, 2) beavers establish a long-term presence in the watershed, 3) beavers abruptly abandon or are removed from a watershed where they have had a long-term presence and 4) the drainage network undergoes a transition in character as the drainage hydrology and geomorphology adjust to increases or decreases in beaver activity. The length of the transition period will vary depending on the scale and timing of the next human disturbance, antecedent conditions (e.g. how long beavers had been present/absent in the drainage), and the erosivity of features within the drainage (e.g. wetlands versus pond sediments).

The data and theory used to build the beaver-dominated conceptual model of drainage system response to beavers entering a drainage and beavers being trapped out, or abandoning an area, are presented separately. The equilibrium drainage networks that develop are presented before discussing how downstream hydrographs changed because the networks shed light on why flood magnitudes, durations, and the frequency of large magnitude floods are different under the two scenarios. The portion of the model addressing stream-system response to beavers entering a drainage is discussed first.

Conceptual Model Part 1: Watershed Response to the Establishment of a Long-Term Beaver Presence

This section examines the channel morphologic and hydrologic response, fluvial processes, and the sequence of events that occur when beavers enter a drainage area (Figure 29). I will discuss the effect of dam building and pond development on 1) the local hydrology and vegetation, 2) the local and downstream hydrographs, and 3) the drainage-network pattern in a watershed that contains a stable beaver population. T he changes begin with dam building and foraging for vegetation around the pond area. The model separates the effect that beavers have on local and downstream hydrology and on local vegetation. The local effects are further broken down into low-energy environments and high-energy environments. The distinction is made because dams in low-energy environments tend to be stable allowing wetlands to form and evolve into

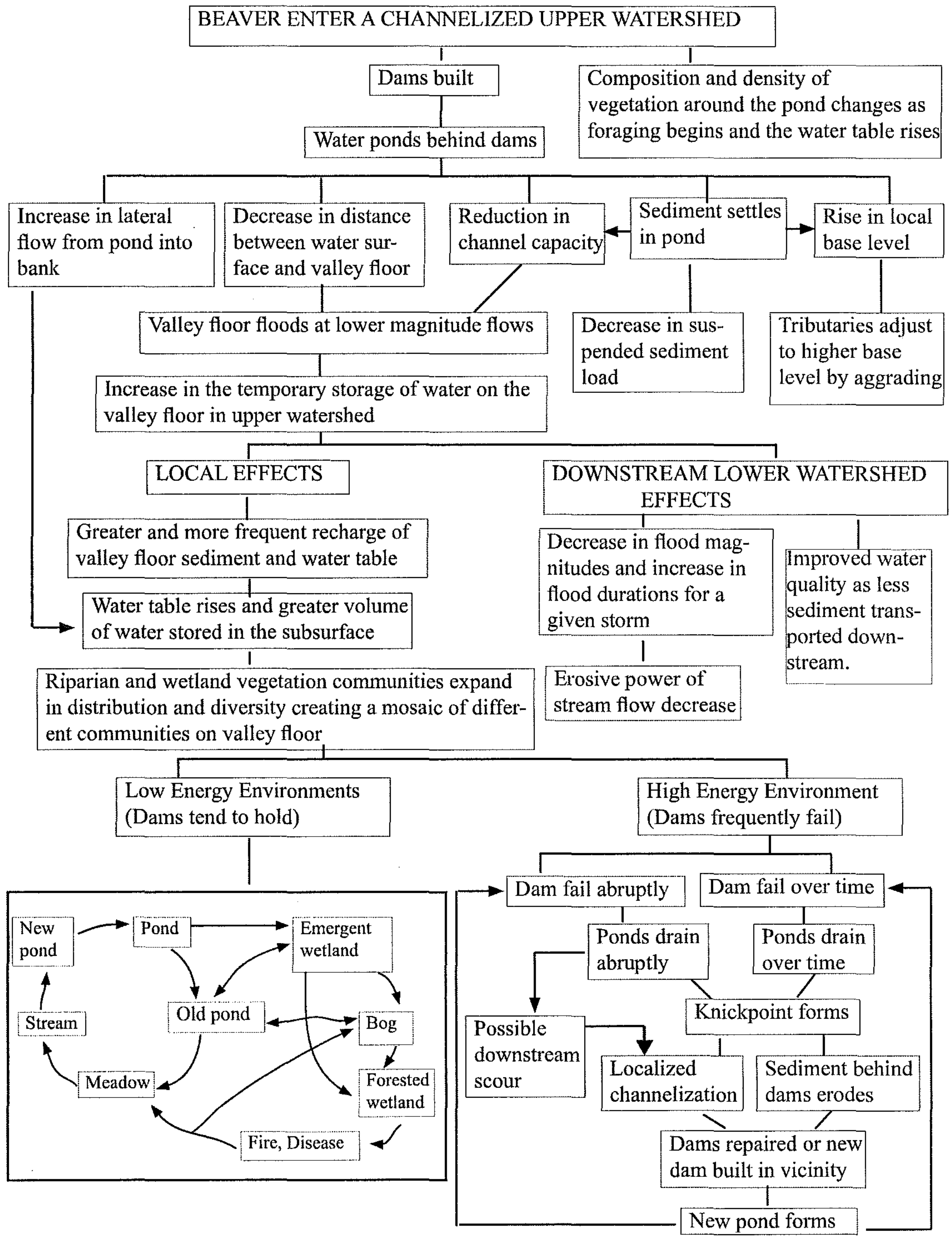


Figure 29. Conceptual model of how beavers influence fluvial systems. The portion of the model in the box is from Naminan et al. 1988. Arrows used for clarification of direction only.

meadows while dams in high-energy environments (i.e. steeper gradient streams, higher discharge streams) are more prone to periodic failure and wetlands and meadows are less likely to form (Meentemeyer and Butler 1999). The distinction in reach evolution in the high versus low energy environments is presented in the lower part of Figure 29 in the two flow boxes.

Dam Building and the Transformation of the Drainage Network

The building of beaver dams and the ponding of water behind those dams are the key events that set all others in motion. Beaver dams are normally made of logs and branches, piled in a more or less random fashion, and weighted down with mud and stones (Ives 1942; Figure 30a). The preferred building material are aspen, cottonwoods, and willows (Hall 1960; Olson and Hubert 1994), though they will build dams with whatever materials are available – tree branches, sagebrush, rocks, bottles, or tin cans (Olson and Hubert 1994). The dam shapes vary but arch dams that are concave on the upstream side are the predominant form (Ives 1942; Figure 30b). Dam heights and lengths vary. Reported dam heights range from 0.11 to 6 meters with the majority between 0.3 and 1.8 meters. Reported dams lengths range from 2 to 652 meters with the majority between 10 and 67 meters long (Ruedemann and Schoonmaker 1938; Ives 1942; Beedle 1991; Butler and Malanson 1995).

a.

b.

Figure 30. Examples of intact beaver dams. a) Example of a channel dam, Price Creek, Montana. b) Example of beaver pond from the air showing the arcuate nature of the beaver dam, Main Diamond Creek, New Mexico 1995.

There are four types of dams: channel dams, valley dams, lake dams and sidehill dams (Retzer et al. 1956). Channel dams form ponds that tend to be narrow and deep and are rarely branched. They occur where the valley floor is narrow (Retzer et al. 1956) or in wide valleys with entrenched channels. The presence of a channel dam in a wide valley is probably just an indication that the dam has not been in place long. Over time a channel dam in a wide valley will be expanded and develop into what Retzer et al. (1956) refers to as a valley dams. These dams are often long, branched and tortuous in their outline. Dams may be a single entity or networked with branches leading off to form other impoundments. The resulting ponds tend to be large. Sidehill dams occur on the sides of hills and tend to be low in height, tortuous in shape and networked. The water source for these dams is springs or seeps, and the lack of large discharge fluctuations makes the dams very stable. Finally lake dams are usually composed of a single small dam at low depressions around the perimeters of lakes. Though the dams are small, the amount of water impounded is great.

Local Hydrologic and Vegetative Response to Dam Building and Pond Development

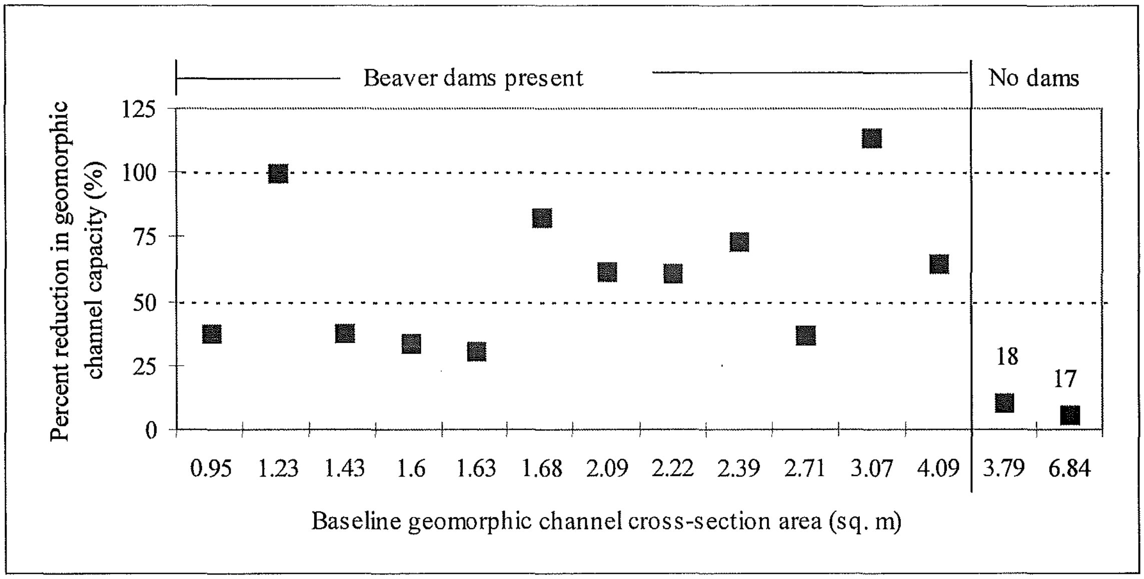
Dam building and pond development increase the distribution and abundance of surface and subsurface water in the upper watershed. The portion of first through fourth-order streams that have been impounded ranges from 20 to 87 percent (Retzer et al. 1950; Naiman et al. 1986; Johnston and Naiman 1990). The increase in surface water stored in a drainage basin with low topographic relief, as a result of beaver ponds, is demonstrated in a 250-km^2 area of the Kabetogama Peninsula in Minnesota. The ponded area increased from 13 to 873 hectares between 1940 and 1986 as beavers moved in and expanded their populations. By 1986 there were 741 ponds on the peninsula with most > 0.5 hectares (Johnston and Naiman 1990). Though the volume of water stored in these ponds was not calculated, similar sized ponds (0.2 to 0.48 hectares) from the Kuiu Island in southeast Alaska had water volumes ranging from 1063 to 3375 m^3, with pond volume generally increasing with increasing surface area (Beedle 1991). Forty-nine pond volumes were found in the literature and these values varied from 10 to 286,277 m^3 with 33 ponds having volumes between 100 and 3000 m^3 (Grasse and Putman 1950; Butler 1989; Beedle 1991; Hillman 1998). Historically, the contribution of beavers to surface water storage appears to have been substantial. Hey and Phillipi (1995) estimated that in the upper Mississippi and Missouri River basins beaver ponds covered 20,679,886 hectares in 1600 and 206,799 hectares in 1990 and wetlands covered 18,089,842 hectares in 1780 and 7,648,725 hectares in 1980.

Beaver ponds increase subsurface water in several ways. First, the beaver ponds trap sediment and water thereby decreasing the amount of space available in the geomorphic channel to transport and store water. The result is an increase in the frequency of overbank flows and an increase in the frequency and amount of water infiltrating into the valley sediments. Second, the ponds increase subsurface water by increasing the amount of stream bank-water interface (Parker et al. 1985) and therefore the potential for water to infiltrate into the stream banks. Finally, the elevated water levels in the ponds result in a decrease or reversal of the hydraulic gradient between the pond water levels and the valley-water table elevation. The reversal of the hydraulic gradient occurs when the elevation of the pond water level is higher than the valley water table. The elevational difference between the two surfaces causes the water to flow from regions of higher (ponds) to lower (water table) head (Dunne and Leopold 1978) allowing the pond to contribute to the amount of water stored in the subsurface.

The effectiveness of the beaver ponds at reducing available channel capacity was well documented on Price Creek in southwestern Montana (Figure 31, Chapter 2). Most Price Creek dam-controlled cross-sections had reductions in available channel capacity of 50 percent or more during the 1995 summer field season as a result of the ponds occupying a large portion of the available channel capacity. At one cross-section, the water overflowed the stream banks onto the valley floor. At another cross-section, water completely filled the channel and marshy areas were developing adjacent to the stream.

Percent reduction in available channel capacity was a function of dam integrity. Variations in the amount of reduction reflected the condition of the dam not baseline cross-section area (Figure 31a) or distance upstream from a dam (Figure 31b). Reductions were greatest when the dams were intact (1995). Available channel capacity increased as the dams failed and ponds drained (1998). The effectiveness of beaver ponds in reducing the available channel capacity is highlighted by the results from cross-sections 17 and 18 located downstream of the beaver-dam controlled reaches. Unlike the cross-sections in the beaver dam-controlled areas, percent reductions in available channel capacity from water in the channel at the two cross-sections were less than 25 percent and constant between the two years. Variations in percent reductions at these two cross-sections reflected variations in their baseline area because the discharge was the same.

a.



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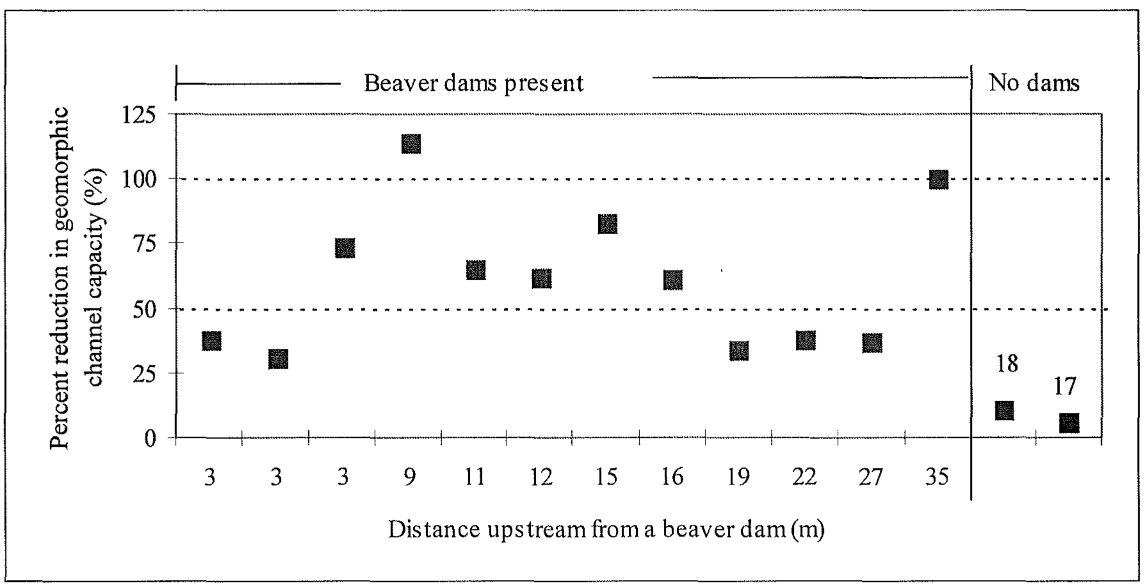


Figure 31. Percent reduction in the available channel capacity in the beaver dam-controlled reaches as a function of the amount of channel occupied by water, Price Creek, Montana. Reductions evaluated as a function of a) the geomorphic baseline cross-section area and b) the distance upstream from a beaver dam. Cross-sections 17 and 18 are shown for comparison. Measurements from Summer 1995.

Evidence for a rise in the valley-floor water table and the expansion of subsurface waters as a result of beaver ponds includes 1) the development of wetlands (Bailey 1936; Johnston and Naiman 1990), 2) rapid willow regrowth in areas with ponds (Apple et al. 1984), 3) the shift from ephemeral to perennial flow downstream of the beaver ponds (Bailey 1936; Schaffer 1941), and 4) the increase in surface flow observed downstream of beaver dams as a result of subsurface inputs (Grasse and Putman 1950). Apple et al. (1984) observed extensive willow regrowth inside a cattle exclosure in Wyoming in those areas adjacent to the ponds but minimal regrowth in those areas without ponds. And Grasse and Putman (1950) observed a doubling of the surface flow within about 400 meters downstream of a 10.5 hectare (25.98-acre) beaver pond as a result of water percolating through the dam and through the earth under and downstream of the dam.

The significance of the ponds in storing surface and subsurface water becomes particularly visible during times of short-term drought. Stream flows have been observed to continue downstream of beaver ponds during drought but cease in reaches without beaver ponds during droughts (Bailey 1936; Grasse and Putman 1950). In addition, vegetation on the valley floors remains riparian and does not shift to more drought-tolerant species (Bailey 1936; Schaffer 1941).

Rates of Local Hydrologic and Vegetative Change

Examples of how quickly vegetation and hydrologic conditions can change once beavers enter a watershed are provided in Table 11. These examples document the impact that ponds have at both the local and watershed scale.

Table 11. Examples of the speed at which hydrologic and vegetative conditions change in the presence of beaver ponds.

Location	Time Interval	Vegetation Change	Total Time	Source
Crane Creek, OR	1936 to 1938	Channel has incised 25 feet since 1925. Beavers reintroduced in 1936. Within 2 years the water table has risen and hay meadow production has improved (fields being subirrigated again). 1939 is a drought year, but water is abundant on the ranch with beaver ponds, but absent downstream on the ranch without beaver ponds.	2 years	Schaffer 1941
Currant Creek, WY	1981 and 1982 to 1984 or 1985	Beavers reintroduced in 1981 and 1982 into a cattle exclosure. By end of third year (1984 or 1985) full riparian recovery underway. Willow regrowth and resprouting averaged 1.6 to 2 m in height after three years of rest in areas adjacent to beaver ponds. In areas rested, but without beaver ponds, willow regrowth was negligible.	3 years	Apple et al. 1984
Cold Springs at Ranger Station, Ochoco National Forest, OR	1920 to 1931	In 1914 the draw below the ranger station cabin was dry. 1920 beavers move into area and construct dam near large spring. By 1931 more dams exist and there are approximately 0.8 hectares of wet beaver meadows and swamps. Springs have also developed 274 m below the wet meadow. "During the past season, driest on record, water was plentiful for a distance of a quarter mile [0.42 km] below the beaver dams, and springy places were increased all down the draw…at least 20 acres [8.1 hectares] of land that were dry in the very wet season of 1914 are kept fairly moist."	11 years	Bailey 1936
Near Little Summit Ranger Station area, OR	1925 to 1929	Area was formerly full of beavers, but the last appear trapped out by 1925. "From that date to 1929 (4 years) the old ditch and the entire meadow were fast becoming a dust bed. During 1928 and 1929 no water ran out at the lower end of the station (p. 222)."	4 years	Bailey 1936
	1929 to 1930	"* * * Some beavers moved back in 1929 and by the fall of 1930 the meadow in the pasture was 75 percent irrigated (1 year). The old ditches were full of water and a nice stream was running at the lower end of the station (p. 222)."	1 year	Bailey 1936
Kabetogama Peninsula, MN	1940 to 1981	Beavers re-enter area in 1940. Between 1940 and 1986 the ponded area (includes open water and areas with floating mats) increased from 20 to 1422 hectares, wet areas from 23 to 562 hectares, and moist areas from 214 to 1212 hectares. In terms of vegetation communities, the largest increases occurred for wet meadows (101 to 616 hectares,	41	Johnston and Naiman 1990

Table 11 continued.

Location	Time Interval	Vegetation Change	Total Time	Source
		shallow marsh (17 to 476 hectares) and wet deciduous shrubs (45 to 301 hectares). The amount of the peninsula that was affected by impoundment increased from one percent in 1940 to 10 percent in 1961 and 13 percent by 1986.		

Naiman et al. (1988) and Johnston and Naiman (1990) provide the best overall example of the speed of a watershed-wide transformation as beavers reenter and expand their range. The transition from a channel-dominated to a beaver-dominated drainage network in the Kabetogama Peninsula in Minnesota took about 46 years, with the greatest amount of change occurring within the first 21 years. Total area of impoundment rose from 1 to 10 percent of the study area between 1940 and 1960 and to 13 percent by 1986. This equals an increase in area affected by impoundments from 257 hectares to 3196 hectares. Wetland expansion accounted for the majority of the change. By 1986 73 percent of the impounded area (2323 of 3196 hectares) was in the form of wetland vegetation with the remaining 27 percent (873 of 3196 hectares) occurring as open water (Johnston and Naiman 1990). Beavers altered an additional 12 to 15 percent of the uplands as they browsed the area for food and building material (Naiman et al. 1988). Whether this rate and extent of watershed change would occur in the West is uncertain given its drier condition. However, the results from the Kabetogama Peninsula provide a benchmark from which to evaluate watershed changes in the West as a result of beaver reintroductions.

The Scale of Beaver Influence in a Watershed

The amount of a drainage network that is affected by the long-term presence of beavers varies with drainage basin and stream order. Several studies have found that the amount of first to fourth-order streams within a watershed potentially impacted by beaver activities to range from 20 to 87 percent (Retzer et al. 1956; Naiman et al. 1986, Johnson and Naiman 1990).

Naiman et al. (1986) examined two nearly pristine watersheds with intact beaver populations. The Matamek River (673 km^2) and Moisie River (19,871 km^2) watersheds, both located in Quebec, Canada, have experienced only minimal historic trapping and no logging or road building. In these watersheds, only 30 percent of the total length of the second to fourth-order streams was considered unsuitable for beaver because of stream gradient or inadequate flood supply (Naiman et al. 1986). The Matamek River has about 322 km of second to fourth-order streams and about 225 km are suitable for beaver dam building and habitation. The density of intact dams on these streams ranged from 8.6 to 16 dams/km with an average of 10.6 dams/km (Naiman et al. 1986). This dam density translates into roughly 1935 to 3600 intact dams on 225 km of the Matamek River, each providing some pond storage and increased valley-floor access. Stream length was not listed for the Moisie River but the number is probably even larger given its greater drainage area.

Retzer et al. (1950) examined 61 streams and 448 km of streams in western Colorado. The total drainage area of the study is 809 km^2 and average watershed of these streams is about 14 km^2. Unlike the two watersheds in Quebec, these systems were trapped. Beavers occupied 47 percent of the stream length studied, 22 percent had been abandoned, and 31 percent had never been occupied. This equates to about 69 percent of suitable stream habitat, an amount similar to that found in the Quebec study.

Finally, the studies of Namain et al. (1988) and Johnston and Naiman (1990) on the Kabetogams Peninsula (250 km^2) in Minnesota examined the influence of beavers returning to a drainage area over a 46-year period. A 38-km^2 portion of the peninsula, containing 46.92 km of stream, was examined in detail. Johnston and Naiman (1990) found that 53 percent of the first-order streams (12.17 km), 55.1 percent of the second-order streams (8.13 km) and 87 percent (5.5 km) of the fourth-order streams were impounded. The third-order streams were lobes of the lake and could not be impounded. These studies show that beavers can influence a large percentage of the drainage network and their dams can increase the valley-floor access during high flow along substantial portions of the drainage.

The Drainage Network Pattern in the Presence of Abundant Beavers

The above studies show that beavers can influence a considerable amount of first to fourth-order streams. The channelized drainage network becomes repeatedly interrupted with the ponds and wetlands that develop because of dam building across the channel. The drainage network that develops in the upper watershed is a complex mix of ponds, wetlands and channels sections and zones of open canopy (Naiman et al. 1986).

Pond Storage, Valley-Floor Detention Storage, and Reductions in Downstream Flood Magnitudes

Beaver ponds have long been attributed with reducing downstream flood magnitudes and stream power through pond storage and/or valley-floor detention storage (Dobyns 1981; Parker et al. 1985; Naiman et al. 1988). Actual studies quantifying the influence of beaver ponds on flood magnitudes, however, are few and have focused on small headwater streams and only considered the role of pond storage in flood peak reductions. Burns and McDonnell (1998) compared the stream hydrographs of two small watersheds (0.4 and 0.61 km^2), one of which had a single 1.3-hectare beaver pond located at the downstream end of the small headwater stream. They found that this single pond provided minimal retention during several large runoff events. Another study explored how storm hydrographs responded to increasing amounts of beaver pond storage as the numbers of ponds in series and their sizes increased (Beedle 1991). His study watersheds were 6.2 km^2 or less and his maximum pond size was 0.6 hectares. He found that the amount of reductions varied with storm size, pond size, pond numbers, and pond storage capacity available prior to the flow event. His findings suggest that abundant beaver ponds could make a difference in the flood magnitude, but that the importance of the effect decreases with flood magnitude:

> A single full beaver pond was found to theoretically reduce peak flows by no more than 5.3 % regardless of the return interval or watershed size. The shape of the outflow hydrographs were the same as the inflow hydrographs, with only a 10 or 15 minute delay in the time to peak and slightly increased duration. Reductions in peak flows became increasingly large as the number of ponds in a series increased. Five large-sized (0.6 hectare) beaver ponds in series reduced the storm peak flow by 14% for a 2-year event, but only 4% for a 50-year event (Beedle 1991, p. ii).

The two studies show that beaver ponds provide some flood storage directly, with the amount varying with pond size and numbers. However, the greatest contribution towards flood reductions occurs when flood waters access the valley floor where the detention storage is much greater. By reducing the available channel capacity, the ponds cause the flood flows moving downstream to overtop the stream banks onto the valley floors at lower discharges. The greater detention storage available on the valley floor means that flood magnitudes decrease in response to the temporarily detention of flood waters.

Reductions of flood magnitudes as a result of valley-floor storage have been documented by a number of researchers (Campbell et al. 1972; Dunne and Leopold 1978; Osterkamp and Costa 1987; Shankman and Pugh 1992; Hillman 1998). Osterkamp and Costa (1987) estimated water depths at three valley cross-sections on Plum Creek in Colorado (850 km^2) during a 900 to 1600-year recurrence interval flood. Depths averaged from 2.4 to 2.9 meters, but were as great as 5.8 meters. The computed velocities for the floodwaters ranged "from 1.3 m/sec over terraces at the valley sides to 5.4 m/sec in deeper flows in the central parts of the valley (Osterkamp and Costa 1987)," reflecting the influence of depth and perhaps roughness on flow velocities.

Dunne and Leopold (1978) examined runoff from four large drainage basins (19,194 to 525,770 km^2) and found that the channel and valley floor detained 57 to 80 percent of the runoff generated by large storms (105 to 329 mm). The percent of the runoff detained decreased as the size of the precipitation event increased. Campbell et al. (1972) used two flood-routing methods to determine the effect of channel straightening on flood magnitudes, durations, and attenuation of the flood peak for 97 km (58 miles) of the Boyer River in Tennessee (3,077 km^2). Channel straightening and the building of dikes were found to increase discharge downstream by limiting access to the valley floor and increasing the stream gradient. They then modeled stream hydrographs under a partial straightening scenario in which sections of the river were left unmodified. Campbell et al. (1972) found that the unmodified portions of the stream substantially reduced the magnitude of downstream flood peaks because as the flood passed through the unmodified stretch it overflowed onto the valley floor. The difference in the results of the two models is striking:

> The unmodified reach, even though short, provides tremendous storage, which can nullify the effects produced by the upstream straightening...16 miles of unmodified river reduced the increase in peak discharge from 90 percent to 15 percent for the condition of high flood plain roughness coefficient. The increase in peak discharge at section 30 [the most downstream section] is 35 percent with high n and 30 percent with low n as compared with 190 percent and 90 percent respectively for complete straightening (Campbell et al 1972, p. 97).

The floodplain in this area averaged 2.1 km wide. Its floodwater storage potential was substantial as was its contribution to flood peak reductions. This is born out by historical observations that describe long periods of standing water and swampy conditions on the valley floor because of periodic overflowing of the river (Campbell et al. 1972).

Finally, Hillman (1998) observed a large reduction in a peak flows on Rocky Creek (18.7 km^2) in central Alberta after the flood wave entered a 90-hectare wetland containing a sedge meadow, willows, a small lake, and several beaver ponds. By the time the flood had passed through the wetlands and reached the main gage, located about 6.5 km downstream of the failure, the flood peak was only 6 percent of the peak estimated to have entered the wetlands. Hillman (1998) concluded that wetlands, especially when large, are very effective in regulating high flows, even more so than beaver dams because the dams often wash out during high floods.

While the magnitude of the contribution of beaver ponds to flood storage is uncertain given the limited studies, their contribution towards reducing available channel capacity and therefore increasing valley-floor access is clear. And as the above discussion highlights, valley-floor storage is capable of significantly reducing flood peaks at all scales of drainage area and storm size.

Conceptual Model Part 2: Watershed Response to Extensive Beaver Trapping after a Long-Term Presence

The first half of the model (Figure 29) examined the hydrologic, vegetative and channel morphologic changes that would occur as a result of beavers entering a channelized drainage basin. The second half of the model examines the response of a drainage basin to beaver removal after a long-term presence (Figure 32). The significance of a rapid decrease in beaver populations is not the dam failures themselves, which occurs when beavers are present, but the fact that the dams are not repaired. The nonrepair of the dams sets in motion a change in the character of the drainage network and in downstream flood magnitudes, frequencies, and durations, as well as initiates the severing of the hydrologic connection between a stream and its valley floor. In the absence of trapping, Tularemia, a contagious disease that affects beavers, is the other event most likely to rapidly decrease populations. In those cases where beaver colonies are infected with the disease, most of the population will be lost (USDI BLM 1992).

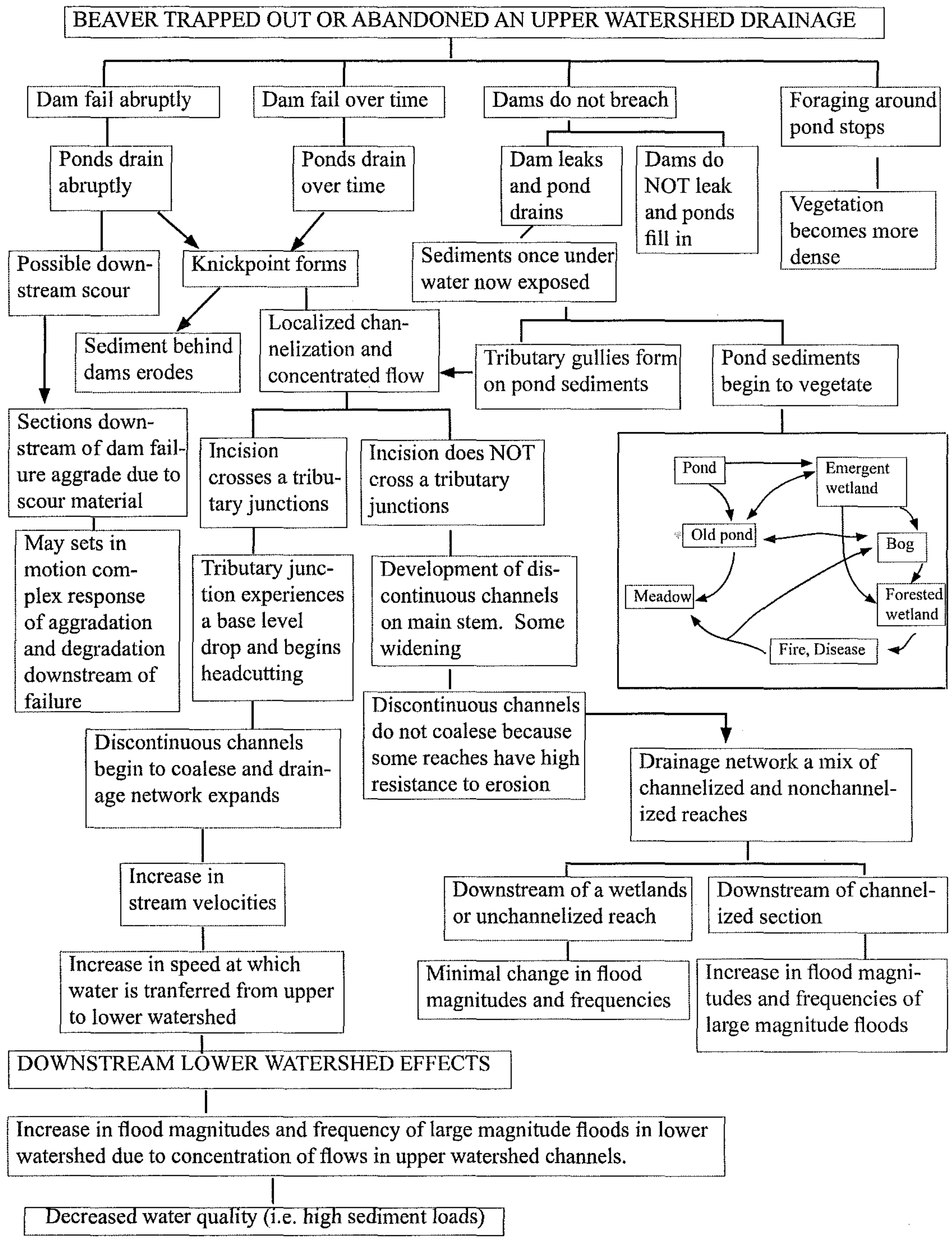


Figure 32. Conceptual model of how beaver trapping or site abandonment influence fluvial systems. The portion of the model in the box is from Naiman et al. (1988). Arrows used for clarification of direction only.

Forest Service investigations estimated that about half of the beaver population in Grant County, Oregon died in the winter 1941-1942 as a result of the disease (USDA Forest Service 1944), demonstrating its ability to rapidly decimate numbers.

Dam Failures, Channel Formation, and the Expansion of the Drainage Network

The development of a drainage network can be examined from two perspectives: 1) the controls and mechanisms leading to the development of the drainage network, and 2) the features in the drainage basin that inhibit the development of a channelized network. Both are important for predicting the drainage network that develops once beavers disappear from a drainage after a long-term presence.

Three things happen when a beaver dam fails: 1) the pond drains, 2) the local base-level drops, and 3) a knickpoint forms (Figure 32). Beaver-dam failures can occur abruptly or over time with failures occurring at the ends, bottoms, and tops of beaver dams (Retzer et al. 1956; Figure 33). If the failure is abrupt, the sudden draining of the beaver pond will result in higher than normal stream discharges and velocities. In addition to creating a knickpoint at the point of failure (Retzer et al. 1956; this study), the abrupt failure can result in channel scour downstream of the failure (Retzer et al. 1956; Butler 1989; Kondolf et al. 1991; Hillman 1998). Over time the knickpoint will migrate upstream, creating or deepening a channel. Whether the channel that develops remains a local feature, spatially separated from other localized channels, or begins to

a) b)

Figure 33. Examples of two types of dam failures on Price Creek, Montana. a) End breach. b) Top breach. Dam heights are about 1.5 meters.

affect the tributaries and valley floor depends on 1) the location of the channel in the drainage network (distant or near to a tributary junction) and 2) the erosional resistance of the channel bed, channel banks, and valley floor upstream and downstream of the developing channel (Hillman 1998; Kondolf et al. 1991; this study).

Dam failures lead to increased available channel capacity as the fine sediments trapped behind the dams erode and the ponds drain. The depth to a resistant layer will determine how deeply a channel can incise before stabilizing, and therefore the potential elevational drop in the water table and likelihood of channel enlargement through channel widening (Schumm et al. 1984). At Price Creek (3.9 to 14.3 km^2) channel incision ranged from zero to 0.8 m deep, and channel cross-section area increased from zero to 1.08 m^2/yr between 1997 and 1998 (Figure 34). The initial rates of cross-section area change in the dam-controlled reaches varied with proximity to a dam, the length of time that the controlling dam had been in place prior to failure, and time. The annual rates of change are expected to drop eventually to zero as the creek incises down through the soft sediments to a more resistant channel-bed layer.

The annual rates of cross-section area change at Price Creek sites with and without beaver dams are compared. In contrast to the high annual rates at most sites in the dam-controlled reaches, the eight cross-sections in the reaches without dams showed minimal change (Figure 34). As discussed in Chapter 2, this difference in rates of change is a function of bed erodability. The beaver dams had effectively captured the suspended sediment resulting in bed aggradation as the fine, easily eroded sediment settled. The absence of beaver dams or any other sediment-trapping mechanism (e.g. lush riparian vegetation) in reaches without beavers allowed the suspended load to be transported through the reach. In these reaches the stream is left with eroding its more resistant channel bed. Cross-section 19, located in a dam-controlled reach, is identified in Figure 34 for comparison with results presented in Figure 35.

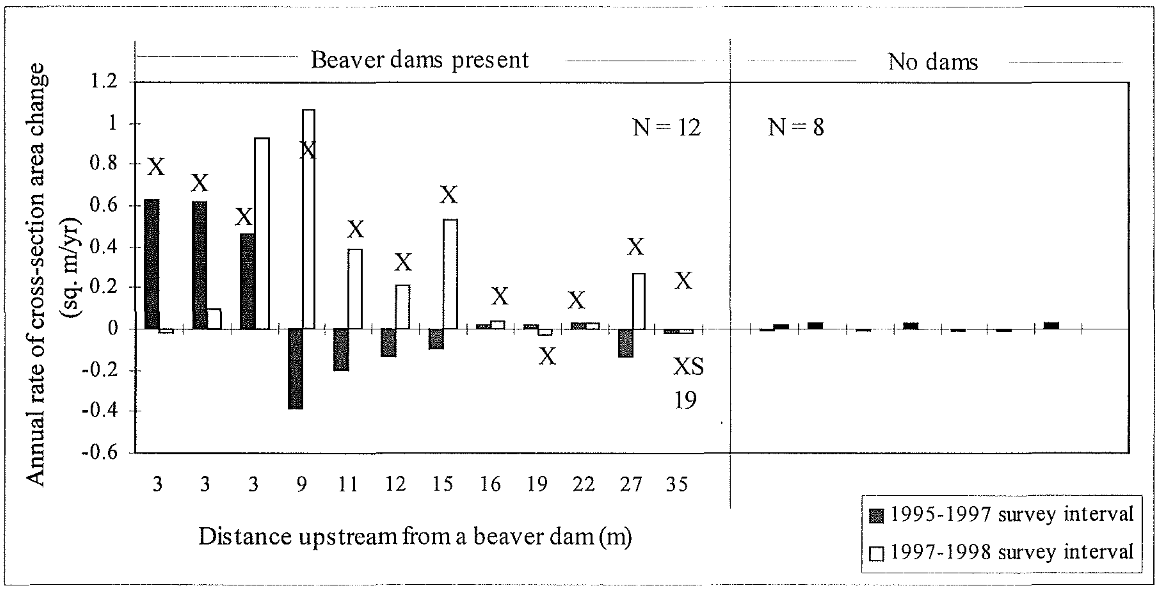
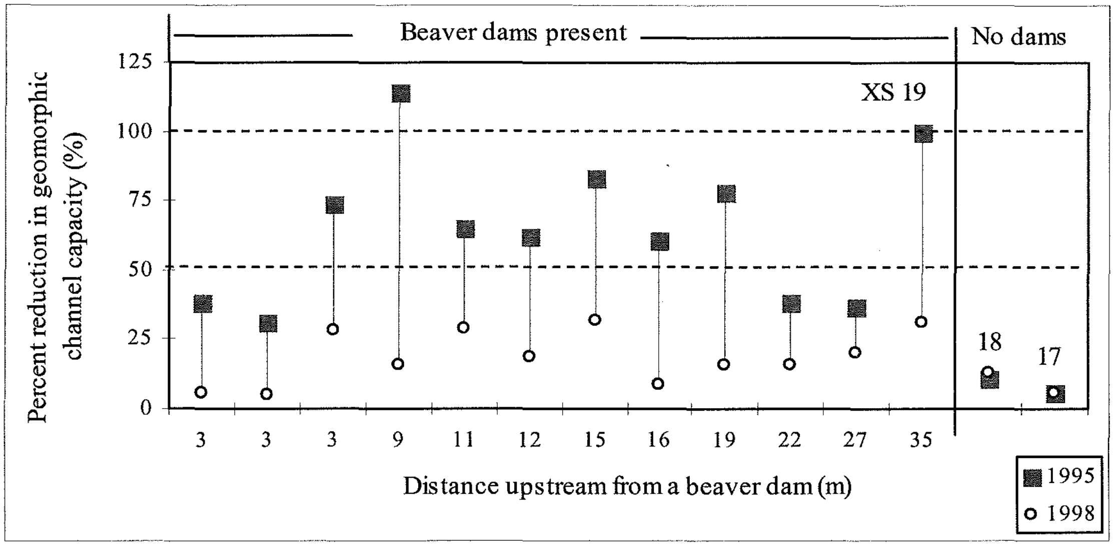


Figure 34. Annual rates of cross-section area change as a function of beaver-dam integrity in the Price Creek cattle exclosure, Montana. 'X' indicates the survey interval during which the dam failed. Some sites had multiple surveys that were post-failure. BLACK = 1995 to 1997 interval. WHITE = 1997 to 1998 interval. Annual rates for Price Creek cross-sections not influenced by beaver dams are shown for comparison.

The influence of pond drainage on the channel capacity is obvious when comparing percent reductions in available channel capacity in 1995 with percent reductions in 1998 (Figure 35). In 1995 the majority of the cross-sections had reductions in available channel capacity of 50 percent or more. In 1998 the dams were failing or had failed and reductions in available channel capacity had decreased to less than 25 percent of the geomorphic channel as the ponds drained. As the available channel capacity increased, the hydrologic connection between the stream and its valley floor decreased.

Differences in the 1998 percent reductions in the dam-controlled reaches were a function of dam condition and not distance upstream of a dam, baseline channel area, or variations in discharge between the two years. This is evident in Figure 35a in which cross-sections with similar baseline areas (e.g. 1.6, 1.63 and 1.68 m^2) had different percent reductions, and in Figure 35b in which cross-sections located at the same distance upstream of a beaver dams (e.g. 3 m) also had different percent reductions. And as cross-sections 17 and 18 show, the changes in available channel capacity between 1995 and 1998 in the beaver-dam controlled reaches were not related to lower discharges in 1998. Cross-section 17 and 18 are located downstream of the dam-controlled reaches and downstream of the confluence of Price Creek and the West Fork of Price Creek. Minimal net change in cross-section area occurred at these two sites between 1995 and 1998 (0.06 m^2, -0.01 m^2) and the percent reductions in available channel capacity from water were the same (Figure 34). This supports the contention that discharge between the two years was similar and that the increase in available channel capacity in the dam-controlled reaches was a function of beaver-dam integrity.

a.



b.

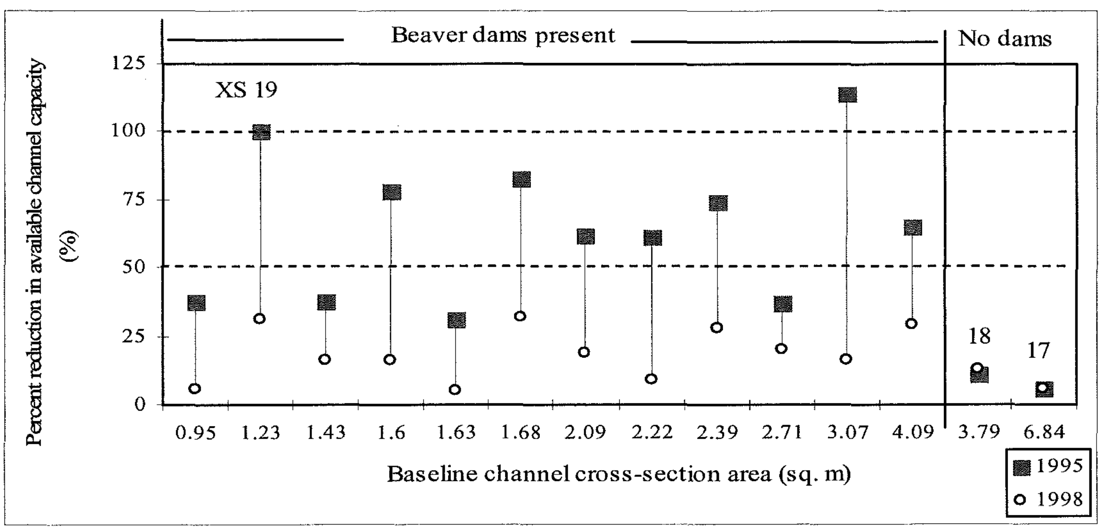


Figure 35. Changes in the percent reduction in available channel capacity as a result of beaver-dam failures and pond drainage post 1995, Price Creek, Montana. The dams were intact in 1995, though some were not being maintained. Dams had completely failed or were breaching by 1998. a) as a function of baseline channel cross-section area. b) as a function of distance upstream of a beaver dam. Cross-sections 17 and 18 are shown for comparison.

Both sediment erosion and pond drainage increase available channel capacity. The loss of the ponds, however, is more significant because water is seasonally abundant and can quickly reduce available channel capacity to zero even when sediment deposition is minimal. For example, cross-section 19, noted in Figures 34 and 35, had an annual reduction in the geomorphic channel capacity of 0.02 m^2/yr due to sediment deposition, but a 100 percent reduction in available channel capacity because of water ponding behind an intact dam. The seasonal abundance of water, in conjunction with presence of the dams, allow for rapid restoration of the stream and the valley-floor hydrologic connection, and for its equally rapid disconnect upon dam failure and pond drainage.

Rates of Channelization and Local Hydrologic and Vegetative Changes

The response of vegetation, hydrology, and the drainage network to beaver trapping or abandonment varies depending on the condition of the watershed prior to disturbance, much in the same way that antecedent moisture conditions determine runoff rates, and thus stream discharge, after a precipitation event. Table 10 shows the speed at which extensive channelization can occur in response to the headward migration of knickpoints. Channels were observed to headcut from 23 meters in a single day up to 2.5 km in four days. Rates of channel widening also could be extreme with channels widening from averages of 15.2 m to 365.8 m over a 65-year period (Schdumm and Lichty 1963; Figure 28), from 91 meters to 610 meters in 12 years (Burkham 1972), and

14.9 meters to 167.6 meters in less than 36 years (Bryan 1927). The majority of the incision, widening and headcutting occurred in response to storm events. Table 12 shows the speed at which shifts in vegetation from water-dependent to drought-tolerant species can occur in response to channelization. Some of the vegetation changes were in response to the loss of beaver dams after a local area was trapped while others were the result of overgrazing such as in the case of Mountain Meadows in southern Utah (Cottam and Stewart 1940). Changes occurred in as short a time as four years (Bailey 1936) with major shifts in entire vegetation communities in less than 50 years. All of the examples listed in Tables 10 and 12 are post Euro-American settlement.

The speed at which riparian and wetland vegetation shifts to more drought-tolerant species as a result of channelization varies as a function of climate, incision depth, groundwater depth, subsurface stratigraphy, vegetation requirements, and land use. This shift in species occurs for two reasons. First, channelization increases available channel capacity, thereby reducing the frequency of valley-floor flooding (Campbell et al. 1972; Schumm et al. 1984; Shankman and Pugh 1992) and consequently valley water-table recharge. Second, the hydraulic gradient between the valley-floor water table and the stream steepens as the channel incises and widens. This steepening of the hydraulic gradient enhances the flow of groundwater towards the channel (Knighton 1998 referencing Dunne 1980, 1990). These two changes result in an increase in the depth-to-water and a decrease in soil moisture that triggers the resulting shift from riparian species to more drought-tolerant species (Bryan 1928b).

Table 12. Examples of the speed and character of vegetation changes as a result of channel incision. Unless beaver trapping or area abandonment is explicitly mentioned, the cause of the incision is Euro-American settlement activities.

Location	Time Interval	Vegetation Change	Total Time	Source
Santa Cruz River near Tucson	1880 to 1928	From area covered by sacaton grass with groves of mesquite and swampy areas of tule (bulrushes) prior to 1880 to dense mesquite forest by 1928. Arroyo forms in 1880.	Less than 48 years	Bryan 1928b
Sonoita River of Sonora	pre-Aug 6 to 1928	From swampy area prior to August 6 1891 to a dense mesquite forest by 1928. Arroyo forms in August 6, 1891.	Less than 37 years	Bryan 1928b
Yancy Meadows, Yellowstone NP	1903 or 1904 to 1921	Beavers began to desert area in 1903 or 1904. By 1912 the colony was abandoned. Changes from ponds to well formed meadows to solid ground by 1921 with little evidence of the earlier beaver ponds.	17 or 18 years	Warren 1926
Crane Creek, OR	1925 to 1936	Beavers trapped out in 1924. Channel incises in 1925 and vegetation changes from meadows of 'stirrup-high native' grasses subirrigated by beaver ponds to meadows nearly gone, with clumps of new sagebrush and sparse remnants of the original grasses by 1936.	11 years	Schaffer 1941
Near Little Summit Ranger Station area, OR	1925 to 1929	Area was formerly full of beavers, but the last appear trapped out by 1925. "From that date to 1929 (4 years) the old ditch and the entire meadow were fast becoming a dust bed. During 1928 and 1929 no water ran out at the lower end of the station (p. 222)"	4 years	Bailey 1936
Mountain Meadows, southern UT	1884 to sometime prior to 1900	Channel incises into what was once a wet meadow during a series of storms and continues to widen since 1884. Gullies fingering out to nearly all parts of meadow. Shift in vegetation as meadows drain from a wet wiregrass meadow surrounded by numerous springs and a dry grass meadow to desert shrub.	< 16 years	Cottam and Stewart 1940

Climate and land use also exert a strong influence on the speed at which vegetation changes (Cooke and Reeves 1976). In areas where precipitation is distributed throughout the growing season, a decline in the water table may be partially compensated for by precipitation if its abundance and distribution are sufficient to maintain soil-moisture levels. In areas where precipitation is strongly seasonal, such as the Southwest, the decline in water table is not compensated for by precipitation, and wetland species respond more quickly to channelization and a drop in the water table (Table 12; Bryan 1928b). Land uses such as grazing and agriculture also exert an influence on the rates of vegetation response to channelization by altering soil structure and removing vegetation. These two changes increase runoff and decrease stream-bank and valley-floor resistance to erosion, thereby facilitating channel widening during high flows. The reduction in infiltration rates into the soil due to soil compaction further accelerates vegetation changes as precipitation and floodwaters are impeded from recharging the water table and soil moisture.

The degree to which a channelized-drainage network would have developed had trapping been the only Euro-American disturbance is unknown because Euro-American settlement and extensive livestock grazing occurred in most places 30 to 50 years after trapping. Historical observations suggest that channelization may have remained localized and the drainage continued to maintain a mix of channels, ponds and wetlands for a much longer period. For example, Peter Skene Ogden trapped the Crooked River and its tributaries in central Oregon between 1824 and 1830 (Ogden 1950; Buckley 1992). Three of his trapping expeditions were in the vicinity of Camp Creek, a tributary to the Crooked River and his journals reference plentiful beavers, willows, and aspen (Buckley 1992). Later records from 1858 to 1865 note lush grasses, willows, swampy areas, and abundant beavers and beaver dams along Camp Creek. And the still later General Land Office surveys in 1876 also mention the presence of many swampy areas and narrow channels (Buckley 1992), but not beavers. The vegetation, channel descriptions, and swampy areas are reminiscent of the changes Warren (1926) observed in Yellowstone National Park after beavers had ceased to maintain a presence in a creek. The similarity in descriptions suggests that the historical observations from Camp Creek, and other places where similar features are noted, are reflecting watersheds adjusting to reduced beaver populations after a long-term presence in the drainages.

There are limits to using present rates of hydrologic and vegetative change and channel formation as a proxy for historic post-trapping rates of change. Direct observations of the response of stream and riparian systems to historic Euro-American beaver trapping are absent except for a few references from New England in the 1600s (Cronon 1983). Estimating rates of channel and vegetation change during the period between trapping and the introduction of livestock grazing uses observations recorded post-Euro-American settlement as a starting point. In the case of channel widening, incision, and straightening, the rates after Euro-American settlement are probably a good proxy for channelization rates post-beaver trapping because the sediments trapped behind the beaver dams were at least as erodable as valley fill.

I am less certain about the similarity between the pre- and post-settlement rates of vegetation change. Beavers create stable stream-riparian ecosystems that have a high resistance to climatic variability and disturbance (Ives 1942; Naiman et al. 1986, 1988), and wetlands can have long residence times on the landscape when left undisturbed (Warren 1926; Ives 1942; Hendrickson and Minckley 1984; Naiman et al. 1988). As beavers existed in many watersheds for decades if not hundreds of years prior to Euro-American trapping, they would have been able to impart considerable stability to a watershed. The high water tables and stable surface flow downstream of intact wetlands likely initially compensated for the decrease in overbank flooding. The vegetation and hydrologic changes to the Kabetogama Peninsula in northern Minnesota over a 46-year period after beavers reentered the drainage supports the above suggestion. Despite temporary abandonment and drainage, none of the impoundments established over this period the reverted back to forest, their original ecology before impoundment (Johnson and Naiman 1990).

Most research examining how beavers influence drainages has been in Alaska, Canada, Minnesota, Montana, and Colorado. It is possible that streams in the Southwest and Intermountain West may have channelized, and dams failed, more quickly than those in the more northern areas. However, the numerous GLO descriptions of marshes, wet meadows, and swamps in areas that once had abundant beavers (see Hastings and Turner 1965; Cooke and Reeves 1976; Hendrickson and Minckley 1984; Buckley 1992) indicate that wetlands persisted after beaver trapping even in the Southwest and Intermountain West. Therefore, it is highly likely that changes from wetland species to more drought-tolerant species post-trapping, but pre-Euro-American grazing, were initially slower than modern-day rates.

Current rates of dam failures also cannot be assumed to be a good measure of historic rates of dam failures after beaver trapping. Historically dam resistance to failure was probably higher because of willow growth on stable dams (Meentemeyer and Butler 1999) and repeated repairs. Reductions in upland vegetation and soil compaction would not have occurred for another 20 to 50 years or more, with the introduction of Euro-American cattle and sheep. As a result, runoff rates from the uplands would not have increased during the period between trapping and the introduction of Euro-American livestock grazing.

The Drainage Network Pattern Post-Beaver Trapping

Beaver-dam failures throughout a watershed initiate the development of a channelized drainage network by removing base-level controls at multiple places within the watershed. The fine sediment behind the dams becomes exposed to the forces of running water as dams fail, ponds drain, and a knickpoint forms at the elevational difference between the channel bed upstream and downstream of the dam. As knickpoints erode headward through fine textured and unconsolidated sediment they eventually encounter resistant features that may impede any further migration. The result is the development of a drainage network pattern in which channelized reaches of stream are spatially separated by unchannelized reaches. Whether the discontinuous channels connect over time and form a continuous channelized network depends on the character of the resistant features encountered by the knickpoint (e.g. bedrock, wetland, or intact dam) and the feature's sensitivity to future failure or transformation as a result of climatic variability or land uses (e.g. grazing or logging). For example, wetlands inhibit knickpoint migration 1) through enhanced roughness that reduces flow velocities (Hendrickson and Minckley 1984; Cooke and Reeves 1976), 2) through temporary storage that reduces flood peaks (Hillman 1998), and 3) through enhanced subsurface cohesion (Smith 1976; Cooke and Reeves 1976; Hendrickson and Minckley 1984). The presence of wetlands distributed along a stream prevents the discontinuous channels from coalescing into a single connected system. Streams with a long-term beaver presence develop abundant and complex wetland vegetation communities (Johnston and Naiman 1990). Upon the disappearance of beavers from a stream, but before the arrival of livestock, these wetlands would influence rates of channelization ending in drainages with channelized reaches spatially separated by non-channelized reaches. The most distinct difference between the equilibrium drainage networks of systems with beavers and beaver dams and those without (but prior to grazing) is the absence of the copious ponds.

Historical Evidence Supporting the Post-Beaver Trapping Drainage Network

Large areas exist in which the modern-day influence of abundant beavers on the drainage network, the local hydrology, and vegetation is visible and can be studied (Grasse and Putman 1950; Retzer et al. 1956; Naiman et al. 1986, 1988; Johnston and Naiman 1990). There are no similar modern-day analogs that can be studied to evaluate the correctness of the drainage network and the rates of vegetation and hydrologic change presented in this paper when beaver are abruptly eliminated from a drainage. However, historical observations may support to the description of the proposed drainage network that developed after the period of intensive beaver trapping. The evidence consists of observations by early GLO surveyors and military and scientific expeditions to the Southwest and Colorado Plateau prior to Euro-American settlement and grazing. These expeditions noted in their records the simultaneous presence of recent tributary incision, discontinuous channels, and wetlands (Dellenbaugh 1912; Gregory 1917; Bryan 1928a; Gregory and Moore 1931; Hastings and Turner 1965; Cooke and Reeves 1976; Hendrickson and Minckley 1984). The juxtaposition of features indicative of a stable fluvial system (wetlands, wet meadows) and features indicative of a destabilized fluvial system (discontinuous arroyos, incised tributaries) suggests that the destabilization of the fluvial systems had been fairly recent.

The suggestion that the destabilization of fluvial systems was a recent occurrence is supported by the similarity in the channel morphology of these post-trapping, pre-settlement discontinuous arroyos and incised tributary channels and later post-Euro-American settlement arroyos. In addition, many of the vegetation communities were in the process of changing from wetland-dominated to drought-tolerant species at the time of these surveys. Later observations of rates of vegetative changes in response to channelization indicate that changes in species type from wetland to drought-tolerant species can occur in less than 50 years (Table 12), supporting the suggestion that the destabilization had happened sometime within the last 50 years.

I tested the validity of the hypothesis that those early observations reflected watershed response to recent and widespread Euro-American beaver trapping using a three-step process. The first step was to determine if beavers and beaver trapping occurred in the areas where discontinuous arroyos and incised tributary channels were observed. The second step was to compare the time intervals of channelization recorded post-Euro-American settlement with the time interval that existed between trapping and the first observation of discontinuous channels and incised tributaries. The third step was to qualitatively compare the character and magnitude of the channel incisions and channel widening noted by those early expeditions with the magnitude and character of the channel changes recorded post-Euro-American settlement.

A relationship between historic beaver trapping, dam failures, and arroyo formation is considered supported or at least not disproved if 1) trapping occurred in the area, 2) the time interval between trapping and the next observation (i.e. 15 years) is longer than the time needed for substantial channel incision to have occurred (i.e. < 10 years), and 3) the magnitude of the observed channelization could have occurred within the intervening time (comparison of Tables 10 and 12). In this case, it is highly probable that beaver trapping and dam failures and non-repair led to localized channelization and were partially responsible for the development of these pre-settlement incised tributaries and discontinuous arroyos. Under this scenario, climate variability or random frequency-magnitude variations are considered as playing only supporting roles, perhaps accelerating dam failures as a result of high intensity storms as has been observed by several researchers (Bulter 1989; Kondolf et al. 1991; Meetenmeyer and Bulter 1999). This scenario is in contrast to earlier scenarios whereby that climatic variability and random-frequency events are the likely driving forces behind the early channelization

(Dellenbaugh 1912; Bryan 1928a; Bull 1964; Cooke and Reeves 1976; Balling and Wells 1990). If the time interval between trapping and the next observation (i.e. 15 years) is less than that observed for channelization of a similar magnitude (i.e. 25 years), this does not discount the contribution of beaver-dam failures and non-repair towards initiating channelization. Rather it suggests that climatic events may have accelerated rates of dam failures and channelization. In both cases, dam failures provide a mechanism for locally dropping base level, creating knickpoints, and initiating channelization.

Testing The Hypothesis of a Historical Watershed Response to Beaver Trapping

The General Land Office surveys and early military and scientific expeditions observed discontinuous arroyos and/or incised tributary streams on the San Pedro River in Arizona (Cooke and Reeves 1976), on the Rio Puerco in New Mexico (Bryan 1928a), in the Diablo Range in California (Bull 1964), and on some tributaries to the Colorado River (Dellenbaugh 1912) that pre-date Euro-American settlement. The timing of the baseline General Land Office (GLO) surveys with respect to beaver trapping is important because the GLO notes are frequently used as baseline data on stream and riparian conditions prior to extensive Euro-American settlement activities (Cooke and Reeves 1976; Knox 1977; and others). The baseline surveys focused first on those areas that were about to be settled or were in the process of being settled by Euro-Americans (White 1996) leaving large portions of each state left unsurveyed until later (Clements 1985). Much of what was left unsurveyed was located in the upper watersheds where the impact of beaver trapping and dam failures would have been most noticeable and influential on the drainage network. In addition, some surveys post-date extensive non-Euro-Americans settlement (e.g. along the Rio Grande River valley in New Mexico, Santa Fe area in New Mexico along the Santa Cruz River in Arizona) and Euro-American activities such as mining (e.g. 1849 California gold rush). Therefore it was important to determine 1) if beaver trapping had occurred in the area and 2) the temporal relationships between trapping and the GLO, military and scientific observations.

A review of the published literature found either specific references to the above rivers or areas being trapped or references indicating that trapping had occurred in the vicinity. Once it was confirmed that trapping had occurred at a location, the timing of beaver trapping, the next recorded observation, and the GLO surveys were determined (Table 13). The time intervals in Table 13 were then compared against the rates and distances of knickpoint migrations presented in Table 10.

The first recorded observations of stream conditions and characteristics after the period of widespread Euro-American beaver trapping occur 9 to 47 years later. As Table 10 documents, rates of channel widening, incision and headward migration of knickpoints can be rapid with substantial changes taking place within a single storm event. The amount of time between trapping and the later expeditions would, it appears, have been sufficient time for discontinuous arroyos and incised tributary channels to develop in response to Euro-American beaver trapping, dam failures, and non-repair.

Table 13. The estimated timing of beaver trapping, the next observation, and the baseline General Land Office surveys for areas discontinuous arroyos and incised tributaries prior to Euro-American settlement and cattle grazing.

Location	Dates Area Trapped	Comments	Date of Next Observation	Comments	Estimated time between the two observations	Baseline GLO survey
San Pedro River, AZ[4, 7]	1826-1827[1]	Pattie and his party trap the river in March 1826 and take 200 beavers. They trap the river again in October 1827. No numbers given for the second time[1]	Military expeditions: 1846, 1852, 1859[3]	1846 – description of vegetation patterns in area (Johnston 1847)[3] 1852 near Pomerene: the stream banks not less than 8 to 10 feet high (Bartlett 1854)[3] 1859 – there is a discontinuous gully near Pomerene. The river has a "width of about twelve feet and a depth of twelve inches [water depth], flowing between clay banks ten or twelve feet deep, but below it widens out and from beaver dams and other obstructions overflows a large extent of bottom land, forming marshes densely timbered with cottonwood and ash Hutton (1859)." [3]	19 to 20 years	1851, 1865, 1867[8]
Diablo Range, CA (17 to 25 km west of	1829 to 1843	Hudson's Bay Company trapped in California beginning in 1829 until 1843, returning "every year to trap the Sacramento-San	GLO surveys 1852 to 1854 [7, 8]	GLO surveyors noted the existence of traces of older gullies on some of alluvial fans on the Diablo Range[5]	9 to 25 years	1852 to 1854[7]

Table 13 continued.

Location	Dates Area Trapped	Comments	Date of Next Observation	Comments	Estimated time between the two observations	Baseline GLO survey
the San Joaquin River) [5]		Joaquin River systems and the area around the San Francisco Bay (p. 544)." The company took from the Bay area alone 10,860 beaver between 1830 and 1839.[2]				
Rio Puerco, NM (tributary to the Rio Grande) [4]	1823 to about 1838[9]	"In 1823, however the fur trade from New Mexico had scarcely begun….most trappers certainly centered their operations on the virgin streams of the Pecos and Rio Grande valleys. The beaver supply in this convenient area was already being depleted" and by 1824 trappers were heading west. In 1827 American fur trappers were floating down the Rio Grande trapping as they went. 1832 to 1838 trapping occurs around the settlements along the Rio Grande valley.[9]	Military expedition 1846-1847, 1849 [4]	Abert (1847): banks were 10 or 12 feet high and vertical at a point west of Albuquerque. Banks were 30 feet further upstream near a ruined town. Simpson (1849): channel was 100 feet wide, contained stagnant pools of water; banks were 20 to 30 feet high about 5 miles above Cabezon (small village on the river). Late 1880s: many settlers testify that in many places the river had no banks or only small ones and in flood the river spread out over the entire valley floor.[4]	9 to 23 years	1855[4]
Non-specified tributary in the Colorado River	1824 to probably late 1830s [2, 10]	All the major tributaries of the Colorado River were trapped[10]	The Powell expedition of 1871 or 1872[6]	"I noted the same characteristics [trenching of stream beds] (and others probably also noted) years ago in places where there were no cattle and never had been (p. 656)."	33 to 47 years	1869 (NM), Post-1867 (AZ), Post 1855 (UT), Post 1880 (CO) [8]

Table 13 continued.

Location	Dates Area Trapped	Comments	Date of Next Observation	Comments	Estimated time between the two observations	Baseline GLO survey
region[6]				" I have seen earth-cliffs 30 to 40 feet high with all the characteristics of a rock-cliff erosion (p.657)." [6]		
[1] Pattie (1831)		[6]Dellenbaugh (1912)				
[2] Phillips (1961)		[7]Cooke and Reeves (1976)				
[3]Leopold (1951)		[8]White (1996)				
[4]Bryan (1928)		[9]Weber (1971)				
[5]Bull (1964)		[10]Chittenden (1954)				

While the time intervals between trapping and the next observation were sufficient to allow a change in the character of the drainage network as a result of dam failures, the rates of knickpoint migration and expansion of the drainage network could have been accelerated by periods of higher precipitation. Two periods of above-average precipitation, in fact, have been identified in the tree-ring data from northern New Mexico (D'Arrigo and Jacoby 1991) and from central Montana to southern New Mexico (Meko 1990): 1835 to 1849 and 1905 to 1928. Meko's (1990) study showed the strongest correlations in climate across the Intermountain West occurred in 1905 to 1917 period, suggesting a more localized region of above-average winter precipitation from 1835 to 1849 in the Southwest. The first period of above-average winter precipitation occurred post-beaver trapping (1835 to 1849), though this period was interspersed with years of drought (Meko et al. 1991). The second period of above-average winter precipitation occurred post-trapping and after the initiation of livestock grazing (1905 to 1928). As the largest floods recorded after the installation of stream gages on the Gila River in southeastern Arizona and southwestern New Mexico occurred in response to winter storms (Burkham 1970), it is probable that the period of above-average precipitation accelerated the rate of dam failures.

The Response of Stream Hydrographs to Channelization

Beaver dams increase the frequency of overbank flooding because the ponds decrease available channel capacity (Figure 31). The degree to which overbank flooding decreases flood magnitudes and increases flood durations varies as a function of valley-floor roughness (Campbell et al. 1972; Shankman and Pugh 1992), the amount of storage area (Leopold and Maddock 1954; Campbell et al. 1972; Osterkamp and Costa 1987), and the location of unmodified sections of river with respect to the flood wave (Campbell et al. 1972; Hillman 1998). Even once dams fail and portions of the drainage network channelize, the remaining unmodified reaches will continue to store flood waters and dampen flood magnitudes (Campbell et al. 1972; Hillman 1998). The mix of channelized and nonchannelized reaches results in a similar discontinuity in flood magnitudes, durations and frequencies as a flow moves downstream. Some areas will experience increased flooding while others (e.g. downstream of a wetland) will show minimal changes for the same precipitation or dam-bursting event.

Placing the Beaver-Dominated Conceptual Model in its Historical Context

The beaver-dominated conceptual model is placed in a historical context in Table 14, which summarizes the relative temporal relationships between Euro-American disturbances and subsequent changes in watershed hydrology and geomorphology. This summary underscores the complexity and magnitude of Euro-American impacts on the lower 48 states since their arrival in the early 1600s. Table 14 indicates two waves of large-scale Euro-American disturbances, one that pre-dates a lot of documentation of channel response (beaver trapping) and one that post-dates settlement and thus has a much greater amount of documentation of channel response to various land-use activities (e.g. grazing, road building, agriculture). The specific dates of the watershed disturbances and changes are not given in Table 14 because the dates vary depending on when trapping, settlement, and various climatic events occurred (for examples see: Hastings and Turner 1965; Cooke and Reeves 1976; Knox 1977). I included the timing of stream-gage installations because its inclusion places the stream-gage data in their historical and landscape disturbance context. This placement is important because, as discussed earlier, many researchers have used this data to develop hydraulic geometry relationships and conceptual models of fluvial processes and systems (see Leopold and Maddock 1953; Knighton 1998) that have then been used when designing restoration projects.

Table 14. Summary of the relative temporal relationships of various events related to Euro-American disturbances and their impact on watershed hydrology and geomorphology. Focus is on the changes to the upper watershed.

Beaver enter a pre-Euro-American disturbance watershed	Upper watershed: Channel-dominated. Well-vegetated stream banks. Channel is resistant to stream erosion.
DRAINAGE NETWORK TRANSITION I	Upper watershed: Dams built across the channels and ponds develop. Drainage network shifts from channel dominated to pond-wetland-channel mix. Rapid expansion of the riparian/wetland vegetation communities on the valley floors and along the stream banks.
Long-term presence of beavers in a watershed	Upper watershed: drainage network pattern is a mix of ponds, wetlands and channels. Complex mosaic of riparian vegetation. Stream-valley floor hydrologic connection excellent and the valley floors are flooded frequently. Stream ecosystem has low sensitivity to climatic variability, high resistance to disturbance and recovers rapidly after a disturbance. Lower watershed: Flood magnitudes and the frequency of large magnitude floods decreases and flood durations increase.
FIRST WAVE OF LARGE-SCALE EURO-AMERICAN DISTURBANCES	
Historic Euro-American beaver trapping	Widespread, temporally concentrated, and systematic removal of beaver from upper and lower watersheds.
DRAINAGE NETWORK TRANSITION II	Upper watershed: Dams fail, ponds drain and stream incises into fine sediments trapped behind the dams. Drainage network shifts to an increasingly channel dominated network. Stream-valley floor hydrologic connection decreases as channels incise and widen. Wetland and riparian vegetation patterns begin to change in location and abundance in response to localized channelization, dropping water table, decreased valley floor flooding and beaver forage and exposure of pond sediments. Portions of system continue to have low sensitivity to climatic variability but in other areas the sensitivity is increasing due to channelization. Decreasing resistance to climatic variability and disturbance. Increased

Table 14 continued.

	channelization in the upper watershed results in more rapid transfer of water from the upper to lower watershed. Drainage network is a mix of discontinuous channelized and nonchannelized reaches. Lower watershed: The channel morphology may remain unchanged as valley floor and stream bank vegetation still abundant and dams were located on the floodplains and backwater areas. However, floodplain complexity and vegetation communities are changing as a result of beaver removal. Possible increases in flood peaks and decreases in flood durations as a result of greater channelization in upper watershed and periodic abrupt dam failures.
SECOND WAVE OF LARGE-SCALE EURO-AMERICAN DISTURBANCES	
Euro-American settlement activities (e.g. grazing, logging, road building, farming, ditch and canal building)	Upper and Lower watershed: Vegetation removed from uplands, valley floor and stream banks. Wetlands drained deliberately or incise due to land use activities. Creation of points of flow convergence (roads, canals). Result is large increases in runoff and decreases the resistance of uplands, valley floors, and stream banks to erosion. Upper watershed: Channelization expands and discontinuous channels begin to coalesce.
DRAINAGE NETWORK TRANSITION III	Upper and Lower watershed: Rapid increases in channel incision and widening and therefore increases in channel capacity. The speed of water transfers from upper to lower watershed during a storm event increases. Streams and valley floors hydrologically disconnecting. The frequency of valley floor flooding in upper watershed decreases while the magnitude and frequency of flooding in the lower watershed increases. Stream ecosystem sensitivity to climatic variability increases, resistance to disturbance decreases and recovery rates after a disturbance slower.
Final condition.	Upper and Lower watershed: Channel-dominated. Streams and valley floors hydrologically disconnected. Reduced the complexity, abundance and extent of the riparian zone. Loss of wetlands. Stream ecosystem sensitivity to climatic variability high, resistance to disturbance low and recovery after disturbance low. Lower watershed: Increased flood magnitudes and increased frequency of higher magnitude floods. **Stream gages installed during this period.**

Discussion

The beaver-dominated conceptual model presented in this chapter has two parts. The model examined the processes and sequence of events that would occur in a watershed as beavers re-entered a drainage and established a long-term presence (Figure 29) and then as beavers disappeared from a drainage and dams failed and were not repaired (Figure 32). The conceptual model and the literature review suggest that the changes in the drainage network pattern and in the hydrologic behavior of stream ecosystems, as a result of beaver trapping, were probably much greater and more complex than previously thought. Trapping and dam failures were not simply events that led to channels widening, incising, and straightening but rather events that transformed the appearance and hydrologic behavior of drainage networks.

The combination of the beaver-dominated conceptual model and the summary of historical Euro-American land uses (Table 14) present an opportunity to reexamine historic observations in the context of beavers and beaver trapping and reconsider the implications of these observations on our understanding of fluvial geomorphologic processes. This section, therefore, uses the conceptual model as a starting point to explore three areas. First, I will present an explanation of why beavers and beaver trapping as controls on fluvial processes, watershed hydrology, and drainage network evolution are absent from the discipline of fluvial geomorphology. Second, I will discuss some of the implications for fluvial geomorphology of incorporating beavers and beaver trapping into our discussions and research into the causes and controls on channel morphology and watershed hydrology. Other implications will suggest themselves to the readers that are worthy of further investigation. Finally, I will discuss some areas for future research.

Explaining the Absence of Beavers in the Discipline of Fluvial Geomorphology

Current research and observations of stream response to beavers and beaver trapping (Bailey 1936; Apple et al. 1984; Naiman et al. 1986, 1988; Johnson and Naiman 1990; Chapter 2) document the enormous influence that beavers and trapping exert on stream and riparian systems. However, their influence is not discussed in the discipline of fluvial geomorphology (Dunne and Leopold 1978; Rosgen 1996; Knighton 1998). I suggest that this omission is the result of a complex set of factors that masked the magnitude of influence that beavers and trapping had on the character of fluvial systems and its hydrologic response to climatic events. I have identified four contributing factors that likely contributed to the omission: 1) the timing and spatial geographies of beaver trapping with respect to the later military and scientific expeditions, General Land Office (GLO) surveys, Euro-American settlement, and geomorphic studies, 2) the availability and quality of the records and observations of fluvial systems and channel changes pre- versus post-trapping, 3) the speed at which watersheds adjusted to beaver removal, and 4) the continued presence of beavers in the landscape post-trapping. The timing and spatial geographies, the speed of watershed adjustment and the continued presence of beavers on the landscape are discussed in depth. The factors are discussed separately, but it was their combination that made the magnitude of the influence of exerted by beavers and beaver trapping on fluvial systems invisible. Any factor alone would not have been so effective.

Temporal and Spatial Geographies of Beaver Trapping and the Later Pre-settlement Surveys

Trappers were the vanguard of the move westward (Phillips 1961). Their arrival predates most scientific and military surveys and settlement by at least several decades, with a few exceptions. One exception occurs on the East Coast where settlement and trapping co-existed in time (Cronon 1983) and numerous writings exist from the 1600s and 1700s on the local natural history of those areas (Meisel 1924). The other exceptions are the earliest expeditions into the West. The Lewis and Clark expedition (1804 to 1806), the Long expedition (1819 to 1820) and the Pike expedition (1805 to 1807) all predate extensive trapping in the West (Phillips 1961). Their written observations (Burroughs 1961), along with the writings of the early East Coast naturalists (Meisel 1924; Cronon 1983) and later trappers (Pattie 1831; Work 1945; Ogden 1950), combined with the records from the fur companies (Phillips 1961) reveal complex, multi-channeled rivers abundant with beavers and beaver dams.

July 30, 1805 (Jefferson River, a few miles above Three Forks in Montana)

> …saw a vast number of beaver in many large dams which they had maid in various bayoes of the river which are distributed to a distance of three or four miles on this side of the rivers over an extensive bottom of timbered and meadow lands intermixed. in order to avoid these bayoes and beaver dams which I found difficult to pass, I directed my course to the high plain to the right which I gained after some time with much difficulty and waiding many beaver dams to my waist in mud and water. – Lewis (Burroughs 1961, p. 111).

July 18, 1805 (Vic. Of Ordway's Creek, above Great Falls, Montana)

> Capt. Clark ascended the river on the Star'd side . . . in the evening he passed over a mountain by which means he cut off many miles of the rivers circuitous rout . . . .he passed two streams of water, the branches of Ordway's Creek, on which he saw a number of beaver dams succeeding each other in close order and extending as far up those streams as he could discover them in their course towards the mountains. – Lewis (Burroughs 1961, p. 110).

March 25, 1826 (San Pedro River, Arizona)

> On the 25th we returned to Beaver river [San Pedro], and dug up the furs that we had buried, or cached as the phrase is, and concluded to ascend it, trapping towards its head . . . About six miles up the river we stopped to set our traps . . . We pitched our camp near the bank of the river, in a thick grove of timber, extending about a hundred yards in width. Behind the timber was a narrow plain of about the same width, and still further on was a high hill , to which I repaired . . . Immediately back of the hill I discovered a small lake, by the noise made by the ducks and geese in it. Looking more intently I remarked what gave me much more satisfaction, that is to say, three beaver lodges (Pattie 1831, p. 59).

Yet, it is not these earliest observations, but the later GLO surveys and the post-trapping expeditions into the Southwest that form our baseline image and understanding of the riparian ecology and stream character of the West prior to Euro-American settlement.

The reliance on the GLO notes for baseline information on the geomorphic and ecological character of watersheds and imagery of pre-settlement conditions has embedded in it an unspoken assumption that "the public land surveys were carried forward in virgin territory – unexplored and unmapped – in advance of settlement (Clements 1985, p. 106)." However, trapping predated the GLO surveys by 20 to 40 years. While some researchers acknowledge the occurrence of beaver trapping in their area (Gregory and Moore 1931; Leopold 1951; Dobyns 1981; Hendrickson and Minckley 1984), in most cases (Dobyns is an exception) they treat beaver trapping as a local disturbance rather than one with regional significance.

The time between trapping and the later GLO surveys, and what it means for our use of the GLO notes, is worth examining. Systematic land surveys began in 1785 with the passage of the Land Ordinance. The first survey took place in Ohio in 1785 with subsequent GLO surveys proceeding westward in response to pending settlement (Clements 1985; White 1996). Yet even by 1785 the area east of the Missouri and lower Mississippi Rivers had been heavily trapped for at least 100 years (Phillips 1961), and beavers had ceased to be a dominant feature in the New England landscape as early as the late 1600s (Cronon 1983). West of the Missouri and lower Mississippi Rivers, trapping and the GLO surveys were more coincident in time but trapping still preceded the surveys by several decades (Table 13).

In addition to the temporal differences between trapping and the GLO surveys, there is also the difference in their spatial geographies. The trappers followed non-linear streams in their search for beavers. In contrast, the GLO surveyors recorded information about the land and its resources along linear grid lines spaced one mile apart and focused on those areas being settled (Clements 1985). The GLO method thus missed capturing the broad residual stream-riparian patterns that might have set us to wonder about the impact of beavers and beaver trapping on stream ecosystems. A similar problem exists with the spatial geographies of the military and scientific expeditions that post-date trapping but pre-date Euro-American settlement in the West. These early expeditions, like the baseline GLO surveys, bypassed most of the headwater areas yet it is in the headwaters where beaver trapping would have had left its most visible mark, that being the shear abundance of failing dams. As previously mentioned, the early military expeditions along the Gila River entered the drainage from southern New Mexico via the Lordsburg Plain (Leopold 1951). Observations of any pre-settlement channel incision on the tributaries to the Gila River were therefore restricted to the middle and lower Gila River (e.g. San Pedro River, the Santa Cruz River), while changes in upper Gila River (e.g. San Francisco River, East and West Forks of the Gila River) went unnoticed and unrecorded. All of these tributaries were trapped between 1826 and 1834 (Pattie 1831; Weber 1971). The observations of discontinuous arroyos on the San Pedro River in 1846 suggest that discontinuous arroyos and incised tributaries also existed on the San Francisco River, the East and West Forks of the Gila River and other tributaries to the Gila River.

The Speed of Watershed Adjustment to the Loss of Beavers

The lack of recognition regarding the influence of beaver trapping on the streams may be also be indicative of the speed at which fluvial systems of first through fourth-order streams adjusted to the widespread removal of beavers. With the loss of beavers, dams failed and were not repaired throughout countless tributary streams. Each failure contributed to further dam failures as knickpoint developed at the point of failure and migrated headward, creating channels that conveyed water more rapidly downstream.

Tree-ring data from California, Nevada, Utah, Colorado, Arizona, and New Mexico indicate a period of above-average precipitation from 1835 to 1849 or shortly after extensive trapping ceased in the Southwest (Meko 1990; D'Arrigo and Jacoby 1991; Meko et al. 1991). Unusually large rainfalls or high spring runoff flood discharges have been known to trigger abrupt beaver dam failures (Butler 1989; Kondolf et al. 1991; Meentemeyer and Butler 1999) suggesting that this period of above-average winter precipitation post-trapping likely accelerated the rates of dam failures and knickpoint migration. Discontinuous arroyos and incised tributary channels were observed in all these areas prior to Euro-American settlement (Table 13).

A second period of above-average winter precipitation noted in the tree-ring data, and the one more commonly referenced, occurred from 1905 to 1920 or 1928 depending on the tree-ring chronology used (Meko 1990; D'Arrigo and Jacoby 1991). The 1905 to 1920/1928 interval is post-trapping, settlement, and livestock grazing, and also during the time interval when large floods widened many streams in the West (Burkham 1972; Cooke and Reeves 1976). Researchers studying Southwestern streams have focused on channel response to this second period of above-average precipitation as they sought a causal mechanism to explain both pre- and post-settlement changes in channel morphology and hydrology (Bryan 1928a; Burkham 1972; Cooke and Reeves 1976; Balling and Wells 1990). The publication of the tree-ring data identifying the earlier period of above-average precipitation post-dates these earlier publications and explains the absence of any analysis regarding how the period of above-average precipitation from 1835 to 1849 interval may have impacted channel morphology, hydrology, and drainage network development.

A Continued Presence

The continued presence of beavers in the West may be another reason why the impact of beaver trapping on watershed hydrology, channel morphology, and stream ecosystem stability were not considered as causal mechanism to explain the pre-settlement discontinuous arroyos in the Southwest. Beavers had somewhat recovered from near extinction in the time between the intensive Euro-American trapping and subsequent exploration and settlement and were observed on the San Pedro River (Hastings and Turner 1965), the San Carlos River (Leopold 1951), the Little Colorado River (Colton 1937), and on tributaries to the Santa Cruz River (Cooke and Reeves 1976) during the late 1840s and 1850s. Hastings and Turner (1965) noted that before the Civil War the San Pedro and Santa Cruz Rivers and their tributaries "wound sluggishly along for much of their course through grass-choked valleys dotted with cienagas and pools. In spite of the onslaught by the mountain men, beaver dams were still numerous, and as late as 1882 a settler on the San Pedro River could report that: "Our ditch was just above a beaver dam and if the water was low and we tried to irrigate at night the beaver would stop up our ditch so that the water would run into their dam. (Hastings and Turner 1965, p. 35)." If, however, the San Pedro River is representative of channel changes that post-date trapping, then considerable changes had indeed occurred since James Pattie trapped the river in 1826. Observations from the late 1840s and 1850s recorded discontinuous channels on the San Pedro (Cooke and Reeves 1976) and the following spacing of beaver dams in 1858:

> The San pedro river as they Call it—is a stream one foot deep six feet wide and runs a mile and half an hour and in ten minutes fishing we Could Catch as many fish as we Could use and about ever 5 miles is a beaver dam this is a great Country for them – (Hastings and Turner 1965, p. 35).

Frequent is in the eye of the beholder. Comparisons of the 5 mile (8 km) dam spacing on the San Pedro River with recent studies of drainage basins that contained relatively unexploited beaver populations found much closer dam spacing. Naiman et al (1986) found an average of 10.6 dams/km in their study of two drainage basins in Quebec. Naiman et al. (1988) found an average of 2.5 dams/km in their study of the Kabetogama Peninsula in Northern Minnesota. Both studies are further north and ecologically different than the San Pedro River, but they provide a point of comparison with the 8 km single-dam spacing noted on the San Pedro River in 1858. In addition, beaver densities in the present day average one to two colonies per mile on streams with suitable habitat and often two or three dams per colony (Olson and Hubert 1994). Based on Pattie's description of the San Pedro and the 200 beavers trapped in 1826 (Pattie 1831), it seems likely that the dam spacing on the San Pedro River was smaller and dams more abundant prior to trapping.

When the GLO surveys and early military expeditions arrived in the West, the signature of a long-term beaver presence was still visible in the swamps, ciénégas, wet meadows and narrow channels they recorded in their notes. However, research attention quickly focused on trying to understand the causes of pre- and post-settlement arroyos and incised channels because of the speed and magnitude of the post-settlement arroyo formation and its impact on settlements. As a result the significance of the odd juxtaposition of wetlands and recent channel incision in the pre-settlement period was left unexamined. East of the Missouri and Mississippi Rivers, signature of a beaver influence was even less visible than in the West because the time interval between beaver trapping and the GLO surveys was greater. Trapping had been ongoing in some areas since the mid-1500s (Phillips 1961). Therefore, while the hillslopes and valley floors remained well vegetated and runoff volumes unchanged at the time of the GLO surveys and subsequent settlement, the character of the drainage networks had undergone a transformation in response to the loss of beavers and subsequent dam failures.

It was into this changing landscape that the field of geomorphology emerged in the 1870s. It was not, however, until the 1940s that fieldwork and quantification of field data took hold in the discipline (Morisawa 1985), and by then most streams in the lower 48 states had undergone multiple adjustments in channel morphology and hydrology in response to various land uses and climatic events. The baseline from which future fluvial geomorphologists would come to asses rates, magnitudes, and processes of channel change would consist of data collected at stream gages installed in the early 1900s, the GLO notes, and the post-trapping expeditions to the Southwest and Intermountain West. The contribution of beavers to stream ecosystems was already becoming a fragmented and fading influence by the 1850s when the GLO surveyors began collecting data in the West and by the 1940s it had become invisible.

The continued presence of beavers and their perceived abundance fostered the impression that though locally important, their ecological and hydrologic significance at the watershed and regional scale was minimal because the settlers and early expeditions lacked information on pre-trapping numbers, distributions, and the appearance of stream ecosystems. The speed of the dam failures, the linear methodology of the GLO surveys, and the geographies of the GLO and military surveys versus the trapping expeditions resulted in the beaver story going unnoticed at a time when their signature was still visible. However, the records from the GLO surveys and early expeditions contain a wealth of information. It is now time to reexamine those observations with beavers in mind and begin to integrate beavers and beaver trapping into our conceptual models of fluvial systems and their response to this massive disturbance.

Implications for Fluvial Geomorphology

The beaver-dominated conceptual model presented in this chapter had two parts. The model examined the processes and sequence of events that would occur in a watershed as beavers re-entered a drainage and established a long-term presence (Figure 29) and then as beavers disappeared from a drainage and dams failed and were not repaired (Figure 32). The conceptual model and the literature review suggest that the changes in the drainage network pattern and in the hydrologic behavior of stream ecosystems, as a result of beaver trapping, were probably much greater and more complex than previously thought. Trapping and dam failures were not simply events that led to localized channel widening, incising, and straightening but rather were events that transformed the appearance and hydrologic behavior of drainage networks. The combination of the beaver-dominated conceptual model and the summary of historical Euro-American land uses (Table 14) present an opportunity to reexamine the underpinnings of fluvial geomorphology and some of its many facets. Other implications will suggest themselves to the readers that are worthy of further investigation.

The Role of Beavers in Wetland Development in Southwestern Fluvial Systems Prior to Euro-American Settlement

The early military and scientific expeditions and GLO surveys observed wetlands, wet meadows and ponds in the Southwest and Colorado Plateau prior to Euro-American grazing and settlement (Gregory 1917; Gregory and Moore 1931; Leopold 1951; Hendrickson and Minckley 1984). Several factors contributed to their presence: 1) the existence of local geologic, geomorphic or biologic features that determine groundwater intersects the surface (Hendrickson and Minckley 1984) and 2) check dams built by Native Peoples (Reagan 1924). A third contributor, and one briefly mentioned by Hendrickson and Minckley (1984), is beaver dams. The factors leading to wetland development are discussed below and beavers placed within the context of the other causes.

Hendrickson and Minckley (1984) found that cienégas (mid-elevation wetlands characterized by permanently saturated, highly organic reducing soils) occurred where 1) groundwater intersected the surface, 2) discharges were stable, and 3) flood peaks were low thus minimizing the potential for scouring flows and channel incision. The features they identified causing groundwater to intersect the surface included upfaulted bedrock, changes in base level of the receiving stream, stream impoundments by landslides, and the development of a concave-convex profile. In their discussion of the concave-convex profile they identified two mechanisms leading to profile development: the deposition of coarse sediments and the placement of beaver dams along the stream (Hendrickson and Minckley 1984). While Hendrickson and Minckley (1984) consider beaver dams as a mechanism for creating the concave-convex profile and contributing to the formation of cienégas, it is only briefly mentioned. However, the influence of beaver dams extends beyond simply the creation of the profile. Like landslides, beaver dams also impound streams, though on a smaller scale, raise the base level of the channel bed as they pond water and trap sediment, and provide a local base-level control. Though not as stable as bedrock, as long as beavers are present in the system to repair the dams, the dams will operate as a "continuously renewed, erosionally resistant substrate (Parker et al. 1985)."

The potential contribution of beavers to cienéga development is most visible on San Pedro River in southern Arizona. Here beavers, beaver trapping, abundant cienégas, and discontinuous arroyos were contemporaneous in time and space. The San Pedro River was trapped during the period from 1826 to 1834 (Pattie 1831; Weber 1971). James Pattie, a beaver trapper, and his party found beavers so abundant that they named the river the Beaver River and took 200 beavers in 1826 (Pattie 1831). His descriptions of the river and surrounding landscape indicate a water-lush environment. Twelve to 20 years later (1846), discontinuous arroyos were noted on the San Pedro along with large cienégas (Hastings and Turner 1965; Cooke and Reeves 1976; Hendrickson and Minckley 1984). With the loss of beavers from the river the dams would have ceased to act as "continuously renewed, erosionally resistant substrate" akin to bedrock becoming instead points of base-level drop and knickpoint initiation. The connection between beaver trapping and the development of discontinuous arroyos will be discussed in depth in the next section.

In evaluating the potential contribution of beavers to wetland development in the Southwest, the two other requirements for their development were examined: stable discharge and low flood peaks. Both requirements are met in the presence of intact and maintained beaver dams. The beaver ponds that develop behind the dams stabilize surface discharges and decrease flood peaks largely by decreasing available channel capacity resulting in more rapid access of flood waters to the valley floor during times of high runoff where detention storage and roughness are greater. The contribution of subsurface water to stabilizing stream flows can be considerable and in a few places large ponds in the headwaters have been observed to effectively dampen the effects of both large runoff events and prolonged drought (Grasse and Putman 1956).

The contribution of Native Peoples has also been suggested. Reagan (1924) observed that "Every side-wash, canyon and flat had its village or villages, its dams, ditches and reservoirs, as is readily seen by examining the region (Reagan 1924; p. 341)." He argued that irrigation systems and check dams built by Native Peoples were responsible for the development of ponds, wetlands, and aggrading surfaces. The loss of Native Peoples due to contact with Euro-American diseases and conflicts would have led to dam failures, nonrepair, and channel incision. One point of interest is that Reagan's (1924) description of dam heights, composition and locations of the check dams is similar to characteristics of beaver dams. The dams were made of earth and about 1.5 m tall and, like beaver dams, the check dams would have required constant maintenance. It is possible, therefore, that some of the dams he attributed to being built by Native Peoples were beaver dams. This is probable given the wide distribution of beavers in the West prior to Euro-American trapping.

In conclusion, ciенégas, wet meadows, and the ponds observed in the Southwest prior to Euro-American settlement developed from multiple causes, beaver activity one important factor in their development and stability. Present day studies show that beaver activity can rapidly lead to the development of wetlands and introduce stability into fluvial system capable of resisting short-term climatic variability (Bailey 1936; Ruedemann and Schoonmaker 1936; Apple et al. 1984; Hendrickson and Minckley 1984; Naiman et al. 1988; Johnson and Niaman 1990) suggesting that their contribution to wetland development prior to trapping was much greater than previously thought.

Beaver Trapping as a Mechanism Leading to the Development of Discontinuous Arroyos and Incised Tributary Streams Prior to Euro-American Settlement

The prior section discussed the potential contribution of beavers to the development of extensive ciénegas/wetlands in the Southwest and Intermountain West. However, in addition to observing ciénegas/wetlands and ponds, the early military and scientific expeditions and GLO surveys also observed discontinuous arroyos and incised channels that pre-date Euro-American livestock grazing and settlement (Dellenbaugh 1912; Bryan1928a; Bull 1964; Cooke and Reeves 1976; Balling and Wells 1990, Table 13), some of which occurred just downstream of ciénegàs. This section explores the question of arroyo formation and as well as the juxtaposition of ciénegas and arroyos in the context of beaver trapping and subsequent dam failures. The influence of the large livestock herds of Spanish and Mexicans in the Southwest from 1750 to 1825 on channel morphology is discussed in Chapter 4.

Prior to about 1865 observations of arroyos by Euro-Americans were few in number and their scattered geographic distribution has been interpreted as indicting that they were rare and insignificant prior to Euro-American settlement and grazing (Cooke and Reeves 1976). I suggest another explanation for the apparent scarcity of these features. I suggest that, rather than a rare occurrence, the early military and scientific expeditions and GLO surveys simply missed those areas where arroyos and entrenched tributaries were relatively abundant.

The influence of beavers on channel morphology and drainage network characteristics would have been greatest in the upper watershed prior to trapping and the impact of trapping would have also been greatest. These areas were not, however, the areas initially explored by the GLO surveys or early military expeditions. For example, the Gila River watershed was trapped between 1826 and 1834 and specific references are made to removing beavers from the San Pedro and San Francisco Rivers, the West and East Forks of the Gila River, and the lower Gila (Pattie 1831; Weber 1971). However, when the early military expeditions (1848 to 1852) entered the Gila River drainage they did so from southern New Mexico via the Lordsburg Plain (Leopold 1951), thereby restricting observations of pre-settlement channel incision to the middle and lower tributaries to the Gila River. The observation of discontinuous entrenchment on the San Pedro River in 1846, a lower tributary to the Gila River and trapped, suggests that discontinuous arroyos and tributary entrenchment would have existed on the West and East Forks of the Gila River, San Francisco River and other headwater tributaries. As these streams were not explored, any evidence of recent incision went unrecorded.

The baseline GLO survey in Oregon is another good example of how location and timing influence what is observed and recorded. The baseline GLO survey for Oregon occurred in 1851 in the Willamette Valley area (White 1996), while the Crooked River area in eastern Oregon was not surveyed until 1876 (Buckley 1992) or about 50 years after the streams of the Crooked River drainage had been trapped. Beaver dams are mentioned in early trapper journals and in the military journals of 1858. They are not mentioned in the GLO survey notes of 1876, though there is frequent reference to swampy areas and wet meadows (Buckley 1992), the signature of past beaver activity. Other examples comparing the timing of the early expeditions, GLO surveys, and beaver trapping are presented in Table 13.

The GLO surveys post-dated beaver trapping everywhere as well as activities such as the California gold rush and non-Euro-American settlement along the Rio Grande River valley in New Mexico. Baseline surveys were site-specific, focusing first on those areas that were about to be settled or in the process of being settled by Euro-Americans (White 1996) leaving large portions of each state unsurveyed until sometime later (Clements 1985).

> By the 1860's, the surveys had been extended across the Mississippi and embraced practically all of Louisiana, Arkansas, Missouri, Iowa, and southern Minnesota; . . . large areas in California and Oregon had been surveyed to accommodate the settlement following the gold rush of 1849 and the migration to the Oregon Territory. The map accompanying the report of 1865 shows surveys in eastern Kansas and Nebraska and along the old Santa Fe Trail in New Mexico in advance of settlement in that area. That

> map also shows limited surveys in Utah to accommodate the influx of Mormons. Vast areas comprising the Dakotas, Montana, Idaho, Wyoming, Nevada, much of Kansas, Nebraska, Colorado, Utah, New Mexico, and all of Oklahoma (then Indian Territory) and Arizona were entirely unsurveyed at this time (Clement 1985, p. 106).

This limited exploration prior to Euro-American settlement and grazing resulted in what Graf (1984) refers to as a "spatial bias." He sees this bias as "a major hazard in geomorphic theory development because of the relatively small size of the geomorphic research community." The limited number of researchers means that "individual scientists can affect the development of theory with relatively few publications, and therefore the field origins [*emphasis added*] of those few publications [or observations] assume disproportionate importance (Graf 1984, p. 78)." The assignment of disproportionate importance has indeed occurred in the case of the scattered pre-settlement arroyos and tributary entrenchments. Their presence has been central to the debate about whether Euro-American livestock grazing or climate change or variability was the dominant causal mechanism leading to widespread arroyo development after Euro-American settlement (Cooke and Reeves 1976). The presence of pre-historic arroyos (Love 1979; Balling and Wells 1990) and the pre-settlement, but clearly recently formed arroyos, has led some to suggest that climate was the dominant causal mechanism and Euro-American livestock grazing merely a "trigger pull which timed a change about to take place. (Bryan1928a, p. 281)." These pre-settlement arroyos have also be used as evidence of the sensitivity of Southwestern streams to climatic variability. Yet when one considers the temporal and spatial distribution of the early expeditions and GLO surveys with respect to beaver trapping, different conclusions emerge regarding the fluvial and ecological significance of those early observations and the stability of the fluvial systems.

Cooke and Reeves (1976) provide an excellent conceptual model of the various morphological, biological, and climatic random frequency-magnitude events that could have led to isolated arroyo formation in pre-Euro-American settlement times. They do not however, include beaver trapping and dam failures as a potential causal mechanism leading to channel entrenchment in their model. One intriguing spatial relationship they note that is suggestive of a beaver influence is the presence of discontinuous arroyos downstream of cienégas in southern Arizona. They considered whether the incisions downstream of the cienégas were the result of a slightly steeper valley slope downstream of the cienégas but concluded that the evidence of a cause and effect relationship was inconclusive. They offered no other explanation for the pattern. However, the abrupt reduction in beaver activity and dam maintenance would explain the spatial relationship.

The juxtaposition of the cienégas (indicative of stable fluvial systems) and arroyos (indicative of unstable or destabilizing fluvial systems) would occur in a watershed recently depopulated of beavers (Figure 32) after a long-term presence (Figure 29). The long-term beaver presence would result in the development of stable and extensive wetlands (Ruedemann and Schoonmaker 1938; Henderickson and Minckley 1984; Naiman et al. 1986; 1988). The greater resistance of the cienégas to incision, compared to the valley-fill sediment or dam sediments, would effectively halt the headward migration of a knickpoint generated by a base-level drop downstream, due perhaps to dam failure. The result would be the development of the observed spatially separated or discontinuous zones of erosion. Discontinuous arroyos occurred downstream of cienégas on the San Pedro River and on the Santa Cruz River and some of its tributaries. Both rivers were trapped between 1826 and 1834. The next observation is not occur until the late 1840s and early 1850s. As Table 12 shows, 12 to 20 years is plenty of time for substantial channel incision, widening and headward migration to occur.

Other places where pre-Euro-American tributary incisions, headcutting, and arroyos have been observed, though not in conjunction with cienégas, are on the Colorado Plateau, the Zuni River in Arizona, the Rio Puerco in New Mexico, and the Diablo Mountains in California. In the early 1870s, Dellenbaugh (1912) noted earth-cliffs bordering unnamed tributaries in the Colorado River area that were 9 to 12 meters high. He stated that Euro-American livestock grazing had not yet reached this area and suggested that the tributaries were responding to a drop in base level on the main stem that had occurred for some unknown reason. The Colorado Plateau had been trapped in the 1820s and perhaps as late as the 1840s (Phillips 1961), and Dellenbaugh's observations (30 to 50 years later) are consistent with beaver-dam failures on the main stem triggering multiple points of base-level lowering. Drops in the base level of the main stem would have set in motion tributary entrenchment with the initiation point at the confluence between the main stem and the tributary stream (Schumm et al. 1984).

The Zuni River is a special case because documentation exists of arroyos that pre-date both Spanish and Euro-American activity. These early arroyos date from about 1680 and tree-ring dates indicate that the Zuni River had eroded to its present level by 1776 when Fray Dominguez observed an arroyo adjacent to the Zuni Pueblo as well as arroyos upstream of the pueblo (Balling and Wells 1990). Balling and Wells (1990) analyzed the morphology and potential causes of arroyo formation in this area using modern precipitation records and post-settlement arroyo development and identified links between arroyo formation and changes in local precipitation patterns, particularly precipitation intensities. However, several factors suggest that their link between arroyo formation and changes in local precipitation bears further consideration. First, variability in precipitation patterns and intensities are the norm for the Southwest (D'Arrigo and Jacoby 1991; Meko et al. 1991). Second, these early arroyos occurred in the vicinity of a pueblo. Native Peoples may have deliberately or unintentionally altered some feature of the landscape that caused the initiation of arroyos, such as the failure of a check dam. Third, there may have been a change in beaver activity due to disease, fluctuations in flood supply, or reductions in numbers by Native Peoples that resulted in dam failures and the initiation of arroyo formation. Finally, the transfer of modern relationships between arroyo formation and changes in precipitation patterns back to pre-Euro-American settlement times ignores the fact that the current relationships are occurring on highly altered and disturbed systems. Consequently, linking arroyo formation to climatic variability as the cause of the arroyo formation in 1600s is more fraught with ambiguity than previously considered.

The role of beaver-dam failures in the arroyo formation in the 1600s is uncertain, but becomes a more probable contributor in the mid-1800s. The majority of the observations identifying arroyos that pre-date Euro-American grazing and settlement arroyos in the Zuni River area begin in 1849. The 1849 observation describes incised channels in the tributaries and main valley of the Zuni River. Based on the summary provided by Balling and Wells (1990), arroyos expanded in range after 1849. Beaver trapping post-dates these observations.

The Zuni River is a tributary to the Little Colorado River, a river basin that was trapped for beavers in the 1820s and 1830s (Gregory and Moore 1931; Phillips 1961). References exist of beaver lodges in 1852 located slightly upstream from the town of Holbrook, or located about 58 linear kilometers downstream of the confluence of the Zuni River and the Little Colorado River. Beaver also were noted as abundant in places along the Little Colorado River in the 1880s (Colton 1937). In addition, the 1852 expedition observed a beaver dam on the Zuni River below the village of Zuni in an area that is now a dry wash.

> I observed in but one place a few populars (populus augustifolia,) and near these trees was a beaver-dam, in which was growing cat-tail (Leopold 1951 citing Stigreaves 1853).

While this quote suggests that the observation of populars and beaver dams in this area may have been a rare sight in 1852, it indicates that beavers were or had been present in the area. The loss of beavers would have made streams more susceptible to channelization during the period of above-average precipitation from 1835 to 1849 (Meko 1990; D'Arrigo and Jacoby 1991; Meko et al. 1991) that pre-dates Euro-American settlement and grazing. As the arroyos dating from the late 1600s to mid-1700s are few, a localized loss of beavers from select drainages or changes as a result of Native Peoples' land use practices are other viable explanations in addition to the proposed climate-driven explanation.

The above discussion highlights the importance of considering the temporal and spatial location of the GLO and early military and scientific explorations as they pertain to the observations of discontinuous arroyos and entrenched tributaries that pre-date Euro-American settlement and livestock grazing, and later interpretations of their fluvial and ecological significance. Based on a comparison of their timing of beaver trapping and the early observations of pre-settlement arroyos, I suggest that primary cause of the pre-settlement entrenchment was the loss of beavers due to trapping and the subsequent dam failures, augmented to some degree by climatic factors. I conclude this section with an observation from Cooke and Reeves (1976) at the end of their book Arroyos and Environmental Change in the American South-West. "The final conclusion from this brief comparison is perhaps the simplest and most obvious: apparently similar arroyos can be formed in different areas as a result of different combinations of initial conditions and environmental changes. (Cooke and Reeves 1976, 189)." The addition of beaver trapping to the list of Euro-American disturbances and the recognition of its timing adds another piece to the story and provides a very plausible explanation for presence of active arroyo formation just prior to Euro-American grazing and settlement.

Explaining the Absence of Arroyo Formation from 1750 to 1825 Despite Large Herds of Spanish and Mexican Livestock

The relative contributions of livestock grazing versus climate in causing widespread arroyo formation in the Southwest post-Euro-American settlement has been debated for nearly three quarters of a century. One reason that climate has been considered the overriding control on arroyo formation, and livestock simply the trigger, is that large livestock herds have existed twice in the Southwest (1750 to 1825 and 1870 to 1905) but a period of extensive arroyo formation occurred only once and that during the latter period (Cooke and Reeves 1976; Denevan 1967). Both periods had below-normal seasonal precipitation. Possible explanations for this discrepancy in landscape response to livestock grazing include 1) a gradual, long-period of change in climate that altered vegetation to a point where watersheds in the late 1800s were more sensitive to livestock grazing, 2) the coincidence in time of the overstocking of the range and severe summer drought in the late 1800s but not in the late 1700s and early 1800s, and 3) some combination of the two (Denevan 1967; Cooke and Reeves 1976). The discrepancy in landscape response to the two periods of large-scale grazing could also be explained by that fact that beavers were abundant in the late 1700s and early 1800s, but largely absent by the late 1800s due to Euro-American trapping in the 1820s and 1830s. In other words, the Spanish and Mexican sheep and cattle pre-date Euro-American beaver trapping while the Euro-American cattle herds post-date trapping.

The presence of abundant beavers during the time of Spanish and Mexican settlement and sheep and cattle grazing would have mitigated any potential impact as a result of increased runoff. The dams would have kept channel capacities low and effectively captured the increased runoff and distributed it onto the valley floor where its erosive power was less. Wetlands would have provided stability to the fluvial systems in the presence of both drought and heavy rainfall (Bailey 1936; Grasse and Putman 1950; Hendrickson and Minckley 1984; Johnson and Naiman 1990; Hillman 1998). When dams failures did occur, they were rapidly repaired, preventing the development of permanent discontinuous arroyos or a channelized drainage network in this pre-trapping period despite heavy sheep and cattle grazing. With the removal of beavers, these compensating mechanisms would have been lost and dam failures and nonrepair would have set in motion channelization into the fine sediment trapped behind the dams. When the large Euro-American livestock herd arrived in the 1870s the buffering effect of beavers and intact beaver dams was gone and the increased runoff and decreased stream bank resistance to erosion that occurred in this second period of overgrazing and settlement resulted in the development of extensive arroyos.

Areas for Future Research

The conceptual model and supporting research presented in this chapter indicates that beavers and beaver trapping likely had a major influence on the character and stability of stream and riparian ecosystems. Additional research is needed however to verify the model and in the process improve our understanding of the connections between beavers, streams, riparian zones, and fisheries and wildlife populations as well as the time scales required for stream and riparian restoration and the factors limiting that restoration. Some areas for future research include examining how abundant beaver dams distributed throughout watersheds alter the storm hydrographs, local hydrology and stream-riparian ecosystems locally and along the drainage. Unraveling their real rather than their hypothetical impact on stream hydrology will likely required approaching the questions from two different, but complimentary avenues. First, the hydrologic impact of beavers on stream hydrology can be explored by modeling flood peak responses to abundant beaver dams. The modeling would expand on Beedle's (1991) study by examining how flood peaks change if valley floor storage is incorporated into the model. Beedle (1991) only considered the impact of pond storage on flood peaks, but reductions in peak flows have been considerable when flood flows access their valley floors (Campbell et al. 1972; Shankman and Pugh 1992; Hillman 1998).

The second approach involves the selection of permanent study reaches and long-term monitoring of beaver-induced changes to stream-riparian ecosystems as beavers enter a system and expand their range. Paired watershed experiments could be set up in which beaver are reintroduced into one of the watershed. Stream gages would be established to record a variety of storm hydrographs under the two scenarios. One limitation of this approach is that beavers tend to migrate and could easily end up in the control watershed. Therefore, another approach would be to select paired watersheds with good baseline hydrographs and then re-establish beavers in both. In both scenarios, changes in the distributions of beaver dams need to be monitored in order to identify the threshold, storm conditions, and drainage areas under which their influence on the stream hydrographs become visible.

Another research area is to explore how quickly beavers can hydrologically reconnect and stabilize fragmented and degraded stream-riparian-valley-floor ecosystems in lower-order streams. Features of interest would be rates and locations of valley water-table rises, changes in the frequency of valley-floor flooding and its impact on storm hydrographs, changes in valley-floor vegetation communities, and the degree to which stream and riparian sensitivity to climatic variability decreases. Because many of the stream and riparian ecosystems are fragmented and lacking in willows, cottonwoods, and aspen, tracking the changes would help identify the factors limiting the successful reintroduction of beavers and the maintenance of their populations. In the process, we would develop strategies for circumventing the lack of vegetation, such as those used by Apple et al. (1984) in Wyoming. In their study they jumpstarted the restoration process by initially supplying beavers with the vegetation needed to build their dams until the willow population had expanded sufficiently to meet their needs.

A final area of research would to be to quantify the contribution of beavers to stream restoration in post-fire environments. The fires in summer 2000 in the Intermountain West may be indicating what lies ahead as global climate change and past land-use practices begin to converge. As fires of this magnitude will occur again, it is critical that we evaluate post-fire treatments as they relate to streams and fisheries habitat and identify which treatments yield the quickest and best restoration results.

Large-scale fire tends to result in a period of accelerated sediment erosion (e.g. multiple debris/mud flows and hillslope erosion) in the steeper watersheds. A major concern is the potential timing, magnitude, and distribution of these sediment inputs into streams that contain endangered and threatened fisheries. A large number of streams could be affected simultaneously and numerous fisheries wiped out. As most low-gradient streams are not ecologically healthy or functioning properly because of past channel incision and/or widening, these ecosystems are particularly sensitive to large-scale disturbances. Prior attempts at riparian and fisheries-habitat restoration have been only marginally successful because the importance of the stream and valley floor hydrologic connection has been ignored and factors limiting its reconnection have not been addressed.

The ability to reconnect hydrologically streams to their valley floor is currently limited by 1) the lack of sediment needed to build banks and narrow the channel, 2) the lack of mechanisms capable of trapping and storing sediment in an ecologically and financially sustainable manner, and 3) continued beaver trapping and livestock grazing. The post-fire erosion that is anticipated after events such as the fires in Montana in 2000 offers an opportunity to restore the stream and valley-floor hydrologic connection by using beaver dams to trap and store the anticipated influx of large volumes of sediment. If beavers are used in conjunction with other watershed and land-use treatments, beavers can enhance fisheries restoration and help mitigate the impact of accelerated post-fire erosion by providing sediment detention reservoirs for fine sediment that would otherwise be flushed through the system or cover spawning gravels. The study would compare the effectiveness of beavers against other watershed and riparian treatments in addressing the sediment erosion problem, accelerating the long-term ecological restoration of the entire stream-riparian system, and minimizing fisheries impacts. Such a study would provide land managers the information they need to plan effectively when faces with future post-fire conditions. In conclusion, this two-pronged approach towards identifying beaver influences on watershed characteristics (modeling and long-term field studies) would further illuminate how Euro-American trapping altered watersheds throughout North America, the magnitude of that alteration, and its long-term implications for fluvial geomorphology and streams and riparian ecosystems.

Conclusions

In this chapter I presented a conceptual model of the geomorphic, hydrologic, and vegetative effects of beavers and beaver trapping on fluvial systems based on a literature review and my own fieldwork. Beaver trapping by Euro-Americans was a regional disturbance similar to grazing, logging, and agriculture. Cause and effect were, however, reversed. Beaver trapping and dam failures lea to channel incision and eventually changes in vegetation communities and stream hydrographs. Grazing, logging, and agriculture on the other hand altered vegetation that led to increased runoff, decreased resistance of sediments to erosion, increased stream discharges, and eventually channel incision. This distinction is critical when interpreting historic landscapes that post-date trapping, but pre-date grazing, logging and other settlement activities. In this way my model adds to the Cooke and Reeves (1976) conceptual model of arroyo formation by describing the processes and sequence of events that occurred in watersheds prior to where their model begins, but still as a result of Euro-American disturbance.

The model provides a possible explanation for the discontinuous channels (beaver trapping) and wetlands (long-term beaver presence) observed by many of the early expeditions in the 1840s and 1850s in the Southwest that pre-date grazing. A long-term presence of beavers in these watersheds would have contributed to the development of abundant wetlands and complex vegetation communities. Euro-American beaver trapping led to dam failures and to the creation of multiple knickpoints in the drainage. Erosion of the fine sediment, once trapped behind the dams, led to channel formation while wetlands and bedrock outcrops resisted erosion and prevented the development of integrated channelized drainage networks, at least until Euro-American livestock grazing appeared on the landscape. The tributary incisions observed at confluences with other streams reflected tributary adjustments to the lowered base level on the main stem as a knickpoint triggered at a dam failure migrated past the confluence.

The development of channelized flow set in motion local and regional feedback loops that decreased the distribution and abundance of water in watersheds as dams failed, ponds drained, and the valley groundwater table began to drain into the new channels. Locally, vegetation communities in the channelized reaches probably shifted to more drought-tolerant vegetation as water tables dropped and the frequency of valley-floor flooding decreased. Where wetlands existed, however, the changes were probably minimal as current research indicates that wetlands can have a long residence time on the landscape when left undisturbed by human activity (Ruedemann and Schoonmaker 1938; Ives 1942; Naiman et al. 1988). As channelization of the drainage network increased, water would have been transferred more rapidly from the upper to lower watershed leading to increased flood magnitudes with greater frequencies. The speed of that transfer, and its impact on flood magnitudes downstream, would have varied as a function of the location and size of the unmodified reaches (Campbell et al. 1972; Hillman 1998). Thus overall, increases in flood magnitudes and frequencies may have remained overall small (Campbell et al. 1972; Schumm et al. 1984; Shankman and Pugh 1992; Hillman 1998) prior to the advent of Euro-American livestock grazing and logging, though local areas would have occasionally experienced unusually large flows as dams abruptly failed in response to large storm events (Butler 1989; Kondolf et al., 1991; Meentemeyer and Butler 1999) or from other unknown causes not related to precipitation events (Hillman 1998).

The model presented here reveals several limits in our understanding of fluvial systems and demonstrates the importance of taking a longer historic and geographic perspective. The notes of the GLO surveyors and later expeditions have been our principle baseline for interpreting and quantifying landscape changes pre- and post-settlement (Bryan 1928a; Leopold 1951; Bull 1964; Hastings and Turner 1965; Burkham 1972; Cooke and Reeves 1976; Knox 1977). Because these observations post-date beaver trapping by 20 to more than 100 years, we have missed the contributions of beavers and beaver trapping on the development of current drainage network patterns and stream ecosystems, and therefore a potential causal mechanism that can explain the discontinuous channels, incised tributaries, and wetlands observed prior to Euro-American settlement. As a result of their missed presence in our analysis of fluvial systems, it would appear that we have overstated the sensitivity of stream-riparian ecosystems in arid and semi-arid regions to climatic variability. Similarly, we have not recognized that the sensitivity to climatic variability is probably more a post-trapping and post-grazing phenomena rather than an inherent feature of functioning Southwestern streams.

In conclusion, fluvial geomorphologists can play a critical role in advancing the science of stream ecosystem restoration by beginning to incorporate beavers into our conceptual and empirical models of fluvial systems and making explicit the links between stream-riparian restoration and beaver reintroductions and how beavers, vegetation, and channel morphology interact in time and space to create ecosystems. By linking fluvial geomorphology with biology and ecology, we will begin to better understand the complexity of these systems. By including beavers and beaver trapping in our models and research we should be able to explain certain features of the historical landscape whose causes have remained elusive and to improve our success rate when attempting ecosystem restoration.

CHAPTER IV

IMPLICATIONS FOR FLUVIAL GEOMORPHOLOGY

Introduction

Fluvial geomorphologists are in a unique position to make explicit the links between historical and recent channel changes, current rates and processes of stream-riparian restoration, and how human disturbances have interacted synergistically to destabilize landscapes. By linking fluvial geomorphology with biology, ecology, and human disturbance the complexity of fluvial systems becomes better represented and more understandable, and the ability to predict future channel changes improves. A more integrated approach has the potential to explain certain features of the historical landscape whose causes have remained elusive and to improve our success rate when attempting ecosystem restoration.

Two large-scale Euro-American disturbances that influence current and historic channel morphology and watershed hydrology are Euro-American beaver trapping and livestock grazing and were discussed in chapters 2 and 3. These chapters revealed the importance of placing conceptual models, current channel changes, and any comparison of past and present changes into as broad a historical context as possible. Two implications of placing those models, relationships, and changes in a historical context are discussed below.

Placing Current Hydraulic Geometry Relationships and Fluvial Concepts in their Historical Context

Leopold and Maddock's (1953) hydraulic geometry relations have been a cornerstone of fluvial geomorphology and a starting point for refinements to those relationships. However, 70 to 250 years exist between the period of extensive beaver trapping and the installation of the stream gages used by Leopold and Maddock (1953) to determine their hydraulic geometry relationships (Figure 27). The result was probably some increase in downstream flood magnitudes as upper watersheds became more channelized. A second wave of Euro-American disturbances (i.e. large-scale grazing, settlement, mining, agriculture, and logging) furthered altered watershed hydrology and channel morphology (Table 14). Thus when the current conceptual models of fluvial systems (Love 1979; Cooke and Reeves 1976; Knighton 1998) and hydraulic geometry relationships (Leopold and Maddock 1953; Knighton 1998) are placed in their historical context, the models and relationships are revealed to describe processes, relationships, and rates of change that reflect highly altered and degraded fluvial systems. The watersheds they describe are devoid of the stabilizing influences of beavers and abundant watershed vegetation in the upper watersheds (< 5^{th} order streams) and abundant stream and valley floor vegetation, complex, multi-channeled streams, and hydrologically connected stream and valley floors in the lower watersheds. Instead, the relationships and models capture channelized watersheds in which the streams are largely single-thread, entrenched and wide, have minimal stream bank vegetation, and are hydrologically disconnected from their valley floors. Recognition of the above, and the results and analyses presented in Chapters 2 and 3, leads to two questions that have implications for how we interpret current and historic channel changes and predict future channel changes.

1. Is the sensitivity of streams and riparian areas to climatic variability in the arid and semi-arid West a real feature of these systems or simply an artifact of historic Euro-American disturbances?
2. How does incorporating Euro-American beaver trapping and livestock grazing into our examination of large-scale historic channel widening alter our analysis of cause-and-effect relationships?

Stream and Riparian Zone Sensitivity to Climatic Variability -- A Reality or an Artifact of Euro-American Disturbances?

The question of whether the current sensitivity of Southwestern streams to climatic variability is an inherent characteristic of arid and semi-arid streams or an artifact of Euro-American disturbance was discussed briefly in Chapter 3. The apparent sensitivity of Southwestern streams to climatic variability is based on the following events and observations:

1. modern-day channel responses to climatic variability in this region,
2. the occurrence of major channel widening in the late 1800s and early 1900s in the Southwest (Burkham 1972; Cooke and Reeves 1976) coincident in time with the most abrupt shift from severe sustained drought to above-average

precipitation in the last 1000 years (D'Arrigo and Jacoby 1991; Meko et al. 1991)

3. the presence of discontinuous arroyos and incised tributaries in the Southwest and on the Colorado Plateau prior to Euro-American settlement and grazing (Dellenbaugh 1912; Bryan 1928a; Bull 1964; Cooke and Reeves 1976; Balling and Wells 1990),
4. the existence of two periods of large livestock herds in the Southwest -- the Spanish and Mexican herds in 1750 to 1825 and the Euro-American herds in 1870 to 1905 (Cooke and Reeves 1976; Denevan 1967), but only one period of arroyo formation and that during the later period, and
5. the presence of pre-historic cut-and-fill sequences, many of which show multiple periods of wet meadow development and/or valley-floor aggradation (Gregory 1917; Cottam and Stewart 1940; Love 1976).

Recent tree-ring studies have begun to provide information on pre-settlement climatic variability that helps place climate over the last 150 years into a broader and longer-term context. A review of the tree-ring research indicates that shifts in the abundance of precipitation have been the norm for the Southwest and Intermountain West over the last 1000 years (D'Arrigo and Jacoby 1991; Meko et al. 1991) (Figure 36). D'Arrigo and Jacoby (1991) identified five periods of substantial drought and five periods of above-average winter precipitation over the last 1000 years in tree-ring data from northern New Mexico. The droughts varied in length from nine to 21 years and the periods of above-average precipitation ranged from 11 to 23 years. Of the five droughts,

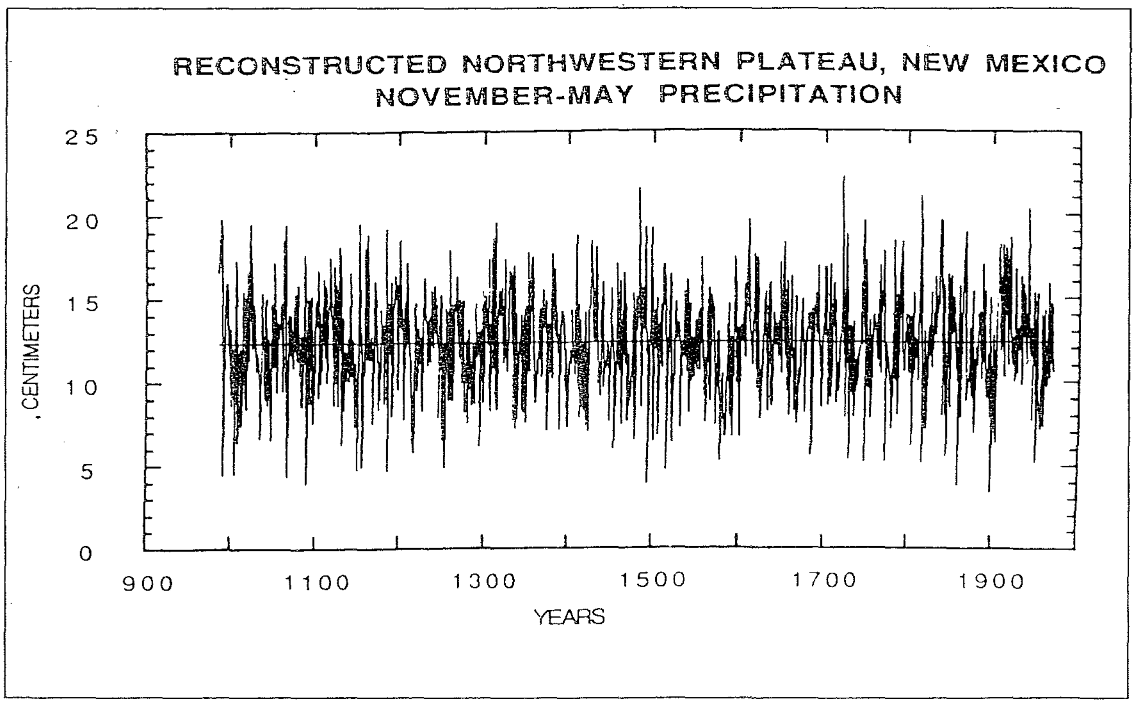


Figure 36. Reconstruction of November to May precipitation for the Northwestern Plateau Climatic Division of New Mexico for AD 985-1970; year-to-year values. Figure and text from D'Arrigo and Jacoby 1990, p. 98.

the drought that occurred in the Southwest from 1895 to 1904 (9 years) was third in severity and length after the droughts of 1577 to 1598 (21 years) and 1955 to 1964 (9 years). Of the five periods of above-average precipitation, the interval from 1905 to 1928 (23 years) was second in magnitude after the 1835 to 1849 period (14 years). Therefore, neither the drought nor the above-average precipitation in the late 1800s and early 1900s is unique over the last 1000 years. The abruptness of the shift from severe sustained drought to above-average precipitation in the early 1900s, however, is unique (D'Arrigo and Jacoby 1991). This combination of climatic events has suggested to some that Southwestern streams are particularly sensitive to climatic variability and that climate was sufficient to explained the channel widening, drainage network expansion, and increased flood frequencies and magnitudes that occurred in the late 1800s and early 1900s. Even those who consider overgrazing by Euro-American cattle as the driving force consider climate an integral part of the story (Cooke and Reeves 1976).

My results and analyses suggest, however, that the apparent stream sensitivity to short-term climatic variability (10 to 30 years) in the Southwest and Intermountain West is a recent development, and is the direct result of the removal of beavers and upland and valley floor vegetation -- features that imparted considerable stability fluvial systems. Evidence supporting the contribution of beavers in creating and maintaining stream and riparian stability comes from published studies. These studies document the effectiveness of large ponds in mitigating the effects of drought and floods on stream flow (Grasse and Putman 1950), the continued presence of wetlands, wet meadows, and stream flow during periods of drought (Bailey 1936; Schaffer 1940), and the long residence times of wetlands across a range of climatic regions in the absence of human disturbance (Ruedemann and Schoonmaker 1938 (New York); Ives 1942 (Colorado); Hendrickson and Minckley 1984 (southern Arizona); Naiman et al. 1986 (Quebec); Johnson and Naiman 1990 (Minnesota)).

Cooke and Reeves (1976) provide an excellent discussion of the various hypotheses and evidence used to explain arroyo formation. However, they did not consider the impact of rapid reductions in beaver numbers on channel stability, nor did others examining the causes of arroyo formation (Bryan 1928a, b; Bull 1964; Hastings and Turner 1965; Cooke and Reeves 1976; Bull 1997). Under the scenario of 1) increased channelization in the upper watershed as a result of beaver dam failures and nonrepair (Figure 32, Chapter 3), and 2) large reductions in riparian and upland vegetation due to livestock grazing, even a minor precipitation event could initiate a large flood and trigger channel incision or widening.

Schumm (1973) captured the increased potential for destabilization over time in his conceptual model of thresholds in geomorphic systems (Figure 37). In his model, valley-floor slope was his variable of interest. However, the concept of decreasing stability and thresholds of change applies to a range of geomorphic features, including channel width – the factors causing destabilization simply varying as a function of feature examined. In Schumm's (1973) case, as the valley-floor slope steepens the slope becomes increasingly unstable and the magnitude of the flood required to initiate channel incision decreases. The result is an increase in the number of potential destabilizing events and therefore the increased probability that channel incision will occur. While a large flood is the apparent cause of incision in his example, the incision could have occurred at lower discharge (Figure 37).

Changes in stream-channel stability can easily be substituted for valley-floor stability. The result of increasing instability and therefore greater sensitivity to climatic variability or flooding is the same -- channel widening and incision -- but the causes of increased instability are different. In the case of stream channels the increased instability occurred because trapping, livestock grazing, and cultivation had removed the stabilizing forces of riparian and upland vegetation and beavers from the watersheds. The reduction in upland vegetation resulted in increased storm runoff while the loss of riparian vegetation from the stream banks and valley floor resulted in decreased roughness and channel resistance to stream erosion. The loss of beavers meant that when beaver dams failed they were not repaired and local points of base level lowering and knickpoint initiation were created (Figure 32). As a channelized drainage network developed, water would have been more rapidly transferred from the upper to lower watershed and flood magnitudes increased for a given storm event.

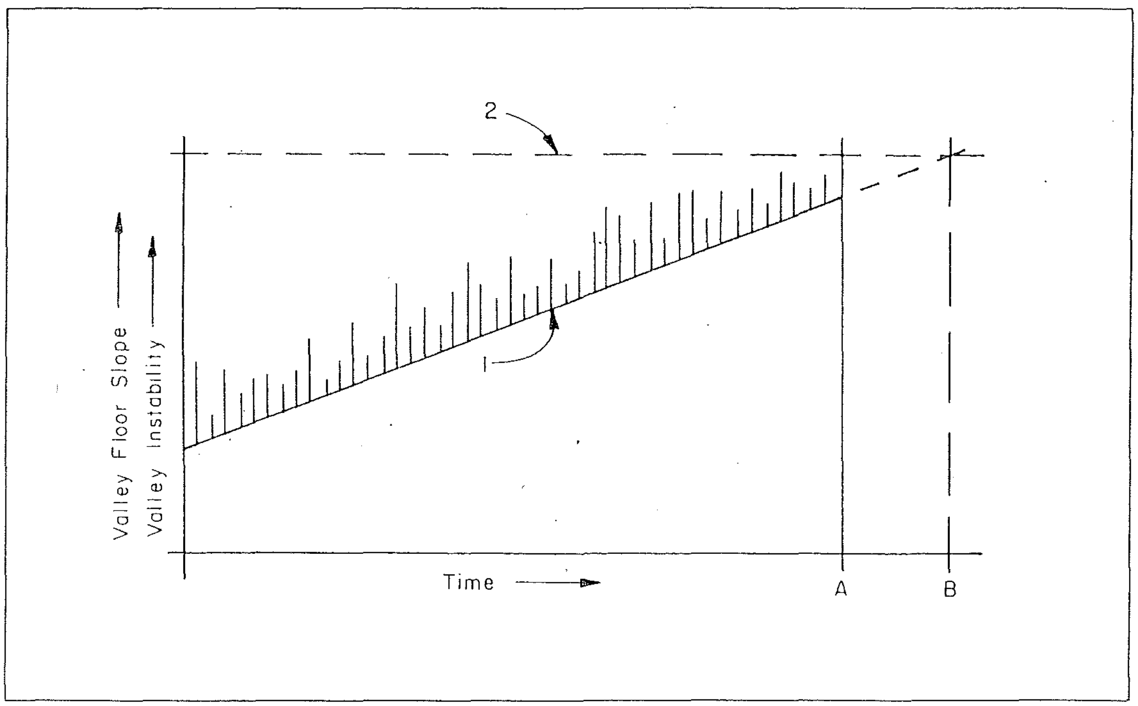


Figure 37. Hypothetical relation between valley-floor gradient and valley-floor instability with time. Superimposed on line 1, representing an increase of valley-floor slope, are vertical lines representing instability of the valley floor as related to flood events. When the ascending line of valley-floor slope intersects line 2 representing the maximum slope at which the valley is stable, failure or trenching of the valley alluvium will occur at time B. However, failure occurs at time A, as the apparent direct result of a major storm or flood event. (Figure and text from Schumm 1973, p. 302).

Reexamining the Causes of Large-Scale Historic Channel Widening in Light of Beaver Trapping and Livestock Grazing

This section presents an example to demonstrate how interpretations of causal mechanisms of change in watershed hydrology and stream-channel morphology can vary once an event is placed in a historical context that includes beaver trapping. The example involves the Gila River in southwestern New Mexico and southeastern Arizona and was selected for analysis because of the relative abundance of information on the timing of key events in this watershed. This analysis builds on an earlier study by Burkham (1972) in which he analyzed the causes and timing of the channel widening of the Gila River between 1905 and 1917. He drew on U. S. Geological Survey gage data, diaries and journals written in 1540, 1846 to 1874, cadastral surveys made during 1875-1894, soil surveys (1904), photographs (1909-1917) and topographic maps of the Safford Valley (1914-1915), Senate document 436 (Olmstead1919) and U.S. Geological Survey Water Supply paper 450-A (Schwennesen 1921), cross-sections (established in 1937 and in 1943), aerial photos (1935 is first year), tree ring data (Stockton and Fritts 1968) and post-settlement precipitation data from rainfall stations in the headwaters (1893 on, Burkham 1970).

Major changes in channel widths took place in the early 20th century on the Gila River in the Safford Valley of Arizona (Burkham 1972). The average channel width increased from less than 46 meters in 1875 to an average width of about 610 meters between 1905 and 1917 during several large magnitude winter floods (Burkham 1972). The bulk of the widening occurred in 1905 and 1906 though floods in 1891 and 1916 also contributed. The large floods had their source in the mountainous headwaters of the Gila River (Burkham 1972). These floods were coincident in time with one of the wettest periods in the last 1000 years according to tree-ring data (Burkham 1972 citing Stockton and Fritts 1968; D'Arrigo and Jacoby 1991; Meko et al. 1991).

Examination of stream discharge and precipitation data available after 1910 shows a strong correlation between large magnitude floods in the Gila River and rain-on-snow events and high-intensity, long-duration storm events (Burkham 1970). Based on the tree-ring data of Stockton and Fritts (1968) and data from stream and precipitation gages, Burkham (1972) concluded that the large flood magnitudes in 1905 and 1906 were the result of precipitation events in the headwaters. The implied assumption in his analysis is that the precipitation events were unusual. However, by 1900 the Gila River watershed was an altered system having been trapped, overgrazed and, to a smaller degree, cultivated.

Burkham (1972) considered the influence of livestock grazing and valley-floor cultivation on both the magnitude of the floods and the susceptibility of the channel banks to erosion. He concluded that the contribution of valley-floor cultivation to the channel widening was minor because only about 3.5 percent of the 20 km by 125 km long valley was under cultivation at the time of the flooding and channel-widening events (Burkham 1972). However, the location of those cultivated acres is important because their location determines the potential effect of that cultivation on stream-bank stability. Burkham (1972) cites Lapham and Neill (1904) when discussing the amount of area under cultivation " … a small portion of the Pecos sand is at present cultivated, mainly because of the difficulty and expense of clearing off the willow, cottonwood, and mesquite, and leveling the land for irrigation (Lapham and Neill 1904, p. 1059)," but does not provide specific locations. However, the reference to willows, cottonwoods, and mesquite removal and irrigation suggests that the plots were in close proximity to the channel. As large portions of the stream banks of the Gila River are composed of sands and silts (pers. observation 1994), the removal of riparian vegetation would have contributed to local reductions in stream-bank stability and may have been of greater consequence then Burkham (1972) surmised based on the numeric amount cultivated, especially when considered in conjunction with intensive livestock grazing in the valley.

With respect to livestock grazing, Burkham (1972) concluded that grazing did not enhance flood magnitudes between 1905 and 1917, though grazing may have somewhat increased the sensitivity of the stream banks to erosion by removing vegetation. He based his conclusions on his understanding that livestock grazing appeared to be largely restricted to the lower watershed while the floodwaters had their source in the mountainous headwaters.

> . . . the lack of precipitation and the extensive grazing prior to 1905 may have contributed to the susceptibility of the alluvial valleys to erosion during high flows. The period 1870-1889 was one of the driest periods of comparable length since 1650, and 1895-1904 was another period having very little precipitation. The years having small amounts of precipitation coincided with the years in which large numbers of cattle were brought into the area. The combination of very little precipitation and extensive grazing caused a deterioration in the vegetation of the valley, which may have made the alluvium more susceptible to erosion (Burkham 1972, G12-13).

Swift (1926), a Forest Service employee in the Safford Valley area during that time, was more definite about the impact of livestock grazing in the Safford Valley on the channel widening:

> During the drought, which started in 1899 and extended to the late summer of 1904, large numbers of cattle were forced to browse on shrubs of all kinds and large herds came to the river to drink. As a result, the willows, shrubs, etc., along the banks of the streams, were practically killed off. Large numbers of cattle died from starvation, and when the drought broke the unprotected banks of the streams melted away like sugar, until the channel reached the mammoth proportions of today (Swift 1926, p. 71).

A review of the published literature suggests that Burkham (1972) may have underestimated the presence of livestock grazing in the upper watershed, and therefore their potential contribution towards increasing volumes and rates of storm runoff in the upper watershed and flood magnitudes in the lower watershed. Swift (1926) noted livestock grazing on Bonita Creek, a tributary to the Gila River upstream of the Safford Valley, as early as 1884. Winn (1926) noted livestock grazing in the West Fork of the Gila River in the 1880s. A 1993 environmental impact statement for a cattle allotment on the East Fork of the Gila River stated that the area was severely overgrazed by 1908 (Department of Agriculture 1993). While the Gila National Forest was not created until the early 1900s, and data on livestock numbers are absent, the reference to overgrazing in the area by 1908 indicates that grazing was occurring prior to this date in this drainage. In addition, there is no reason to assume that the West Fork would have been grazed in the 1880s but the East Fork ignored by early livestock owners. The topography and valley floor of the East Fork of the Gila River are conducive to grazing (pers. observation 1993) and the area continued to be grazed up until the late 1990s.

One disturbance that Burkham (1972) did not discuss was the impact of beaver trapping on flood magnitudes. Extensive Euro-American beaver trapping occurred in the Gila River watershed from 1826 to 1834 (Pattie 1831; Weber 1971, Figure 38). The beaver-dominated conceptual model presented in Chapter 3 (Figure 32) and laboratory studies (Schumm et al. 1984) indicate that Euro-American beaver trapping in the upper watershed would have contributed to channelization because as dams failed and were not repaired they created points of base-level drop. The rate of dam failures and channelization would have been accelerated by the period of above-average precipitation from 1835 to 1849 (D'Arrigo and Jacoby 1991). Increased channelization of the drainage network would transfer water from the upper to lower watershed more rapidly, potentially amplifying flood magnitudes from even small events and thereby increasing the frequency of downstream flooding. This scenario is suggested by historical newspaper accounts and the oral history of the Gila River Pima Indians of floods on the Gila River in 1833, 1869, 1880, 1884, 1889, 1891, 1895, and 1896 (Dobyns 1981; Burkham 1970). Information on the actual discharges of those floods is absent until 1910 when two stream gages are installed on the Gila River -- one on the Gila River near Clifton (09442000) and one on the San Francisco River at Clifton (09444500).

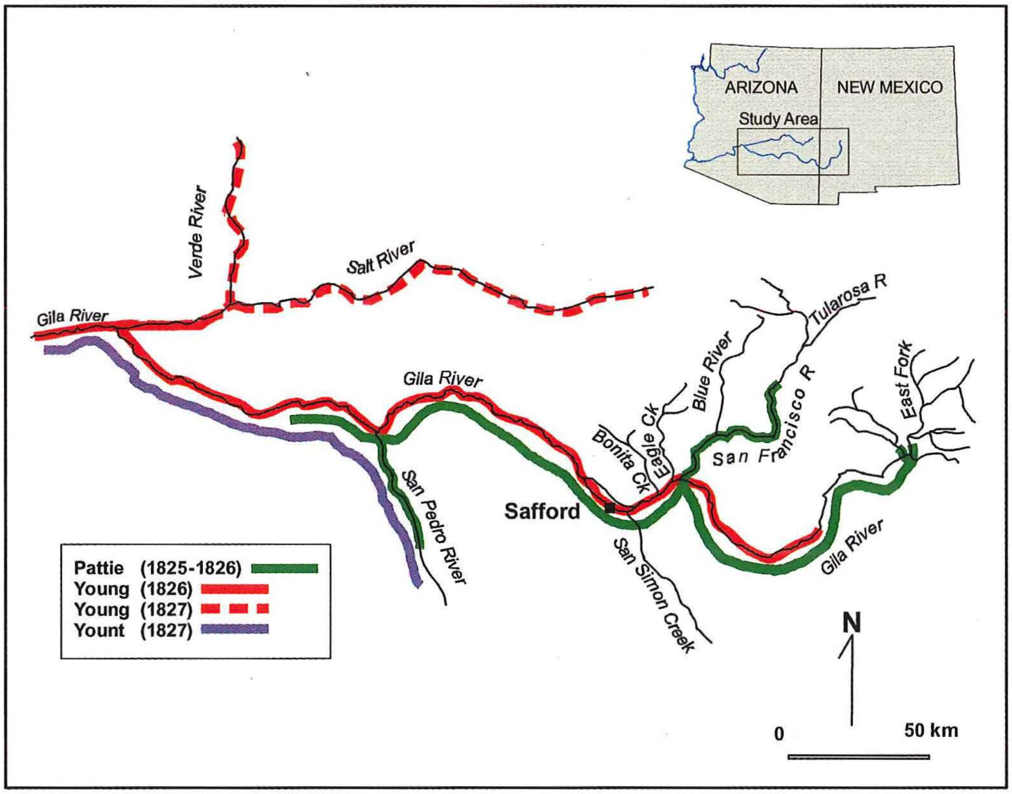


Figure 38. Known location, dates, and movement of trappers in the Gila River drainage basin. Data sources: Pattie (1831); Weber (1971). Map by author.

These pre-1905 floods were not coincident in time with a period of above-average precipitation. Their occurrences suggest a change in the flood regime beginning in the mid-1800s, or post-trapping. The floods of 1833, 1895, and 1896 are of particular interest. The 1833 flood was the first major downstream flood recorded in Gila River Pima oral history (Dobyns 1981). Trapping had been ongoing in the upper watershed since 1826 and Dobyns (1981) suggests that this flood may have been the result of the abrupt collapse of beaver dams destroyed in the preceding decade. This scenario is reasonable and large discharges have been documented occurring in response to abrupt dams failures (Butler 1989; Hillman 1998). The floods of 1895 and 1896 are of interest because they occurred during the third most severe drought in the Southwest in the last 1000 years (DArrigo and Jacoby 1990).

The large flow events between 1833 and 1905 suggests that the character of the upper watershed had changed, or was in the process of changing, in such a way as to cause an increase in flood frequencies and magnitudes. The most logical explanation is the removal of beavers from the upper watershed. Later, intensive grazing in the upper watershed would have further amplified flood magnitudes by increasing the storm runoff volumes and rates. At the same time that conditions were increasingly favorable to generating large floods, the stream-bank resistance to erosion in the lower watershed was decreasing as cattle grazing removed riparian vegetation from the stream banks. The "trigger" for channel widening became the period of above-average precipitation from 1905 to 1923 (D'Arrigo and Jacoby 1991) that now fell onto an increasingly channelized watershed with reduced vegetative cover. This combination of events represents a variation of Schumm's (1973) conceptual model of thresholds (Figure 37), in which he held the variability of the flood events constant and altered only the stability of the valley-floor slope. In the case of the Gila River, however, the floods were increasing in magnitude at the same time stream-bank stability was decreasing. The consequence would be to move the time of failure to the left of Line A in Figure 37, or back in time.

The analysis of channel widening on the Gila River reveals how different Euro-American disturbances in a watershed can interact synergistically to destabilize the river even though the actual disturbances are spatially (upper versus lower watershed) and temporally (early versus mid to late 1800s) separated. The question of whether the large flood magnitudes between 1905 and 1917 were the result of extraordinary or only average precipitation events operating on a degraded landscape will go unanswered because the precipitation gages in the headwaters are not installed until 1893 (Clifton), 1912 (Alpine) and 1917 (Reserve Range Station) (Burkham 1970). However, when beaver trapping and livestock grazing in the upper watershed and two, rather than just one, period of above-average precipitation in the region are included in the history of the Gila River watershed, the analysis reveals complex relationships between climate, Euro-American disturbances, and channel response -- relationships that apply not only to the Gila River, but to rivers throughout the Southwest and Intermountain West.

Conclusions

Separating out cause-and-effect relationships in fluvial systems is challenging because changes to the form and character of these systems are the result of a number of factors interacting over time and space. I have sought to integrate this complexity into my study design by examining how different cattle and elk grazing pressures and levels of beaver activity interacted over time and space, separately and in combination, to influence stream-channel morphology and hydrology. The results of the study provide insights into the directions, processes, and rates of channel change as well as the factors that limit channel-area reductions and the restoration of the stream and valley-floor hydrologic connection. The study provides a starting point from which to evaluate future channel changes as a function of treatment, allowing us to better understand the time scales of change and factors limiting the restoration of stream and riparian ecosystems. The study also underscores the magnitude of the watershed changes that have occurred since the arrival of Euro-American, beaver trapping being but the first of several large-scale human disturbances.

Restoration of the stream and valley-floor hydrologic connection, and the ecological systems that depend on that connection, is complex. The amount of historical stream channel enlargement has been great and, in many cases, may be permanent because sufficient sediment does not exist in the watershed, under current erosion rates, to decrease channel area to its predisturbance area. Upland erosion, mass wasting, and stream-bank erosion are all potential sources of sediment to the channel. However, except in extreme mass wasting events, the volume contributed by each is small, local, and episodic. The situation is further compromised by the fact that sediment-trapping mechanisms are absent in many places along the river as a result of historical and current beaver trapping and livestock grazing. Thus, what sediment does enter a stream is usually transported out of the watershed. The removal or reduction of cattle from the riparian zone is the first critical step. This single step will result in the expansion of riparian vegetation, stabilization of stream banks and channel bars, and the cessation of channel widening and further hydrologic disconnection between the stream and valley floor. However, it is but the first step and restoration will require multiple approaches.

The lack of sufficient sediment under current erosion rates and the lack of sediment trapping mechanisms is a problem when the desired future condition is the restoration and expansion of stream and riparian ecosystems. In larger-order streams (> 4^{th} order), reduction in channel cross-section area and the recovery of the stream-valley floor hydrologic connection is unlikely without massive human assistance and capital given the volume of channel enlargement. In these streams, restoration may be limited to the stream banks and channel bars rather than the valley floor. However, the expansion of channel bars, development of multiple smaller channels in a larger river, and the establishment of riparian vegetation on the bars and banks contributes to ecological restoration and bank stabilization and are, therefore, important components of watershed restoration. The potential for restoration of the stream and valley floor hydrologic connections, and its attendant changes, is more hopeful in first through fourth-order streams because beavers are capable of reducing available channel capacity by building dams that trap sediment and water. A review of the historical literature reveals that beavers were abundant prior to Euro-American beaver trapping and exerted a strong influence on the character and stability of fluvial systems. They remain an important component when attempting large-scale stream and riparian restoration in lower-order streams.

Beaver ponds effectively trap and store both water and sediment. Therefore, channels will experience a reduction in available channel capacity as a result of the ponds, even when sediment inputs are limited. The increased frequency of overbank flooding and the maintenance of elevated water tables as a result of beaver ponds facilitate riparian restoration by eliminating two of the three factors that currently hinder the expansion of riparian ecosystems -- low soil moisture and low water tables. The third limitation, livestock grazing pressure, is a more challenging problem. Cottonwoods, willows, and aspen are important food and building materials for beavers. However, these plant species are heavily utilized by cattle and elk and are limited in the West as a result of long-term and extensive cattle grazing. Without the recovery of riparian vegetation, streams and riparian areas will remain in degraded conditions with marginal value for fish, wildlife, and plant communities and for human communities concerned about water quality, quantity, and flooding.

Beavers are our natural allies in the effort to restore stream and riparian ecosystems. They build and maintain dams for free or, one might say, in exchange for abundant cottonwoods, willow, and aspen. Beavers and their dams are a cost-effective and an efficient way to hydrologically reconnect many lower-order streams to their valley floors, reduce flood magnitudes, and restore critical wildlife and fisheries habitat.

However, the impact of grazing pressure in riparian areas must be addressed because cattle, and in a few places elk, consume the willows, cottonwoods, and aspen preferred by beavers for food and building material and required for bank stabilization. An alternative to beaver dams is check dams, but these are built only at great initial financial costs and have a history of being rarely maintained (Heede 1966; Gellis et al. 1995; Shields et al. 1995). Given the limited amounts of capital available for structural alterations of stream channels and the importance of stream and riparian ecosystems to a variety of human communities and wild species, beavers and the removal or reduction of cattle grazing in the riparian zone represent perhaps the only way to ecologically and economically restore these vital stream and riparian systems on a regional scale.

APPENDIX A

GEOMORPHIC CHANNEL MORPHOLOGY DIMENSIONS

FOR EACH CROSS-SECTION

Basin Creek, Montana

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1995 Ch. XS area (sq. m)[1]	1995 Ch. Width (m)	1995 Max. Depth (m)	1995 Mean Depth (m)	1995 W/Mean D ratio
1995	Main Basin	1	Straight	New EE	1.59	4.1	0.74	0.39	11
1995	Main Basin	2	Straight	New EE	3.29	7.77	0.96	0.42	19
1995	Main Basin	3	Straight	New EE	2.69	6.48	0.88	0.42	15
1995	Main Basin	14	RB = inside	RG	5.57	8.34	1.24	0.67	12
1995	Main Basin	15	Straight	RG	3.12	4.11	1.12	0.76	5
1995	Main Basin	16	LB = inside	RG	3	5.99	0.78	0.5	12
1995	Main Basin	27	Straight	RG	1.91	4.35	0.91	0.44	10
1995	Main Basin	28	RB = inside	RG	2.16	4.14	0.9	0.52	8
1995	N. Basin	4	LB = inside	New EE	1.35	4.71	0.64	0.29	16
1995	N. Basin	5	Straight	New EE	0.38	2.58	0.54	0.15	17
1995	N. Basin	6	LB = inside	New EE	1.81	6.95	0.69	0.26	27
1995	N. Basin	17	Straight	RG	2.12	5.85	1.09	0.36	16
1995	N. Basin	18	Straight	RG	0.87	3.24	0.42	0.27	12
1995	N. Basin	19	Straight	RG	1.08	2.3	0.93	0.47	5
1995	N. Basin	20	Straight	RG	2.35	5.12	0.9	0.46	11
1995	N. Basin	21	Straight	RG	1.17	5.25	0.66	0.22	24
1995	N. Basin	22	Straight	RG	1.37	2.62	0.77	0.52	5
1995	N. Basin	25	Straight	New EE	1.36	6.39	0.44	0.21	30
1995	N. Basin	26	LB = inside	RG	3.19	5.53	1	0.58	10
1995	S. Basin	7	Straight	New CE	1.35	4.85	0.86	0.28	17
1995	S. Basin	8	RB = inside	New CE	10.25	11.68	1.32	0.88	13
1995	S. Basin	9	Straight	New CE	6.69	11.21	0.93	0.6	19
1995	S. Basin	10	LB = inside	RG	7.99	12.07	1.09	0.66	18
1995	S. Basin	11	Straight	RG	7.21	11.69	1.32	0.62	19
1995	S. Basin	12	Straight	RG	4.42	6.9	1.27	0.64	11
1995	S. Basin	13	Straight	RG	2.32	4.55	1.19	0.51	9
1995	S. Basin	23	Straight	New CE	1.97	6.31	0.77	0.31	20
1995	S. Basin	24	LB = inside	New CE	5.39	9.32	1.06	0.58	16

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Basin Creek, Montana

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1997 Ch. XS area (sq. m)[1]	1997 Ch. Width (m)	1997 Max. Depth (m)	1997 Mean Depth (m)	1997 W/Mean D ratio
1995	Main Basin	1	Straight	New EE	1.45	3.76	0.71	0.39	10
1995	Main Basin	2	Straight	New EE	3.04	7.77	0.86	0.39	20
1995	Main Basin	3	Straight	New EE	2.44	6.23	0.86	0.39	16
1995	Main Basin	14	RB = inside	RG	5.44	8.34	1.26	0.65	13
1995	Main Basin	15	Straight	RG	3.07	4.16	1.17	0.74	6
1995	Main Basin	16	LB = inside	RG	2.96	6.14	0.77	0.48	13
1995	Main Basin	27	Straight	RG	1.92	4.35	0.92	0.44	10
1995	Main Basin	28	RB = inside	RG	2.41	4.71	0.93	0.51	9
1995	N. Basin	4	LB = inside	New EE	1.34	5.74	0.68	0.23	25
1995	N. Basin	5	Straight	New EE	0.19	1.17	0.23	0.16	7
1995	N. Basin	6	LB = inside	New EE	1.6	6.95	0.63	0.23	30
1995	N. Basin	17	Straight	RG	2.33	5.85	1.11	0.4	15
1995	N. Basin	18	Straight	RG	0.95	3.82	0.48	0.25	15
1995	N. Basin	19	Straight	RG	1.26	2.42	1.15	0.52	5
1995	N. Basin	20	Straight	RG	2.39	5.4	0.78	0.44	12
1995	N. Basin	21	Straight	RG	1.15	5.29	0.64	0.22	24
1995	N. Basin	22	Straight	RG	1.38	2.77	0.8	0.5	6
1995	N. Basin	25	Straight	New EE	1.11	6.51	0.44	0.17	38
1995	N. Basin	26	LB = inside	RG	2.98	5.3	0.995	0.56	9
1995	S. Basin	7	Straight	New CE	1.26	4.85	1.05	0.26	19
1995	S. Basin	8	RB = inside	New CE	9.95	11.86	1.28	0.84	14
1995	S. Basin	9	Straight	New CE	6.33	11.35	0.94	0.56	20
1995	S. Basin	10	LB = inside	RG	8.16	12.24	1.15	0.67	18
1995	S. Basin	11	Straight	RG	7.05	11.43	1.26	0.62	18
1995	S. Basin	12	Straight	RG	4.37	6.86	1.23	0.64	11
1995	S. Basin	13	Straight	RG	2.34	4.57	1.08	0.51	9
1995	S. Basin	23	Straight	New CE	1.9	6.4	0.82	0.3	21
1995	S. Basin	24	LB = inside	New CE	5.59	9.69	1.04	0.58	17

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Muddy Creek, Montana

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1993 Ch. XS area (sq. m)[1]	1993 Ch. Width (m)	1993 Max. Depth (m)	1993 Mean Depth (m)	1993 W/Mean D ratio
1993	Muddy	1	RB = inside	Old CE	4.27	7.07	1.38	0.6	12
1993	Muddy	2	Straight	Old CE	3.91	6.59	1.13	0.59	11
1995	Muddy	3	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	4	LB = inside	RG	1.29	3.22	0.88	0.4	8
1993	Muddy	5	Straight	RG	0.81	2.42	0.94	0.33	7
1993	Muddy	6	RB = inside	RG	1.66	4.43	1.06	0.37	12
1993	Muddy	7	RB = inside	RG	3.21	4.93	1.26	0.65	8
1993	Muddy	8	LB = inside	RG	2.00	4.93	1.1	0.41	12
1993	Muddy	9	Straight	RG	1.21	3.32	1.13	0.36	9
1993	Muddy	10	LB = inside	RG	1.44	3.78	0.76	0.38	10
1993	Muddy	11	RB = inside	RG	1.80	3.56	0.96	0.51	7
1993	Muddy	12	RB = inside	Old CE	2.58	3.46	1.44	0.75	5
1993	Muddy	13	Straight	Old CE	1.63	3.02	1.41	0.54	6
1993	Muddy	14	RB = inside	RG	1.02	2.62	0.82	0.39	7
1993	Muddy	15	Straight	RG	0.76	2.10	0.62	0.36	6
1993	Muddy	16	Straight	RG	2.18	3.94	1.39	0.55	7
1993	Muddy	17	LB = inside	RG	2.20	3.25	1.11	0.68	5
1993	Muddy	18	Straight	RG	1.37	2.91	0.88	0.47	6
1993	Muddy	19	RB = inside	RG	1.84	3.26	1.04	0.56	6
1993	Muddy	22	Straight	New CE	1.13	2.74	0.59	0.41	7
1993	Muddy	23	Straight	New CE	0.98	4.31	0.50	0.23	19
1993	Muddy	24	Straight	New CE	0.14	1.26	0.19	0.11	11
1995	Muddy	25	Straight	Old CE	*****	*****	*****	*****	*****
1995	Muddy	26	Straight	Old CE	*****	*****	*****	*****	*****
1996	Muddy	30	Straight	Old CE	*****	*****	*****	*****	*****
1996	Muddy	31[2]	RB = inside	Old CE	*****	*****	*****	*****	*****
1996	Muddy	32	Straight	Old CE	*****	*****	*****	*****	*****

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

[2] Cross-section 31: this cross-section crossed the downstream channel and the upstream channel of a bend. There was a problem with the upstream channel survey so this is the downstream channel only.

Muddy Creek, Montana

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1995 Ch. XS area (sq. m)[1]	1995 Ch. Width (m)	1995 Max. Depth (m)	1995 Mean Depth (m)	1995 W/Mean D ratio
1993	Muddy	1	RB = inside	Old CE	4.23	7.15	1.4	0.59	12
1993	Muddy	2	Straight	Old CE	4.05	6.7	1.34	0.6	11
1995	Muddy	3	Straight	RG	1.96	3.5	1.11	0.56	6
1993	Muddy	4	LB = inside	RG	1.33	3.04	0.93	0.44	7
1993	Muddy	5	Straight	RG	0.72	2.07	0.93	0.35	6
1993	Muddy	6	RB = inside	RG	1.55	4.02	1.28	0.39	10
1993	Muddy	7	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	8	LB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	9	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	10	LB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	11	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	12	RB = inside	Old CE	3.20	4.71	1.54	0.68	7
1993	Muddy	13	Straight	Old CE	1.77	3.02	1.46	0.59	5
1993	Muddy	14	RB = inside	RG	0.95	2.52	0.87	0.38	7
1993	Muddy	15	Straight	RG	0.69	2.06	0.61	0.33	6
1993	Muddy	16	Straight	RG	2.26	4.18	1.5	0.54	8
1993	Muddy	17	LB = inside	RG	2.50	3.85	1.18	0.65	6
1993	Muddy	18	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	19	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	22	Straight	New CE	1.08	2.79	0.57	0.39	7
1993	Muddy	23	Straight	New CE	0.75	3.83	0.61	0.2	19
1993	Muddy	24	Straight	New CE	0.18	1.26	0.25	0.14	9
1995	Muddy	25	Straight	Old CE	2.54	5	1.05	0.51	10
1995	Muddy	26	Straight	Old CE	1.04	1.95	0.78	0.53	4
1996	Muddy	30	Straight	Old CE	*****	*****	*****	*****	*****
1996	Muddy	31[2]	RB = inside	Old CE	*****	*****	*****	*****	*****
1996	Muddy	32	Straight	Old CE	*****	*****	*****	*****	*****

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

[2] Cross-section 31: this cross-section crossed the downstream channel and the upstream channel of a bend. There was a problem with the upstream channel survey so this is the downstream channel only.

Muddy Creek, Montana

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1996 Ch. XS area (sq. m)[1]	1996 Ch. Width (m)	1996 Max. Depth (m)	1996 Mean Depth (m)	1996 W/Mean D ratio
1993	Muddy	1	RB = inside	Old CE	*****	*****	*****	*****	*****
1993	Muddy	2	Straight	Old CE	*****	*****	*****	*****	*****
1995	Muddy	3	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	4	LB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	5	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	6	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	7	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	8	LB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	9	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	10	LB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	11	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	12	RB = inside	Old CE	*****	*****	*****	*****	*****
1993	Muddy	13	Straight	Old CE	*****	*****	*****	*****	*****
1993	Muddy	14	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	15	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	16	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	17	LB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	18	Straight	RG	*****	*****	*****	*****	*****
1993	Muddy	19	RB = inside	RG	*****	*****	*****	*****	*****
1993	Muddy	22	Straight	New CE	*****	*****	*****	*****	*****
1993	Muddy	23	Straight	New CE	*****	*****	*****	*****	*****
1993	Muddy	24	Straight	New CE	*****	*****	*****	*****	*****
1995	Muddy	25	Straight	Old CE	*****	*****	*****	*****	*****
1995	Muddy	26	Straight	Old CE	*****	*****	*****	*****	*****
1996	Muddy	30	Straight	Old CE	0.53	1.16	0.58	0.46	3
1996	Muddy	31[2]	RB = inside	Old CE	1.00	2.80	0.63	0.36	8
1996	Muddy	32	Straight	Old CE	3.45	6.93	0.81	0.5	14

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

[2] Cross-section 31: this cross-section crossed the downstream channel and the upstream channel of a bend. There was a problem with the upstream channel survey so this is the downstream channel only.

Muddy Creek, Montana

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1998 Ch. XS area (sq. m)[1]	1998 Ch. Width (m)	1998 Max. Depth (m)	1998 Mean Depth (m)	1998 W/Mean D ratio
1993	Muddy	1	RB = inside	Old CE	4.24	7.25	1.4	0.58	13
1993	Muddy	2	Straight	Old CE	3.86	6.7	1.3	0.58	12
1995	Muddy	3	Straight	RG	1.91	3.97	1.12	0.48	8
1993	Muddy	4	LB = inside	RG	1.19	2.83	0.93	0.42	7
1993	Muddy	5	Straight	RG	0.74	1.97	0.94	0.38	5
1993	Muddy	6	RB = inside	RG	1.40	4.08	1.28	0.34	12
1993	Muddy	7	RB = inside	RG	3.20	4.85	1.2	0.66	7
1993	Muddy	8	LB = inside	RG	1.92	4.8	1.17	0.4	12
1993	Muddy	9	Straight	RG	1.12	3.32	1.18	0.34	10
1993	Muddy	10	LB = inside	RG	1.21	3.16	0.82	0.38	8
1993	Muddy	11	RB = inside	RG	1.51	3.06	0.86	0.49	6
1993	Muddy	12	RB = inside	Old CE	3.37	4.91	0.97	0.69	7
1993	Muddy	13	Straight	Old CE	1.84	3.02	1.37	0.61	5
1993	Muddy	14	RB = inside	RG	0.93	2.44	0.92	0.38	6
1993	Muddy	15	Straight	RG	0.63	1.93	0.63	0.33	6
1993	Muddy	16	Straight	RG	2.32	4.18	1.52	0.56	7
1993	Muddy	17	LB = inside	RG	3.15	4.51	1.18	0.7	6
1993	Muddy	18	Straight	RG	1.19	2.87	0.86	0.41	7
1993	Muddy	19	RB = inside	RG	2.06	3.16	1.16	0.65	5
1993	Muddy	22	Straight	New CE	0.85	2.83	0.51	0.3	9
1993	Muddy	23	Straight	New CE	0.73	4.35	0.62	0.17	26
1993	Muddy	24	Straight	New CE	0.15	1.26	0.27	0.12	11
1995	Muddy	25	Straight	Old CE	2.54	5	1.1	0.51	10
1995	Muddy	26	Straight	Old CE	1.02	1.92	0.77	0.53	4
1996	Muddy	30	Straight	Old CE	0.63	1.61	0.59	0.39	4
1996	Muddy	31[2]	RB = inside	Old CE	1.05	2.76	0.71	0.38	7
1996	Muddy	32	Straight	Old CE	3.46	6.84	0.82	0.51	13

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

[2] Cross-section 31: this cross-section crossed the downstream channel and the upstream channel of a bend. There was a problem with the upstream channel survey so this is the downstream channel only.

Price Creek, Montana									
					1994	**1994**	**1994**	**1994**	**1994**
Baseline Survey Year	**Creek**	**XS**	**Treatment**	**Channel segment**	**Ch. XS area (sq. m)[1]**	**Ch. Width (m)**	**Max. Depth (m)**	**Mean Depth (m)**	**W/Mean D ratio**
1994	Price (lower)	2	RG/BD controlled	RB = inside	4.66	7.31	1.43	0.64	11
1994	Price (lower)	16	RG/BD controlled	Straight	4.39	6.36	1.1	0.69	9
1994	Price (lower)	17	RG	Straight	6.9	7.47	1.33	0.92	8
1994	Price (lower)	18	RG/BD controlled	Straight	3.63	4.63	1.37	0.78	6
1994	Price (upper)	13	New EE/BD controlled	RB = inside	1.54	2.65	0.905	0.58	5
1994	Price (upper)	14	New EE/BD controlled	Straight	1.35	4.09	0.505	0.33	12
1994	Price (upper)	15	New EE/BD controlled	Straight	1.87	5.56	0.68	0.34	16
1995	Price (upper)	19	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	20	New CE/BD controlled	RB = inside	*****	*****	*****	*****	*****
1995	Price (upper)	21	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	22	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	23	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	24	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	25	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	26	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	27	New CE/BD controlled	LB = inside	*****	*****	*****	*****	*****
1995	Price (upper)	28	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	29	New CE/BD controlled	LB = inside	*****	*****	*****	*****	*****

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana									
					1994	1994	1994	1994	1994
Baseline	**Creek**	**XS**	**Treatment**	**Channel**	**Ch.**	**Ch.**	**Max.**	**Mean**	**W/Mean D**
1995	Price (upper)	30	New CE/BD controlled	Straight	*****	*****	*****	*****	*****
1997	Price (upper)	33	New EE/BD controlled	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	4	RG	Straight	0.203	0.96	0.48	0.21	5
1994	W. Fk Price	5	RG	Straight	0.745	1.65	0.725	0.45	4
1994	W. Fk Price	6	RG	Straight	0.465	2.17	0.54	0.21	10
1994	W. Fk Price	7	RG	Straight	0.472	1.24	0.685	0.38	3
1994	W. Fk Price	31	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	32	RG	Straight	*****	*****	*****	*****	*****

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana

Baseline Survey Year	Creek	XS	Treatment	Channel segment	1995 Ch. XS area (sq. m)[1]	1995 Ch. Width (m)	1995 Max. Depth (m)	1995 Mean Depth (m)	1995 W/Mean D ratio
1994	Price (lower)	2	RG/BD controlled	RB = inside	*****	*****	*****	*****	*****
1994	Price (lower)	16	RG/BD controlled	Straight	*****	*****	*****	*****	*****
1994	Price (lower)	17	RG	Straight	6.84	7.46	1.35	0.92	8
1994	Price (lower)	18	RG/BD controlled	Straight	3.79	4.63	1.45	0.82	6
1994	Price (upper)	13	New EE/BD controlled	RB = inside	*****	*****	*****	*****	*****
1994	Price (upper)	14	New EE/BD controlled	Straight	*****	*****	*****	*****	*****
1994	Price (upper)	15	New EE/BD controlled	Straight	*****	*****	*****	*****	*****
1995	Price (upper)	19	New CE/BD controlled	Straight	1.23	2.92	0.72	0.42	7
1995	Price (upper)	20	New CE/BD controlled	RB = inside	3.07	5.84	1.1	0.53	11
1995	Price (upper)	21	New CE/BD controlled	Straight	2.09	2.65	1.32	0.79	3
1995	Price (upper)	22	New CE/BD controlled	Straight	2.22	4.07	0.97	0.55	7
1995	Price (upper)	23	New CE/BD controlled	Straight	1.68	3.51	0.88	0.48	7
1995	Price (upper)	24	New CE/BD controlled	Straight	2.39	4.71	0.76	0.51	9
1995	Price (upper)	25	New CE/BD controlled	Straight	1.6	2.25	1.3	0.71	3
1995	Price (upper)	26	New CE/BD controlled	Straight	2.71	4.09	1.57	0.66	6
1995	Price (upper)	27	New CE/BD controlled	LB = inside	4.09	3.98	1.3	1.03	4
1995	Price (upper)	28	New CE/BD controlled	Straight	1.43	2.94	1.06	0.49	6
1995	Price (upper)	29	New CE/BD controlled	LB = inside	0.95	3.31	0.49	0.29	11

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana									
					1995	**1995**	**1995**	**1995**	**1995**
Baseline	**Creek**	**XS**	**Treatment**	**Channel**	**Ch.**	**Ch.**	**Max.**	**Mean**	**W/Mean D**
1995	Price (upper)	30	New CE/BD controlled	Straight	1.63	5.77	0.51	0.28	21
1997	Price (upper)	33	New EE/BD controlled	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	4	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	5	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	6	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	7	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	31	RG	Straight	0.11	0.42	0.52	0.26	2
1994	W. Fk Price	32	RG	Straight	0.31	2.1	0.36	0.15	14

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana									
					1997	1997	1997	1997	1997
Baseline	Creek	XS	Treatment	Channel	Ch.	Ch.	Max.	Mean	W/Mean D
Survey				segment	XS area	Width	Depth	Depth	ratio
Year					(sq. m)[1]	(m)	(m)	(m)	
1994	Price (lower)	2	RG/BD controlled	RB = inside	*****	*****	*****	*****	*****
1994	Price (lower)	16	RG/BD controlled	Straight	*****	*****	*****	*****	*****
1994	Price (lower)	17	RG	Straight	6.9	7.52	1.35	0.92	8
1994	Price (lower)	18	RG/BD controlled	Straight	*****	*****	*****	*****	*****
1994	Price (upper)	13	New EE/BD controlled	RB = inside	0.87	1.93	0.82	0.45	4
1994	Price (upper)	14	New EE/BD controlled	Straight	0.72	3.28	0.38	0.22	15
1994	Price (upper)	15	New EE/BD controlled	Straight	0.12	2.19	0.075	0.05	44
1995	Price (upper)	19	New CE/BD controlled	Straight	1.19	3.35	0.77	0.36	9
1995	Price (upper)	20	New CE/BD controlled	RB = inside	2.3	5.68	0.89	0.4	14
1995	Price (upper)	21	New CE/BD controlled	Straight	1.81	2.58	1.13	0.7	4
1995	Price (upper)	22	New CE/BD controlled	Straight	2.25	4.07	1	0.55	7
1995	Price (upper)	23	New CE/BD controlled	Straight	1.49	3.64	0.74	0.41	9
1995	Price (upper)	24	New CE/BD controlled	Straight	3.65	4.81	1.13	0.76	6
1995	Price (upper)	25	New CE/BD controlled	Straight	1.64	2.57	1.18	0.64	4
1995	Price (upper)	26	New CE/BD controlled	Straight	2.44	4.17	1.19	0.59	7
1995	Price (upper)	27	New CE/BD controlled	LB = inside	3.69	4.27	1.29	0.86	5
1995	Price (upper)	28	New CE/BD controlled	Straight	1.49	3.57	1.01	0.42	9
1995	Price (upper)	29	New CE/BD controlled	LB = inside	2.19	3.92	0.85	0.56	7

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana									
					1997	1997	1997	1997	1997
Baseline	**Creek**	**XS**	**Treatment**	**Channel**	**Ch.**	**Ch.**	**Max.**	**Mean**	**W/Mean D**
1995	Price (upper)	30	New CE/BD controlled	Straight	2.56	5.72	0.83	0.45	13
1997	Price (upper)	33	New EE/BD controlled	Straight	1.18	3.71	0.5	0.32	12
1994	W. Fk Price	4	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	5	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	6	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	7	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	31	RG	Straight	0.17	0.59	0.57	0.29	2
1994	W. Fk Price	32	RG	Straight	0.3	1.35	0.35	0.22	6

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana

Baseline Survey Year	Creek	XS	Treatment	Channel segment	1998 Ch. XS area (sq. m)[1]	1998 Ch. Width (m)	1998 Max. Depth (m)	1998 Mean Depth (m)	1998 W/Mean D ratio
1994	Price (lower)	2	RG/BD controlled	RB = inside	6.05	7.56	1.53	0.8	9
1994	Price (lower)	16	RG/BD controlled	Straight	5.34	6.39	1.37	0.84	8
1994	Price (lower)	17	RG	Straight	6.9	7.48	1.35	0.92	8
1994	Price (lower)	18	RG/BD controlled	Straight	3.78	4.62	1.445	0.82	6
1994	Price (upper)	13	New EE/BD controlled	RB = inside	1.11	2.41	0.85	0.46	5
1994	Price (upper)	14	New EE/BD controlled	Straight	0.87	3.486	0.385	0.25	14
1994	Price (upper)	15	New EE/BD controlled	Straight	0.65	2.95	0.42	0.22	13
1995	Price (upper)	19	New CE/BD controlled	Straight	1.17	3.03	0.74	0.39	8
1995	Price (upper)	20	New CE/BD controlled	RB = inside	3.36	5.94	1.07	0.57	10
1995	Price (upper)	21	New CE/BD controlled	Straight	2.02	2.65	1.185	0.76	3
1995	Price (upper)	22	New CE/BD controlled	Straight	2.29	4.26	1.06	0.54	8
1995	Price (upper)	23	New CE/BD controlled	Straight	2.02	3.75	0.925	0.54	7
1995	Price (upper)	24	New CE/BD controlled	Straight	3.63	5.08	1.195	0.71	7
1995	Price (upper)	25	New CE/BD controlled	Straight	1.61	2.77	1.16	0.58	5
1995	Price (upper)	26	New CE/BD controlled	Straight	2.71	4.15	1.355	0.65	6
1995	Price (upper)	27	New CE/BD controlled	LB = inside	4.08	4.49	1.305	0.91	5
1995	Price (upper)	28	New CE/BD controlled	Straight	1.52	3.89	1.04	0.39	10
1995	Price (upper)	29	New CE/BD controlled	LB = inside	2.29	3.97	0.85	0.58	7

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

Price Creek, Montana									
					1998	1998	1998	1998	1998
Baseline	**Creek**	**XS**	**Treatment**	**Channel**	**Ch.**	**Ch.**	**Max.**	**Mean**	**W/Mean D**
1995	Price (upper)	30	New CE/BD controlled	Straight	3.49	5.77	1.21	0.6	10
1997	Price (upper)	33	New EE/BD controlled	Straight	2.26	3.93	0.89	0.58	7
1994	W. Fk Price	4	RG	Straight	0.175	0.76	0.59	0.23	3
1994	W. Fk Price	5	RG	Straight	0.864	2.7	0.725	0.32	8
1994	W. Fk Price	6	RG	Straight	0.44	2.664	0.6	0.17	16
1994	W. Fk Price	7	RG	Straight	0.424	1.2	0.705	0.35	3
1994	W. Fk Price	31	RG	Straight	*****	*****	*****	*****	*****
1994	W. Fk Price	32	RG	Straight	0.32	1.83	0.38	0.17	11

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

White Mountains, Arizona

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1994 Ch. XS area (sq. m)[1]	1994 Ch. Width (m)	1994 Max. Depth (m)	1994 Mean Depth (m)	1994 W/Mean D ratio
1994	Hayground	1	Straight	SEMA	1.427	6.37	0.45	0.22	29
1994	Hayground	2	Straight	SEMA	0.93	2.88	0.53	0.32	9
1994	Hayground	3	RB = inside	SEMA	1	7.14	0.39	0.14	51
1994	Hayground	4	RB = inside	New EE	1.64	8.23	0.51	0.2	41
1994	Hayground	5	Straight	New EE	0.59	2.69	0.43	0.22	12
1994	Hayground	6	Straight	New EE	2.62	8.12	0.68	0.32	25
1994	Hayground	7	RB = inside	New CE	0.72	2.7	0.42	0.27	10
1994	Hayground	8	RB = inside	New CE	0.66	3.41	0.32	0.19	18
1994	Hayground	9	Straight	New CE	0.58	1.85	0.56	0.31	6
1994	Home	1	LB = inside	New CE	0.56	2.47	0.38	0.23	11
1994	Home	2	Straight	New CE	0.495	1.89	0.63	0.26	7
1994	L. Burro	1	Straight	SEMA	2.01	4.08	0.81	0.49	8
1994	L. Burro	2	Straight	SEMA	1.086	3.53	0.46	0.31	11
1994	L. Burro	3	Straight	SEMA	1.46	5.43	0.51	0.27	20
1994	L. Burro	4	RB = inside	SEMA	2.02	5.5	0.65	0.37	15
1994	L. Burro	5	Straight	SEMA	1.395	5.74	0.49	0.24	24
1994	L. Stinky	1	Straight	New CE	0.99	3.26	0.49	0.3	11
1994	L. Stinky	2	Straight	New CE	0.86	4.37	0.50	0.2	22
1994	L. Stinky	3	RB = inside	New CE	0.53	2.29	0.48	0.23	10
1994	L. Stinky	4	LB = inside	New CE	1.56	3.14	0.81	0.5	6
1994	L. Stinky	5	Straight	New CE	0.505	3.06	0.28	0.17	18
1994	Mandan	1	Straight	SEMA	0.68	1.74	0.48	0.39	4
1994	Mandan	2	Straight	SEMA	0.84	3.16	0.53	0.27	12
1994	Mandan	3	Straight	SEMA	1.68	3.14	0.80	0.54	6
1994	Mandan	4	RB = inside	SEMA	1.47	7.5	0.51	0.2	38
1994	Mandan	5	Straight	SEMA	1.1	5.15	0.86	0.21	25
1994	Mandan	6	Straight	SEMA	0.266	2.35	0.21	0.11	21

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

White Mountains, Arizona

Baseline Survey Year	Creek	XS	Channel segment	Treatment	1997 Ch. XS area (sq. m)[1]	1997 Ch. Width (m)	1997 Max. Depth (m)	1997 Mean Depth (m)	1997 W/Mean D ratio
1994	Hayground	1	Straight	SEMA	1.52	6.93	0.49	0.22	32
1994	Hayground	2	Straight	SEMA	0.98	2.83	0.5	0.35	8
1994	Hayground	3	RB = inside	SEMA	0.89	7.45	0.39	0.12	62
1994	Hayground	4	RB = inside	New EE	1.34	8.13	0.5	0.16	51
1994	Hayground	5	Straight	New EE	0.68	2.67	0.45	0.25	11
1994	Hayground	6	Straight	New EE	2.67	8.29	0.71	0.32	26
1994	Hayground	7	RB = inside	New CE	0.7	2.68	0.495	0.26	10
1994	Hayground	8	RB = inside	New CE	0.75	3.68	0.35	0.2	18
1994	Hayground	9	Straight	New CE	0.56	1.85	0.58	0.3	6
1994	Home	1	LB = inside	New CE	0.5	2.19	0.385	0.23	10
1994	Home	2	Straight	New CE	0.474	1.89	0.6	0.25	8
1994	L. Burro	1	Straight	SEMA	1.91	4.08	0.81	0.47	9
1994	L. Burro	2	Straight	SEMA	1.12	3.53	0.49	0.32	11
1994	L. Burro	3	Straight	SEMA	1.51	5.46	0.56	0.28	20
1994	L. Burro	4	RB = inside	SEMA	1.885	5.58	0.59	0.34	16
1994	L. Burro	5	Straight	SEMA	1.539	5.74	0.52	0.27	21
1994	L. Stinky	1	Straight	New CE	0.8	3.18	0.45	0.25	13
1994	L. Stinky	2	Straight	New CE	0.95	4.93	0.53	0.19	26
1994	L. Stinky	3	RB = inside	New CE	0.6	2.35	0.47	0.26	9
1994	L. Stinky	4	LB = inside	New CE	1.468	3.08	0.83	0.48	6
1994	L. Stinky	5	Straight	New CE	0.508	2.89	0.26	0.18	16
1994	Mandan	1	Straight	SEMA	0.67	1.68	0.43	0.4	4
1994	Mandan	2	Straight	SEMA	0.824	3.16	0.54	0.26	12
1994	Mandan	3	Straight	SEMA	1.53	3.29	0.64	0.47	7
1994	Mandan	4	RB = inside	SEMA	1.61	7.81	0.495	0.21	37
1994	Mandan	5	Straight	SEMA	1.39	5.38	0.835	0.26	21
1994	Mandan	6	Straight	SEMA	0.35	2.7	0.29	0.13	21

[1] The channel cross-section area values presented in this table were calculated use the Sigma Plot computer program and not by multiplying Cross-section Width x Mean cross-section depth. Values are very similar, but not the same.

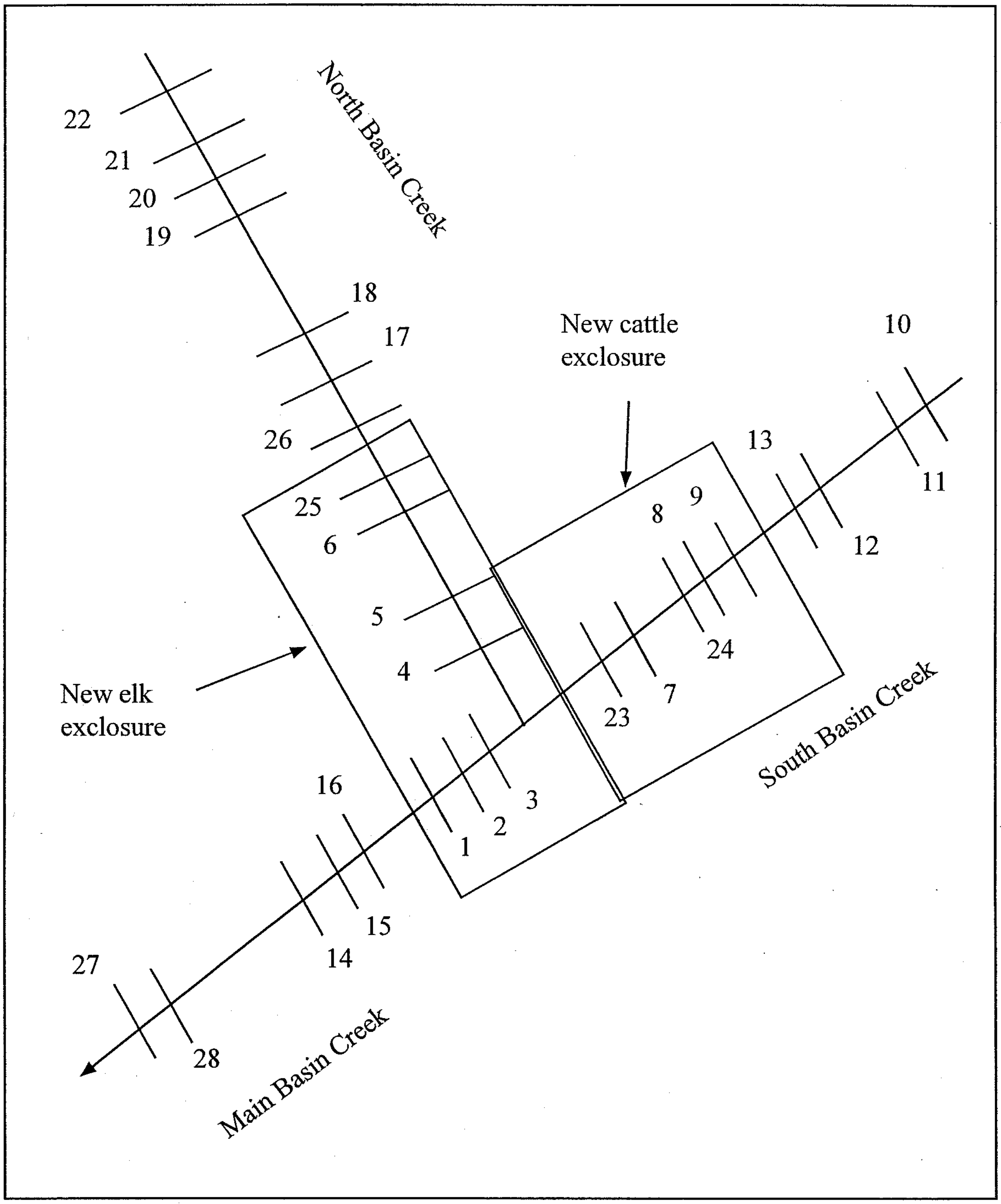
APPENDIX B

CROSS-SECTION GRAPHS, LOCATION INFORMATION, AND THE RELATIVE LOCATION OF THE CROSS-SECTIONS WITHIN EACH CREEK

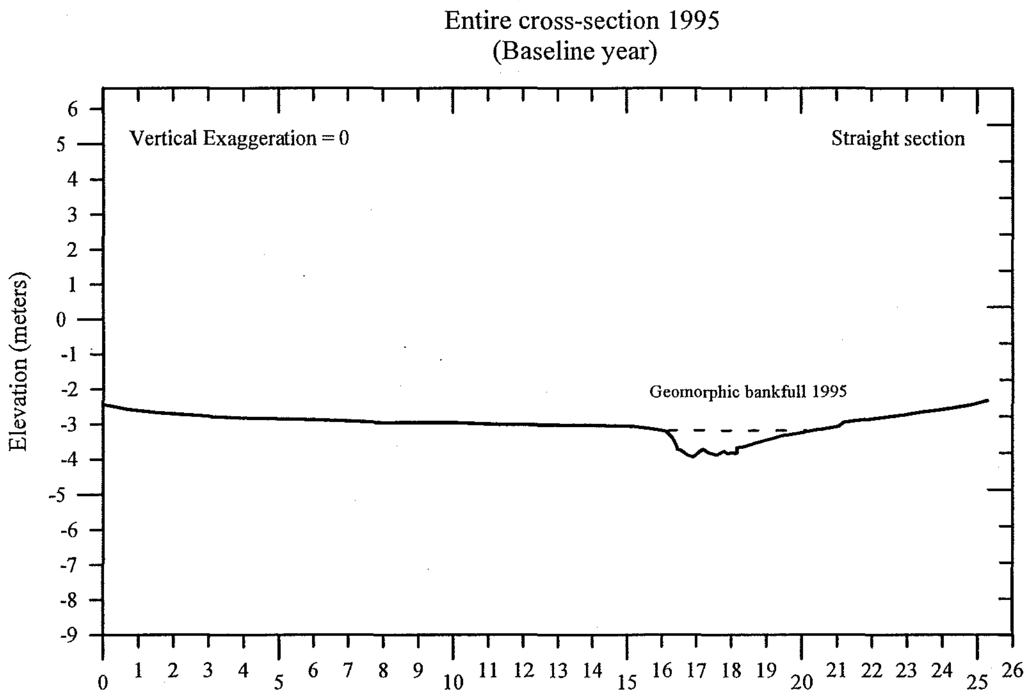
LOCATION OF THE STUDY AREAS

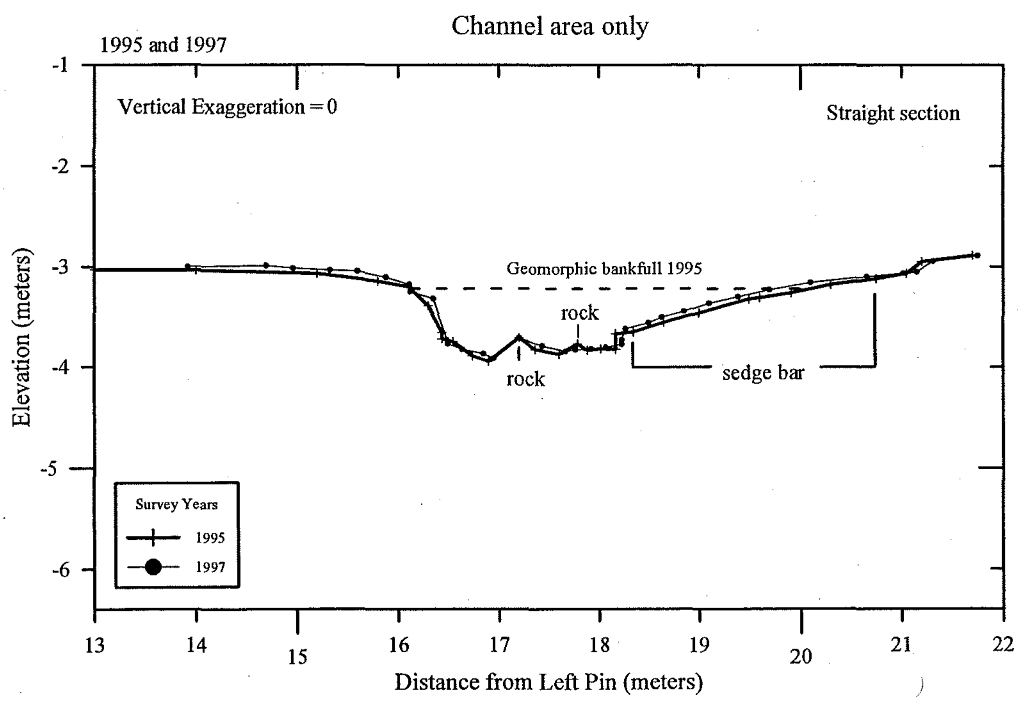
Creek	Topographic Maps (7.5 minute quads)	Latitude	Longitude	Township, Range, Section
Basin Ck, MT	Eureka Basin Quad, MT	44°50'00'' to 44°52'30''	112°00' to 111° 57'30''	T11S, R3W, Sec 20, 21, 27, 28
Muddy Creek, MT	Dixon Mountain Quad, Graphite Quad, Kidd Quad	44°37'30" to 44°52'30"	112°45'30" to 112°57'00"	T13S, R9W; T13S, R10W; T14S, R11W; T13S, R11W; T12S, R11W; T12S, R10W
Price Creek, MT	Corral Creek Quad, Big Table Mountain Quad	44°32'30" to 44°37'30"	112°07'30" to 112°00'	T14S, R4W
White Mountains, AZ	Big Lake South Quad, Big Lake North Quad	33°47'30'' to 34°00'	109°22'30'' to 190°30'	T5N, R27E; T6N, R 27E; T7N, R28E; T5 N, R28E; T6N, R28E

Basin Creek, Montana
Relative location of cross-sections with respect to each other.

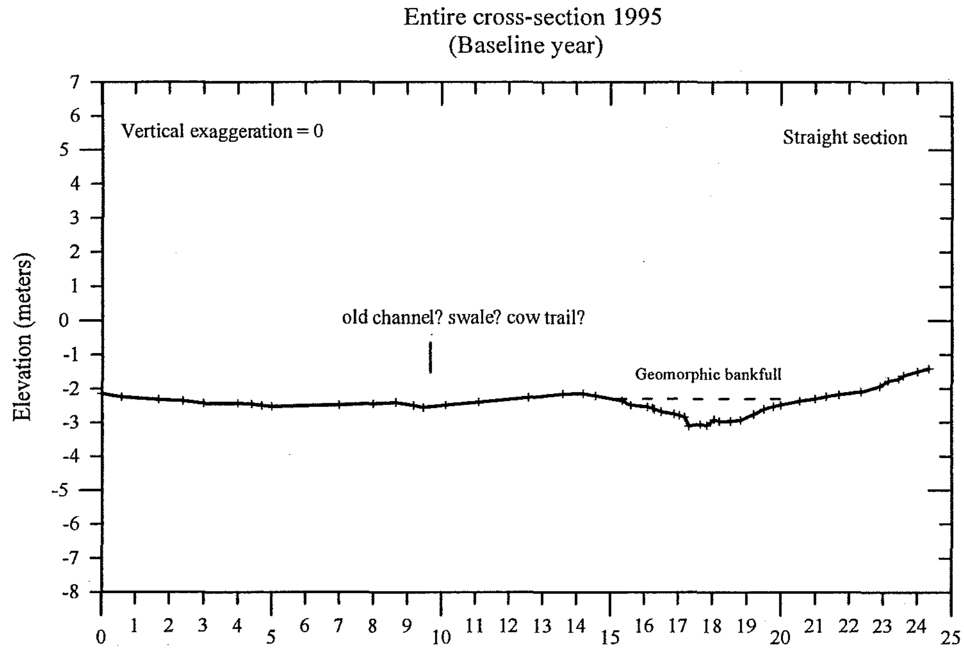


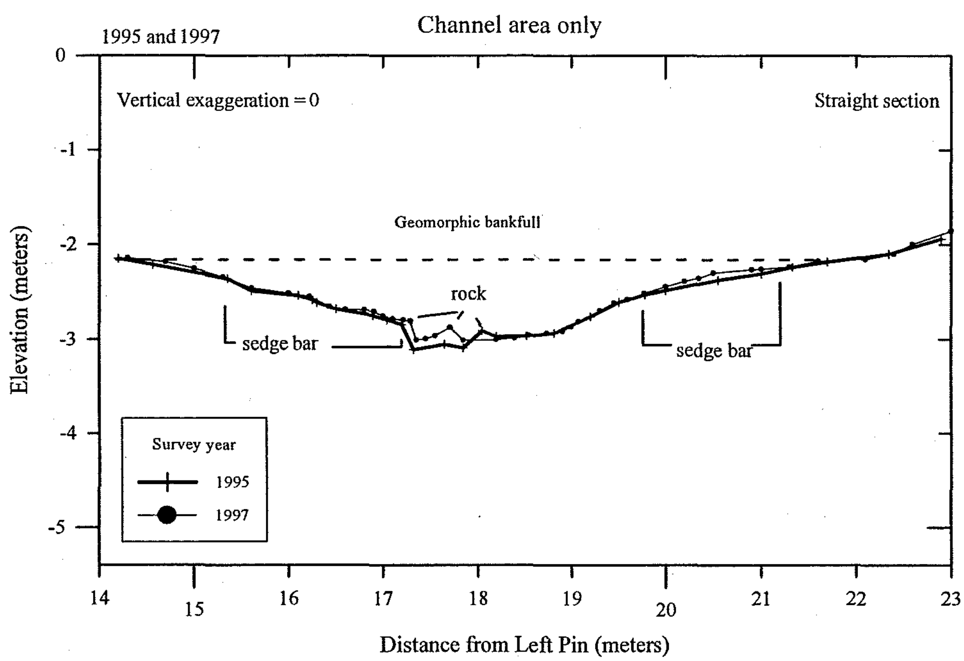
Basin Creek cross-section 1
New Elk Exclosure
1995 and 1997



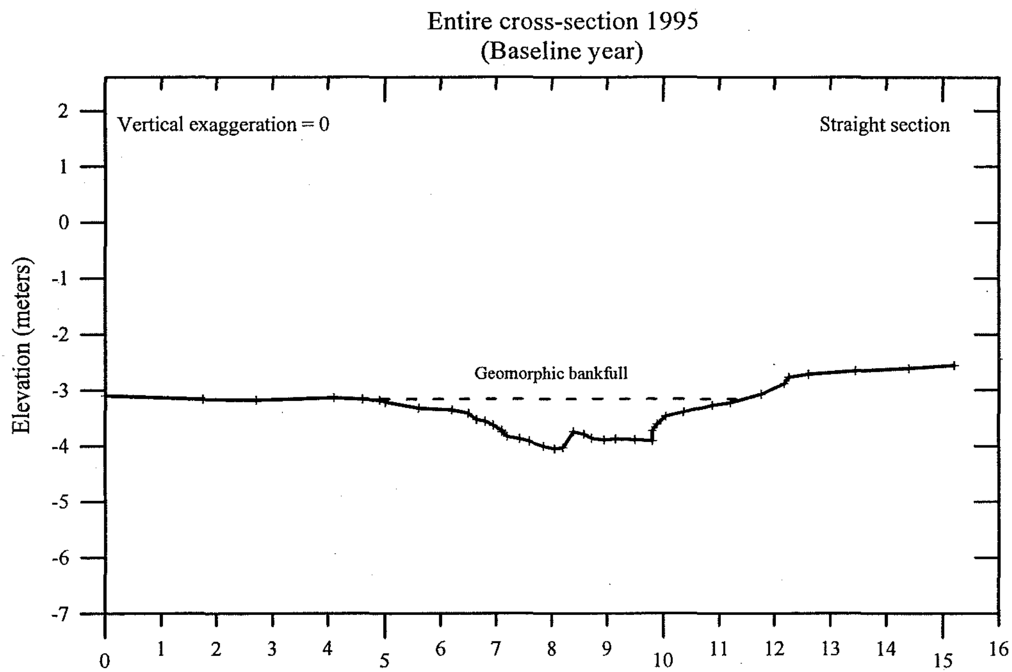


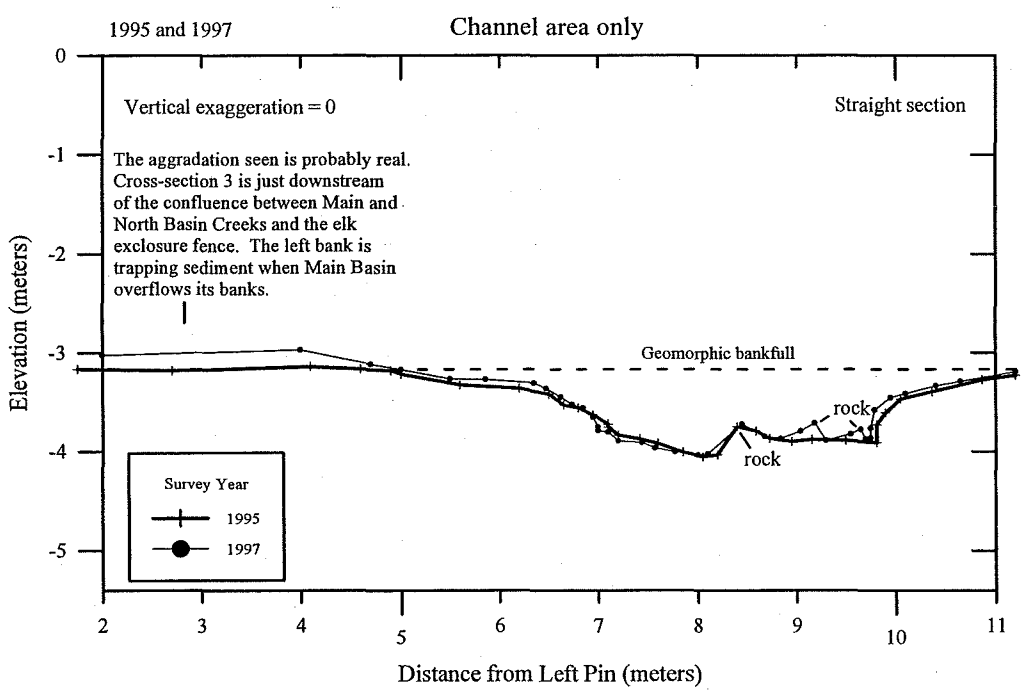
Basin Creek cross-section 2
New Elk Exclosure
1995 and 1997



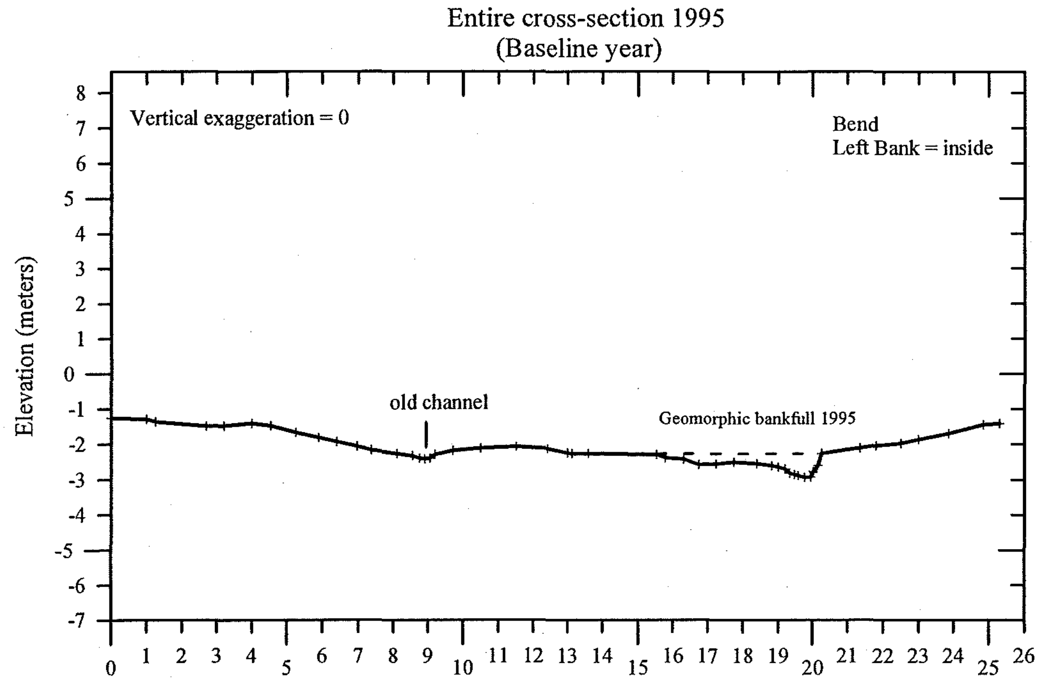


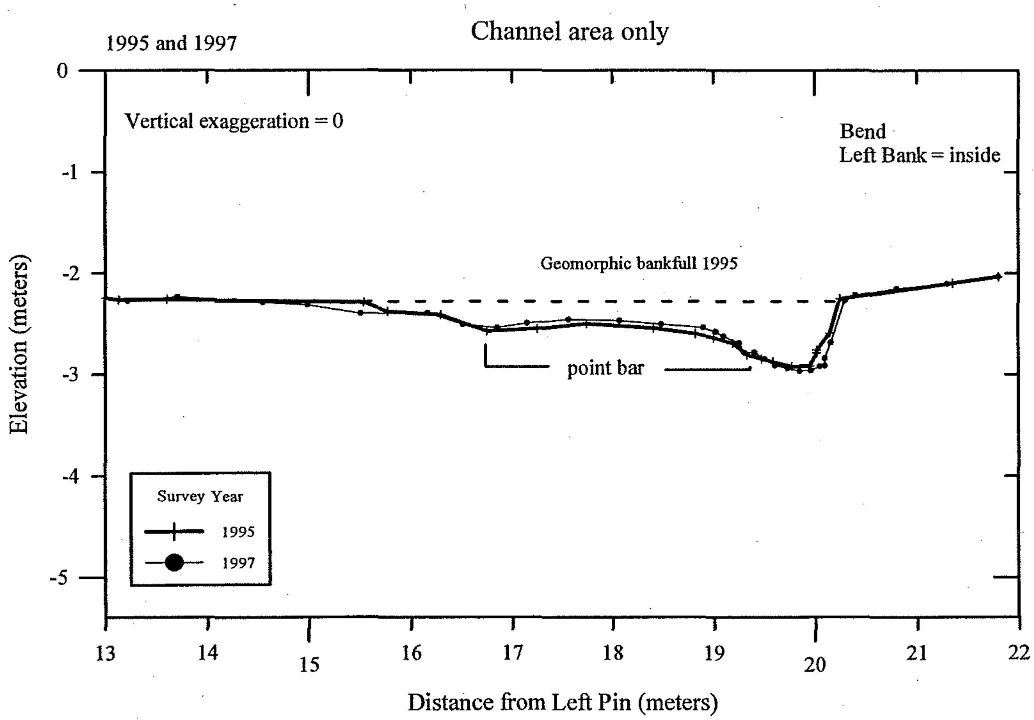
Basin Creek cross-section 3
New Elk Exclosure
1995 and 1997



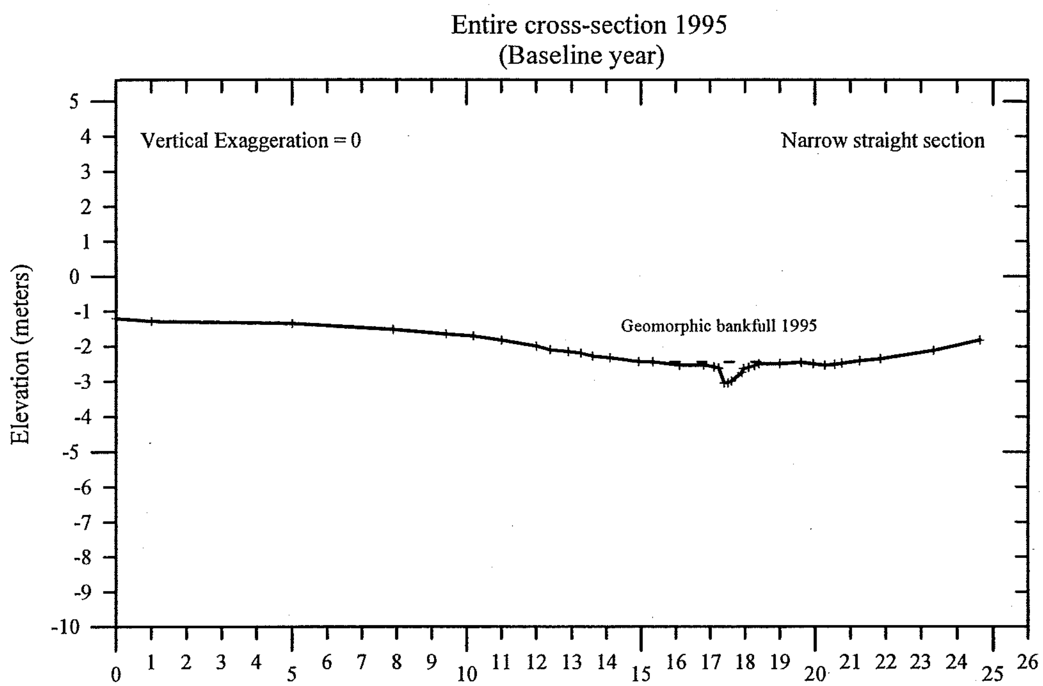


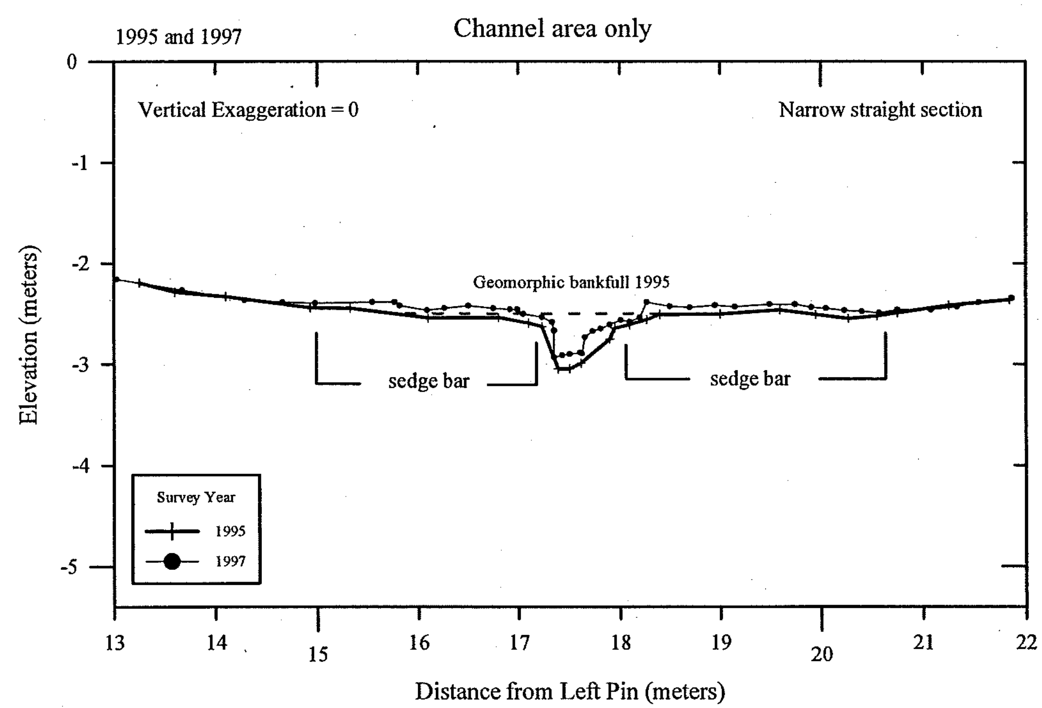
Basin Creek cross-section 4
New Elk Exclosure
1995 and 1997





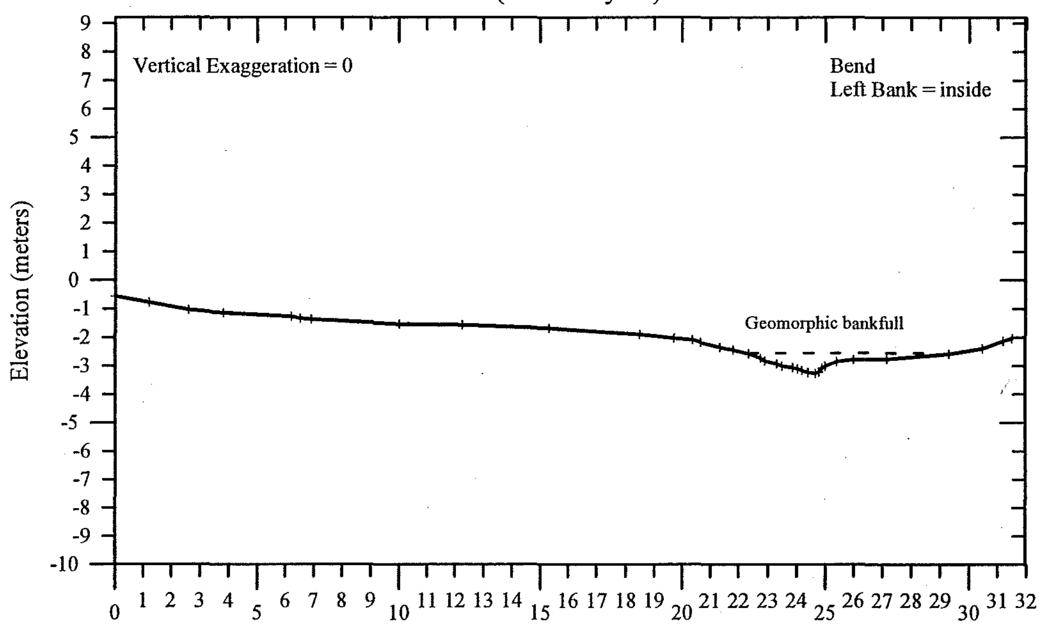
Basin Creek cross-section 5
New Elk Exclosure
1995 and 1997





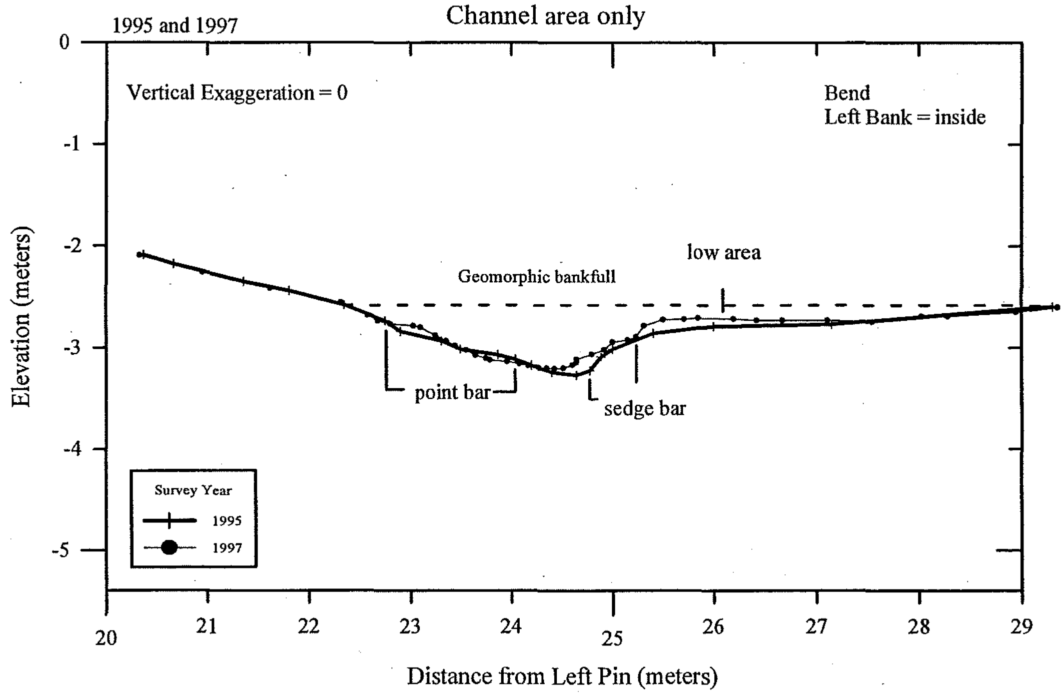
Basin Creek cross-section 6
New Elk Exclosure
1995 and 1997

Entire cross-section 1995
(Baseline year)

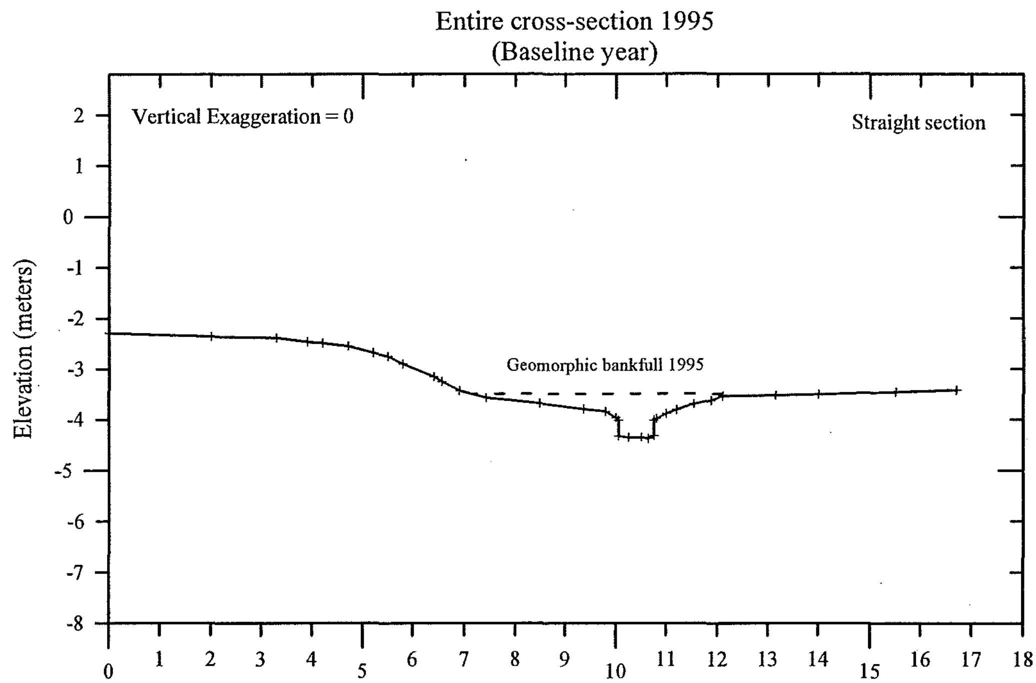


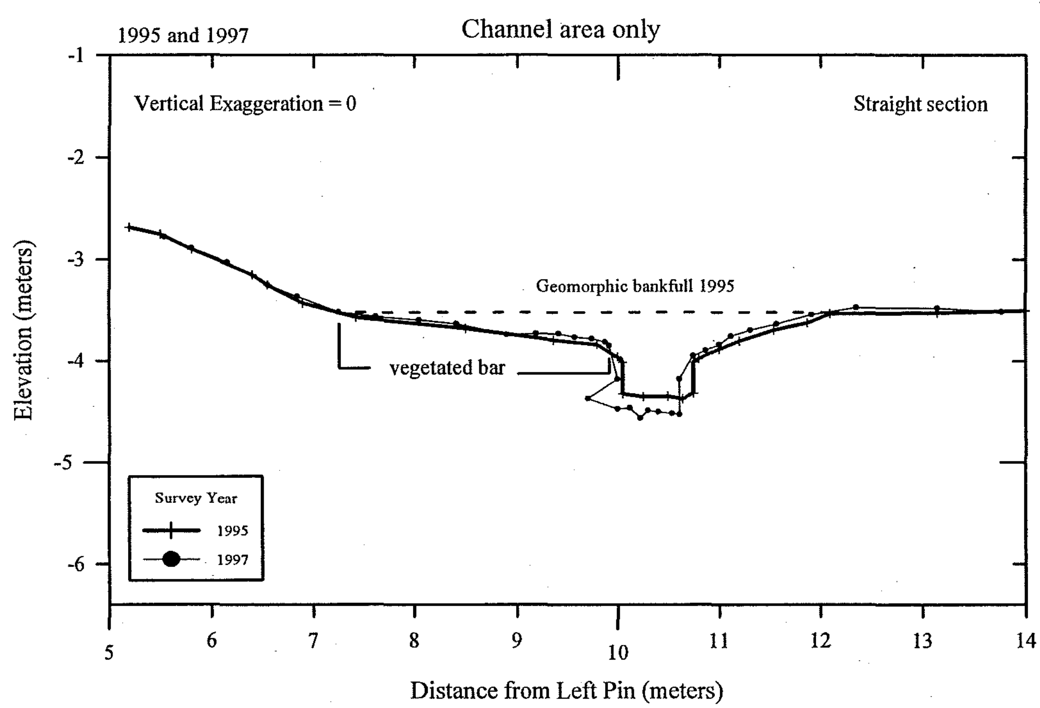
1995 and 1997

Channel area only



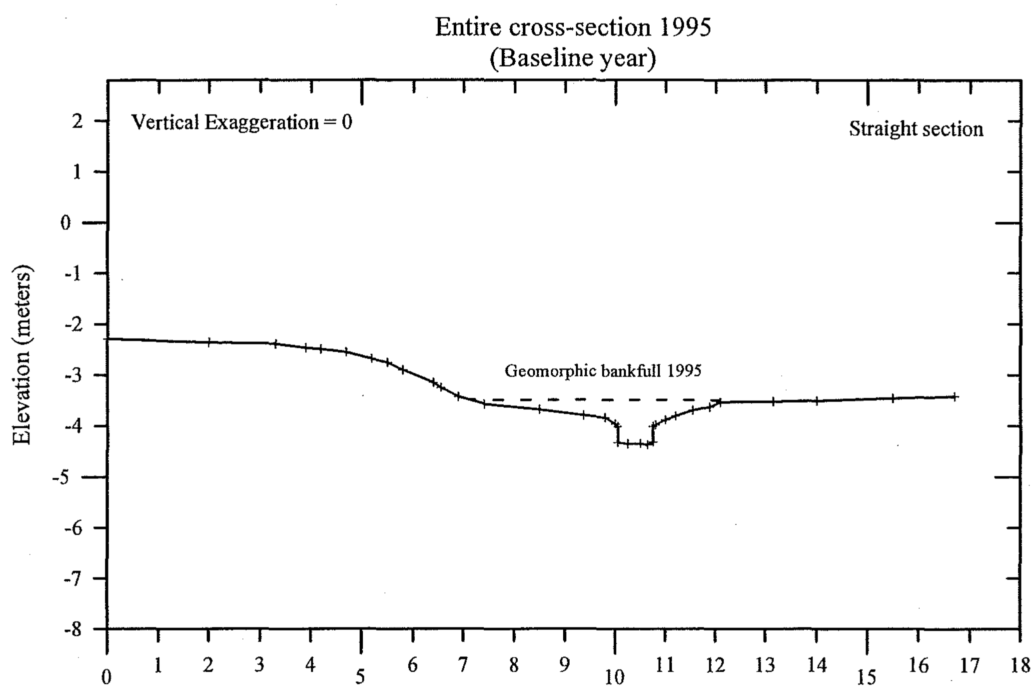
Basin Creek cross-section 7
New Cattle Exclosure
1995 and 1997

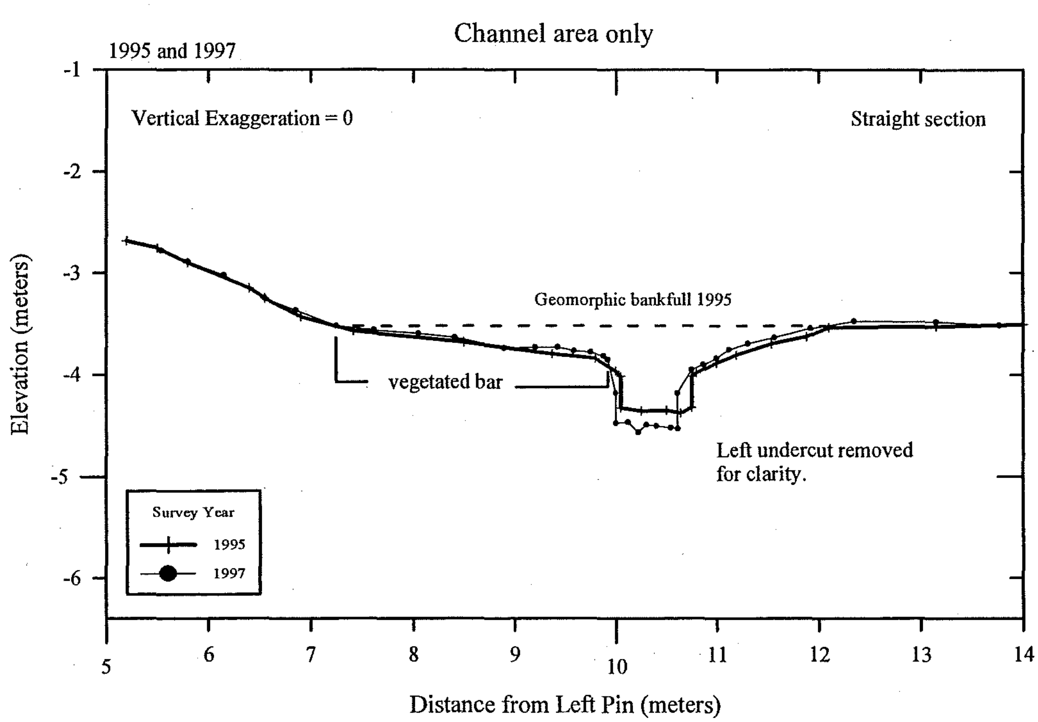




Basin Creek cross-section 7 (continued)
New Cattle Exclosure
1995 and 1997

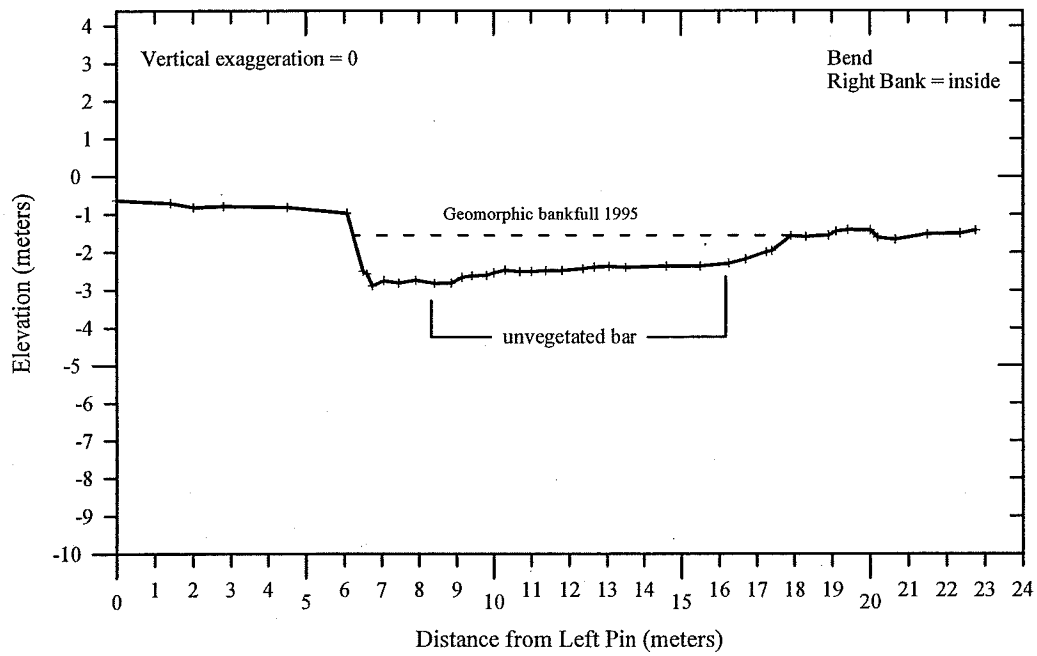
Undercut removed for clarity.





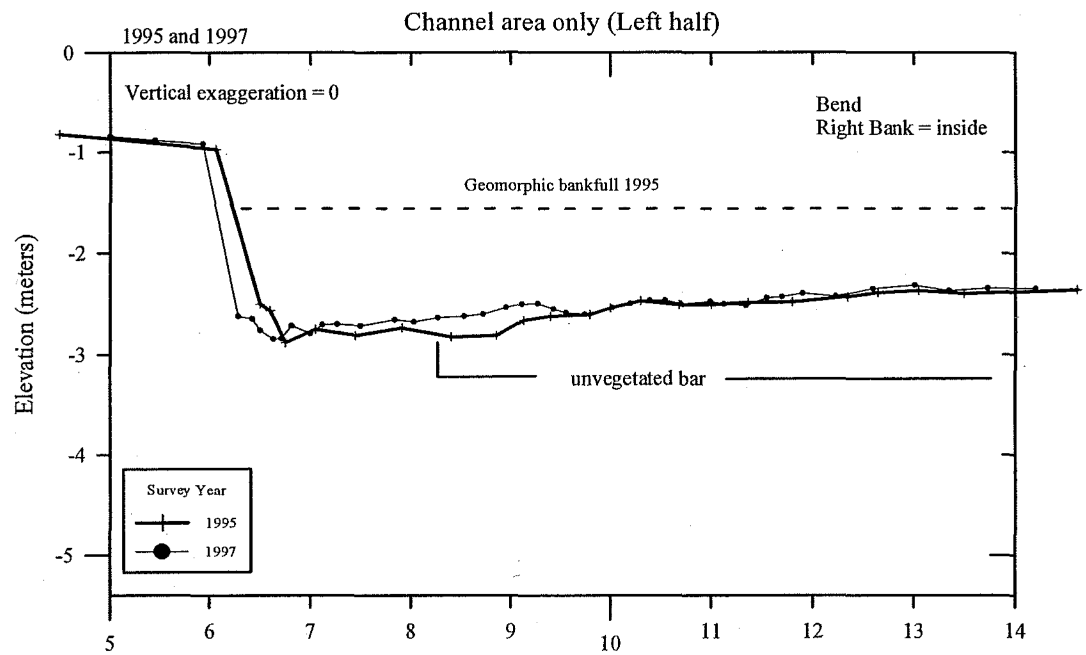
Basin Creek cross-section 8
New Cattle Exclosure
1995 and 1997

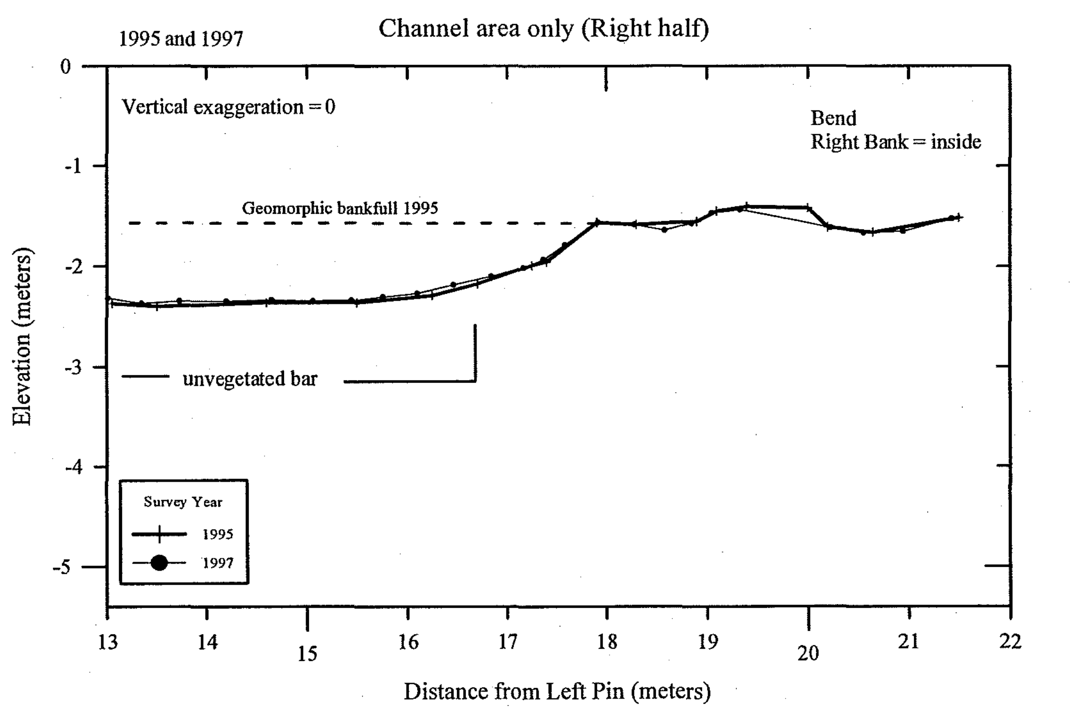
Entire cross-section 1995
(Baseline year)



The length of the channel area for cross-section 8 required that it be split into two sections in order to maintain the same scale as the other channel-area plots. See next page for the cross-section 8 channel-area-only plots.

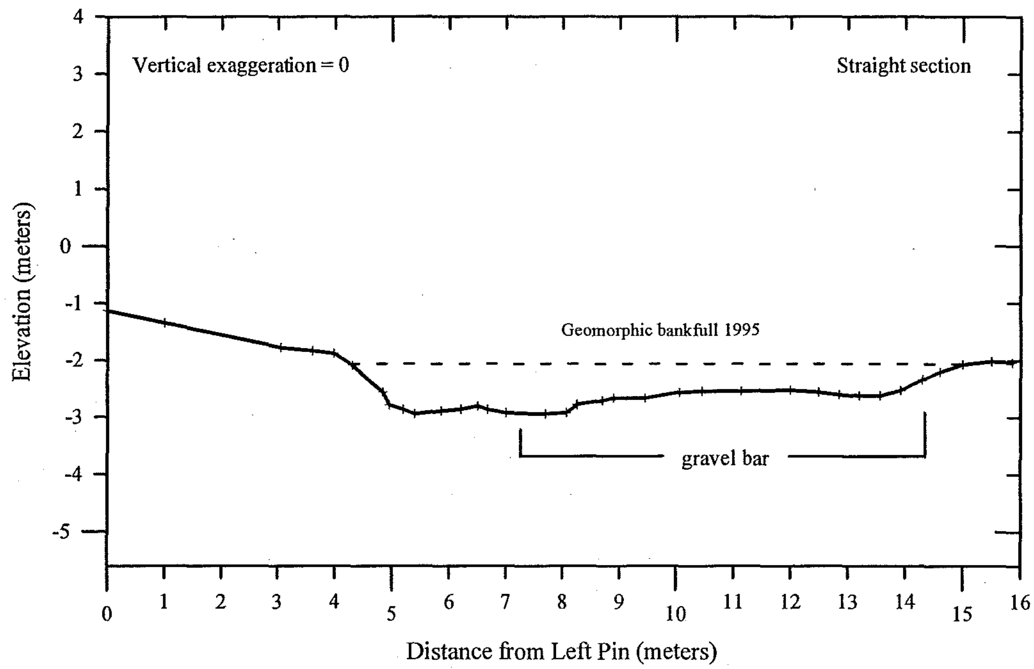
Basin Creek cross-section 8 (continued)
New Cattle Exclosure
1995 and 1997





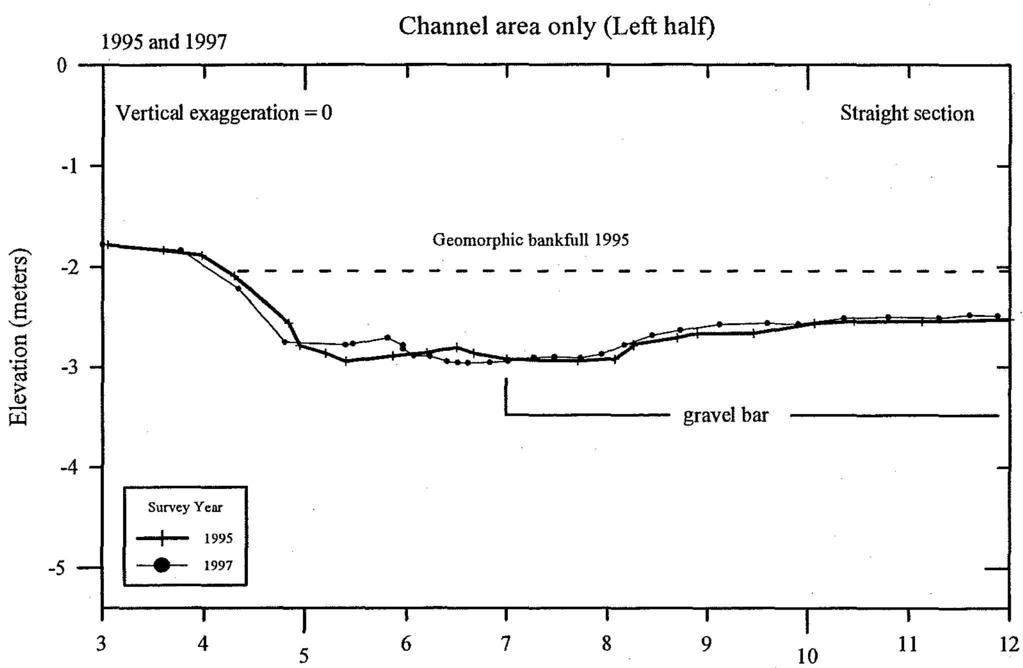
Basin Creek cross-section 9
New Cattle Exclosure
1995 and 1997

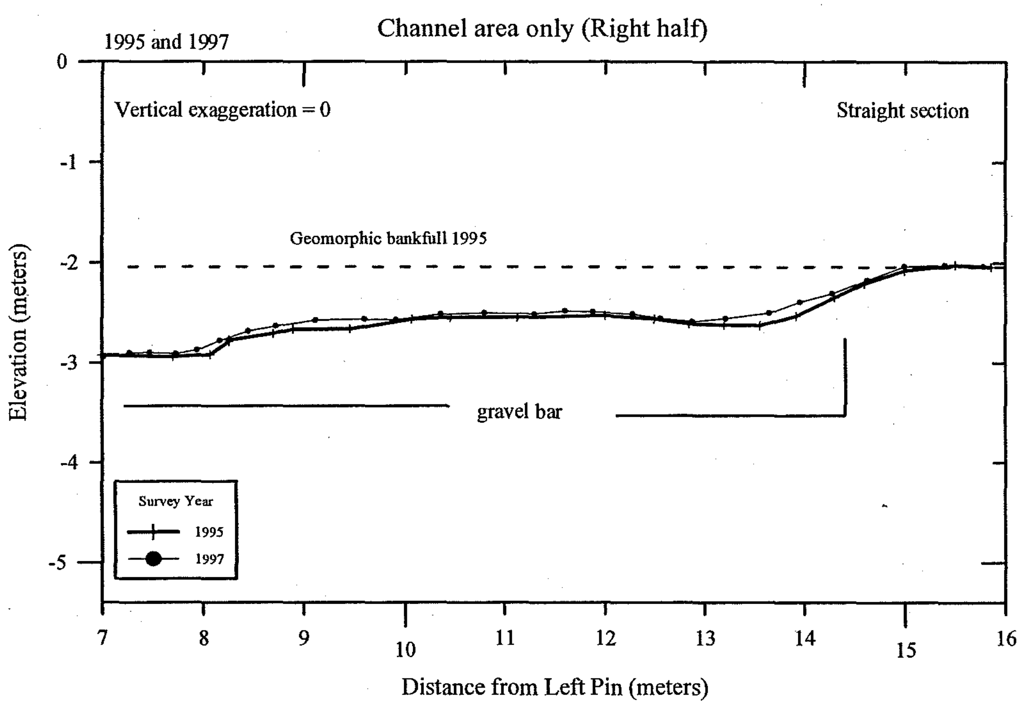
Entire cross-section 1995
(Baseline year)



The length of the channel area for cross-section 9 required that it be split into two sections in order to maintain the same scale as the other channel area plots. See next page for the cross-section 9 channel-area-only plots.

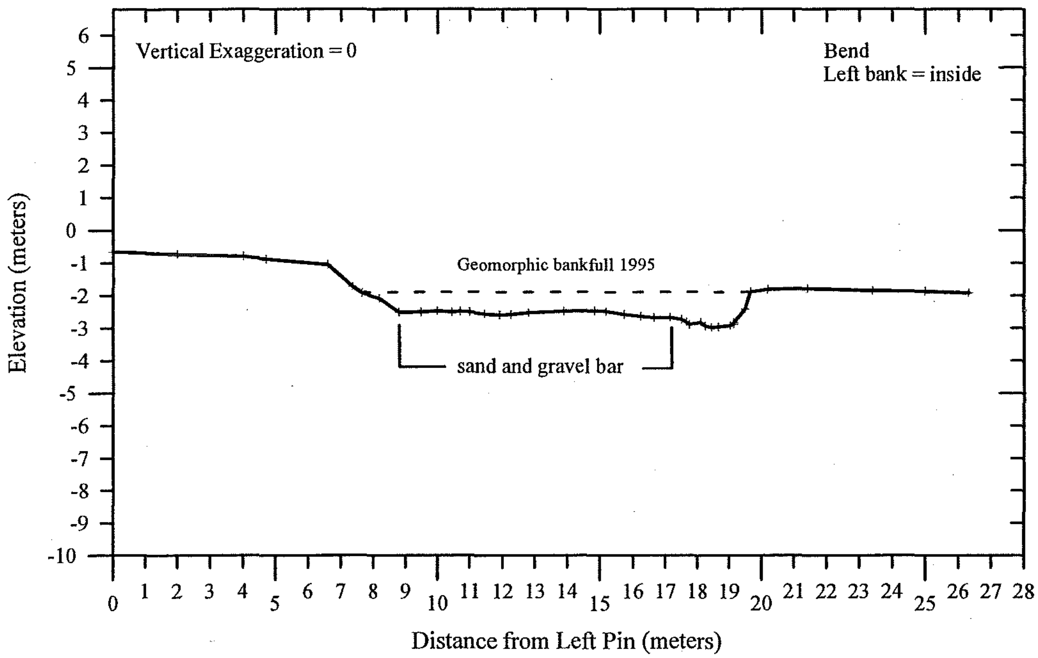
Basin Creek cross-section 9 (continued)
New Cattle Exclosure
1995 and 1997





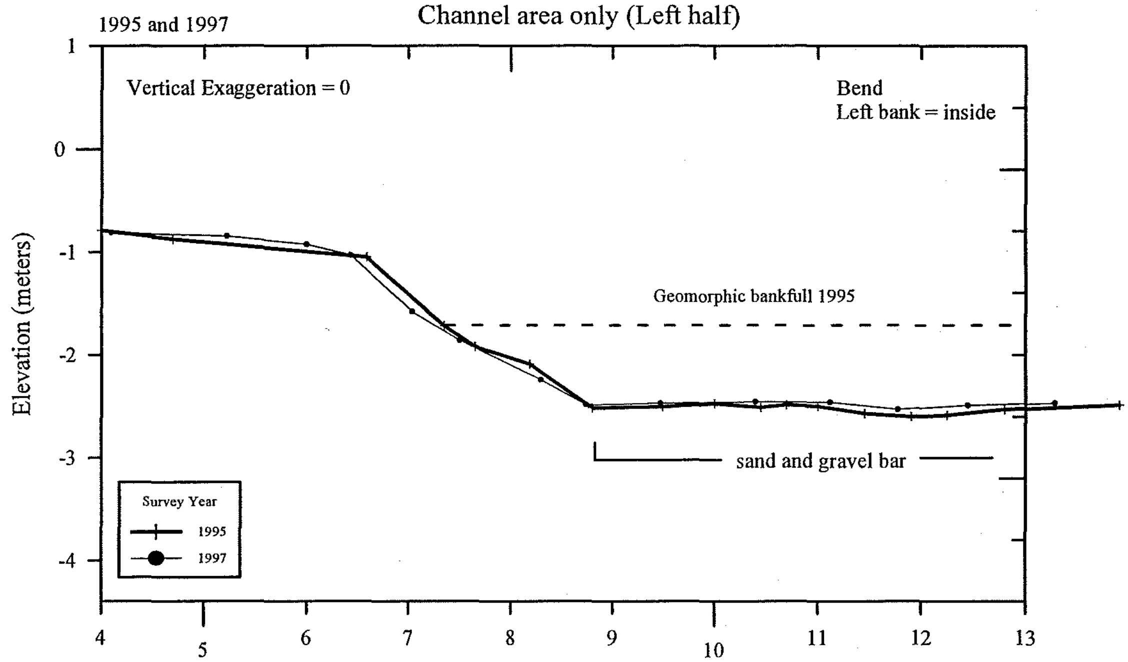
Basin Creek cross-section 10
Riparian Guidelines
1995 and 1997

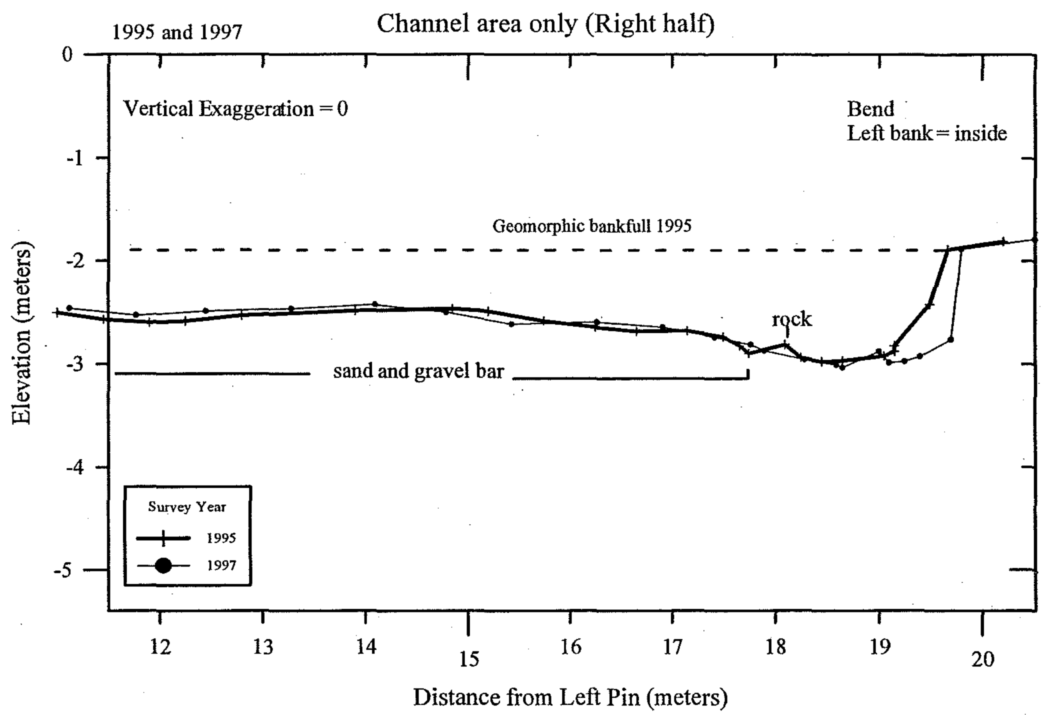
Entire cross-section 1995
(Baseline year)



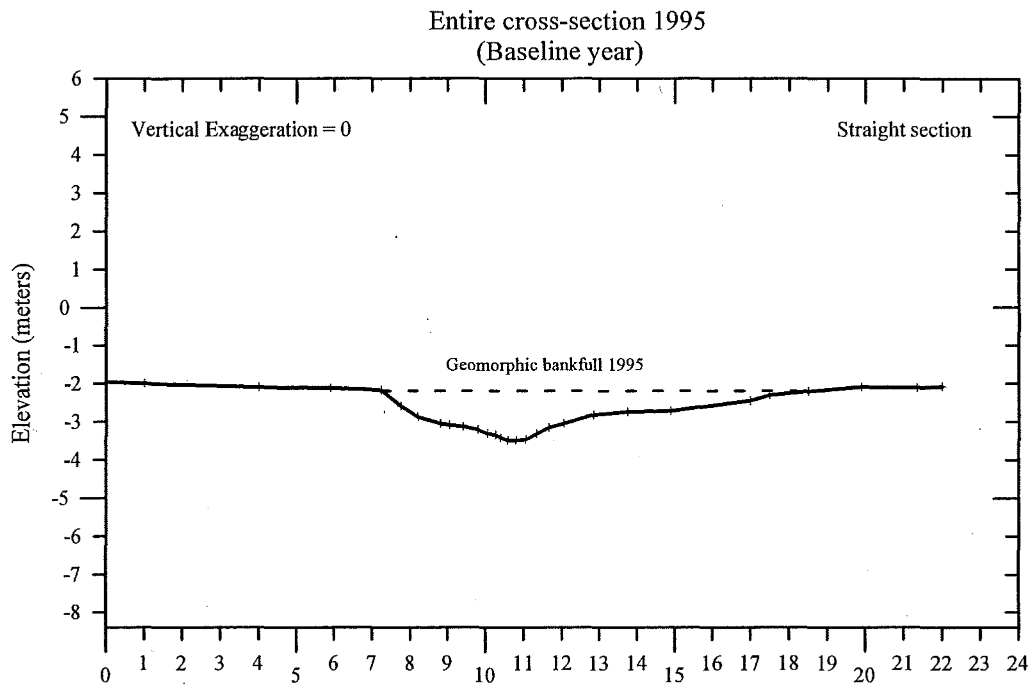
The length of the channel area for cross-section 10 required that it be split into two sections in order to maintain the same scale as the other channel area plots. See next page for the cross-section 10 channel-area-only plots.

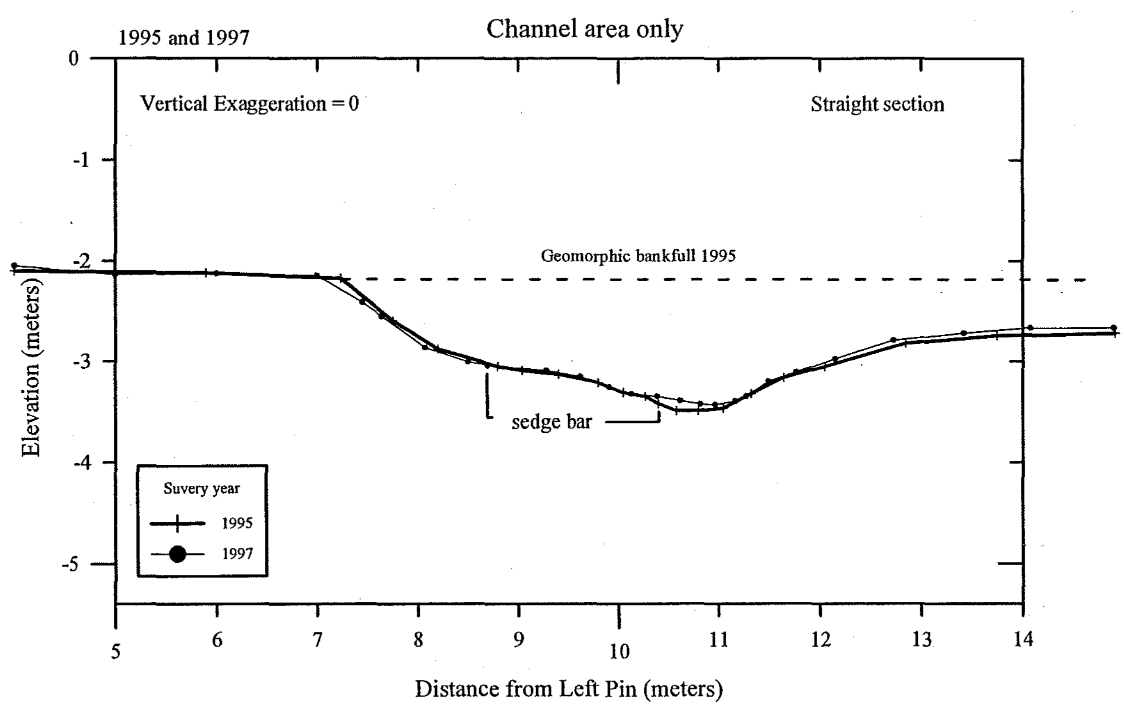
Basin Creek cross-section 10 continued
Riparian Guidelines
1995 and 1997



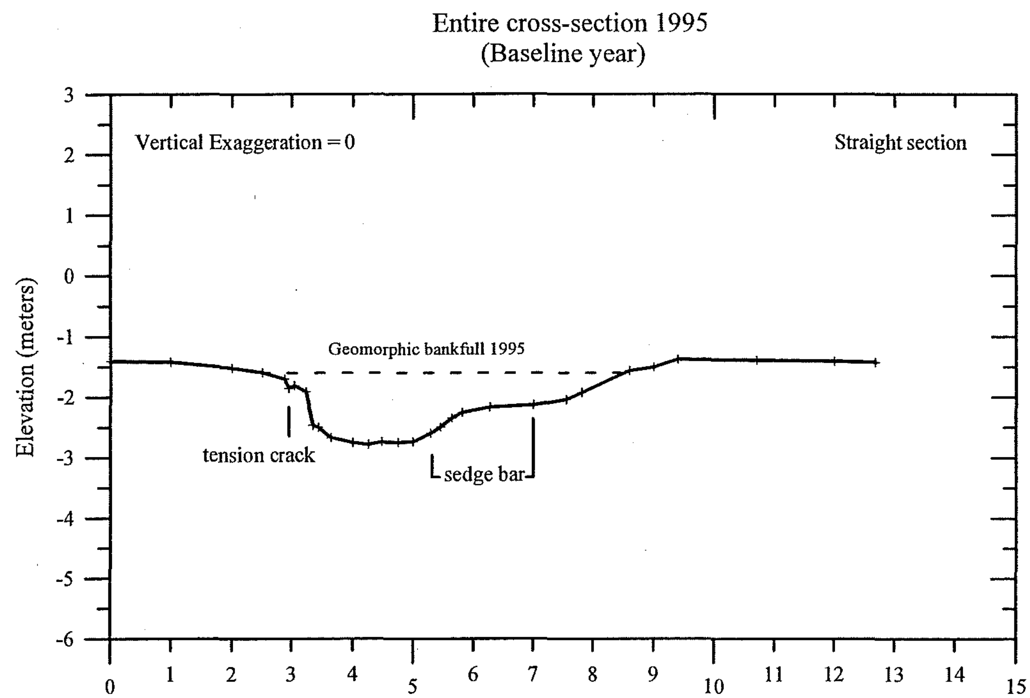


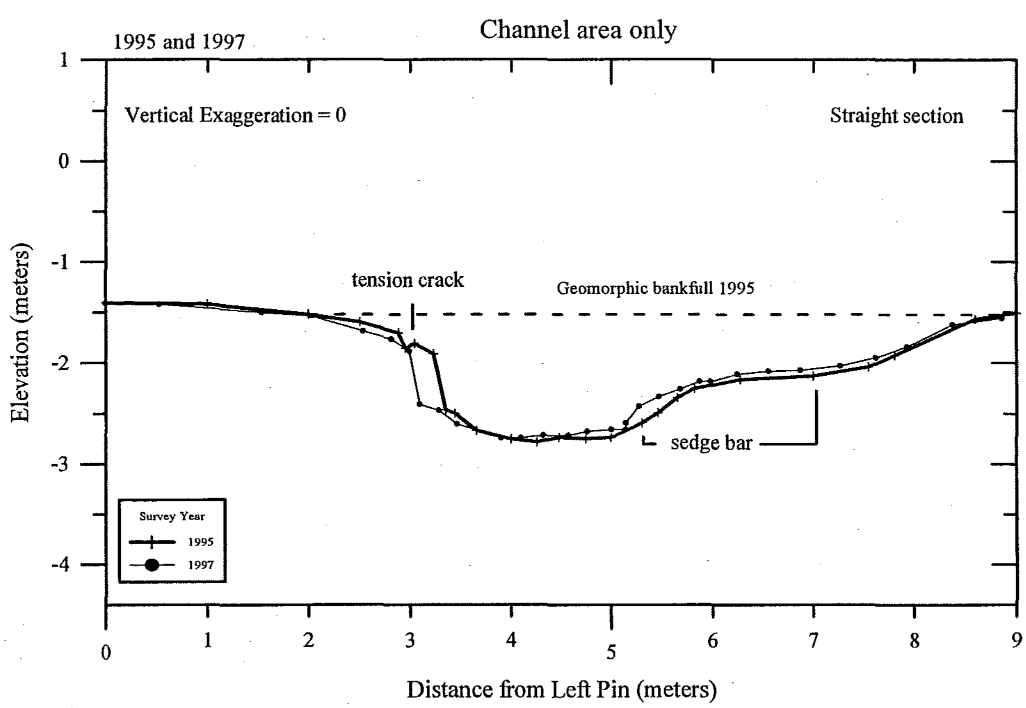
Basin Creek cross-section 11
Riparian Guidelines
1995 and 1997





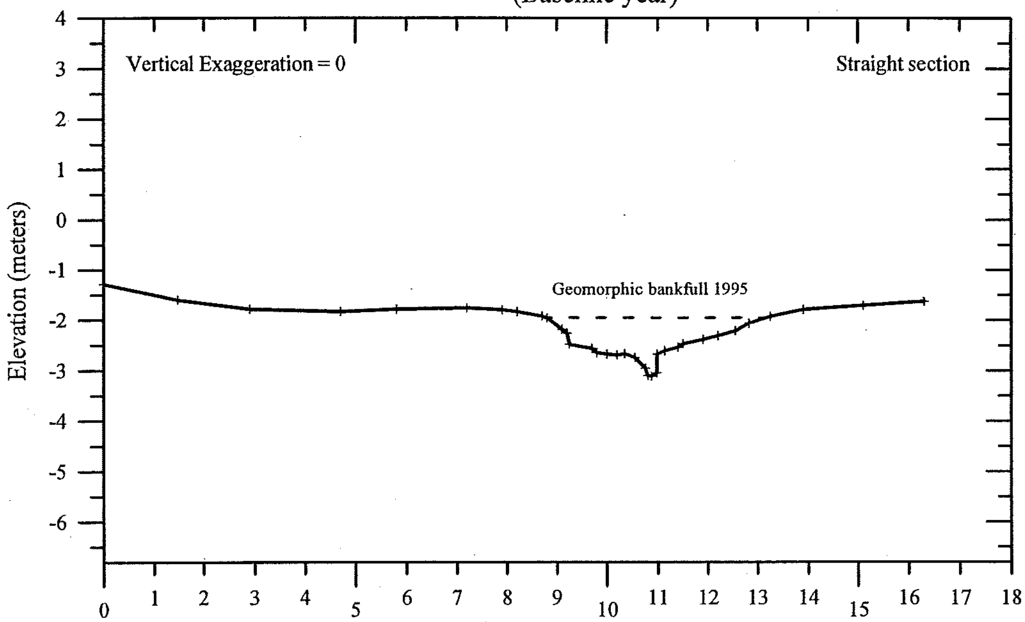
Basin Creek cross-section 12
Riparian Guidelines
1995 and 1997



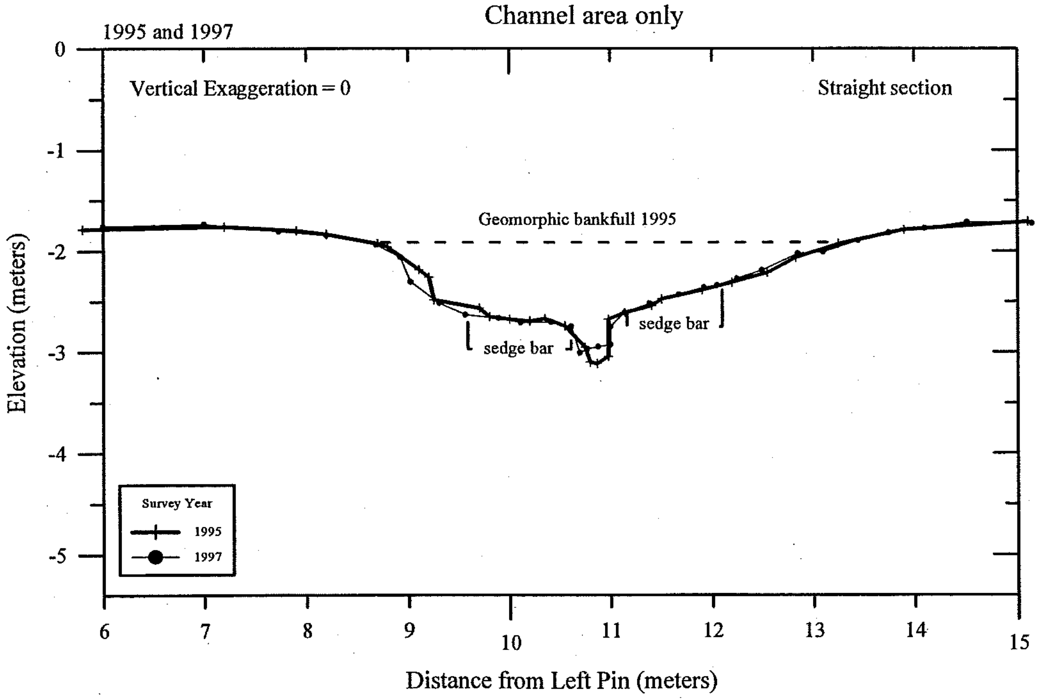


Basin Creek cross-section 13
Riparian Guidelines
1995 and 1997

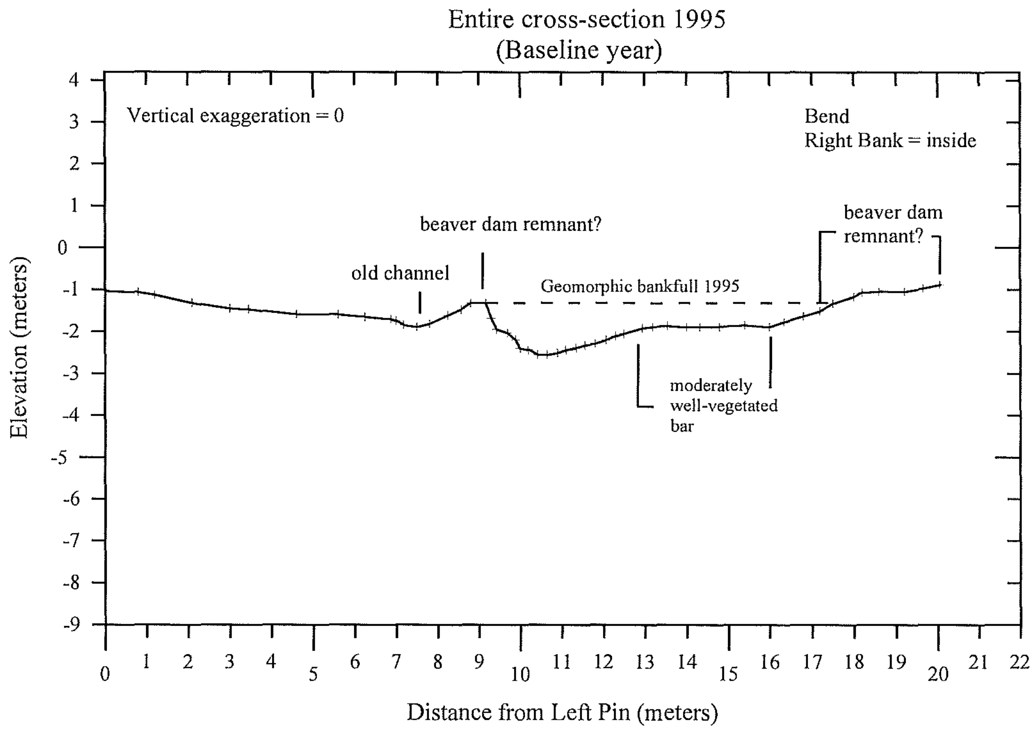
Entire cross-section 1995
(Baseline year)



Channel area only



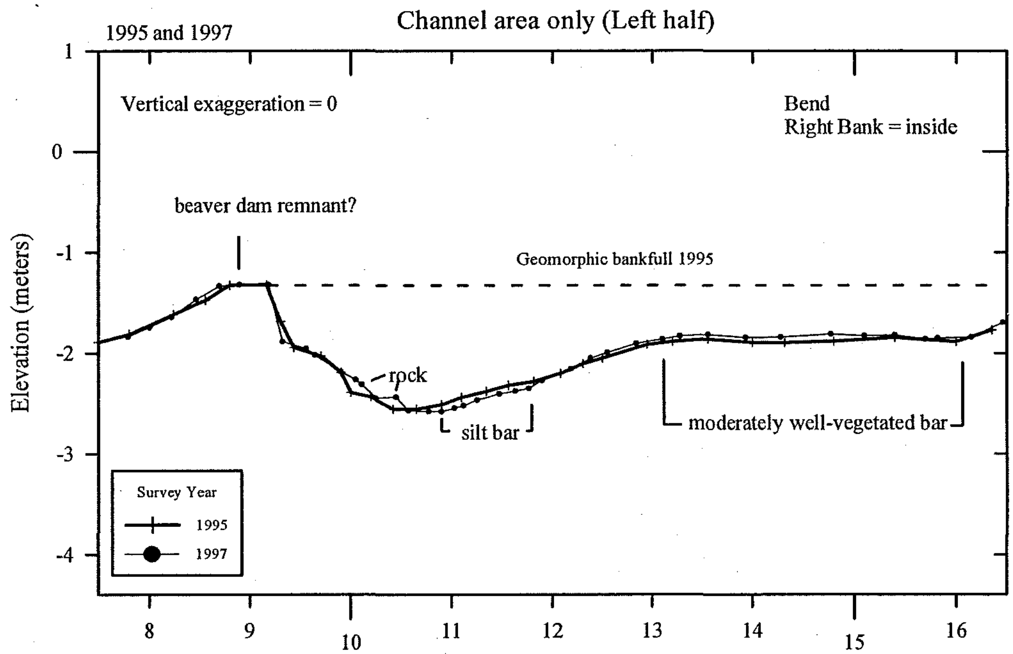
Basin Creek cross-section 14
Riparian Guidelines
1995 and 1997

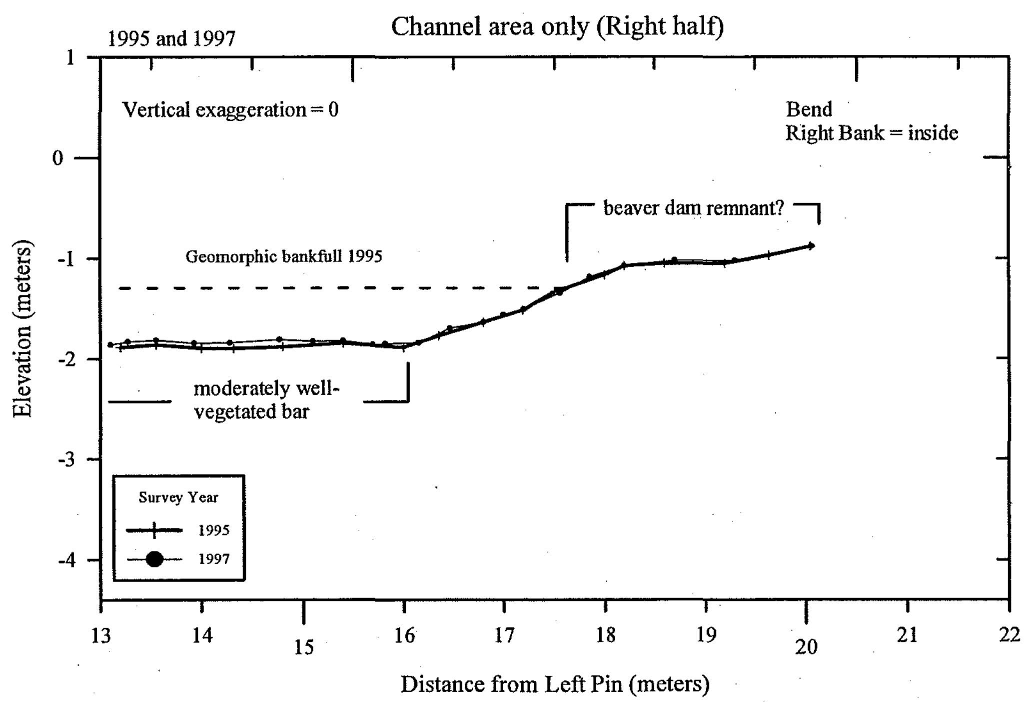


The length of the channel area for cross-section 14 required that it be split into two sections in order to maintain the same scale as that other channel-area plots. See next page for the cross-section 14 channel-area-only plots.

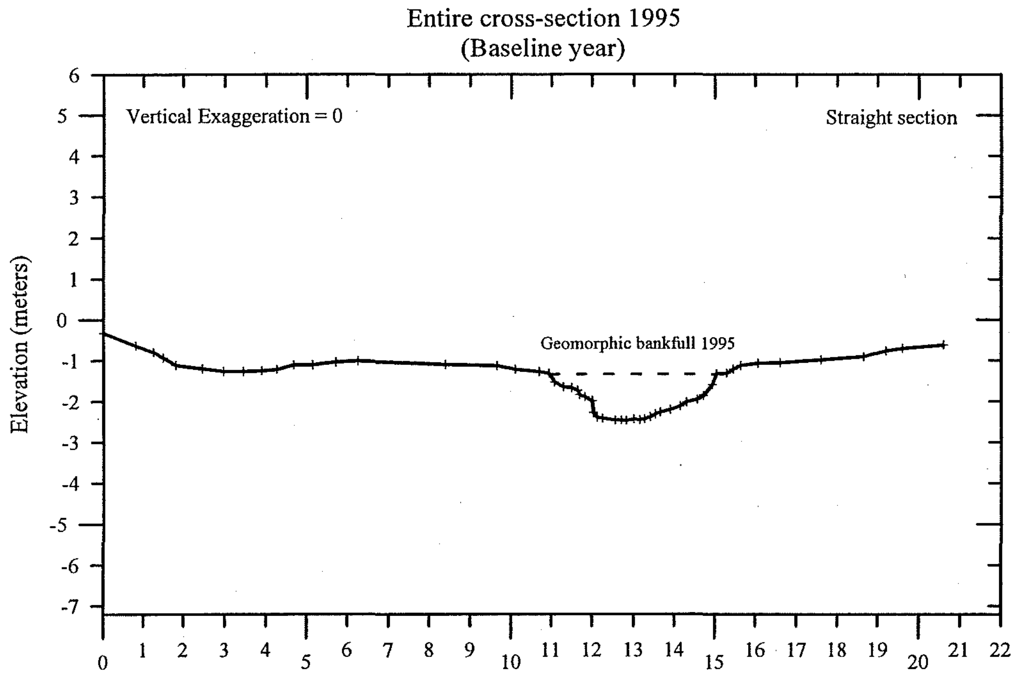
6/02/03 -- Upon review of this cross-section I noted that the geomorphic bankfull location was incorrectly placed. The geomorphic bankfull width should be flush with the valley floor rather then at the top of what may be a beaver dam. A review of the cross-sections from the two years suggests that the net change would be closer to 0 sq. m rather than -0.13 sq. m. This would change the annual rate of change from -0.07 to 0 sq. m/yr and amplify the differences between the Riparian Guidelines and the New Cattle Exclosure. See page 69, Figure 11. It does not however, change the results and conclusions because the sample size for the Riparian Guidelines is large (n = 39).

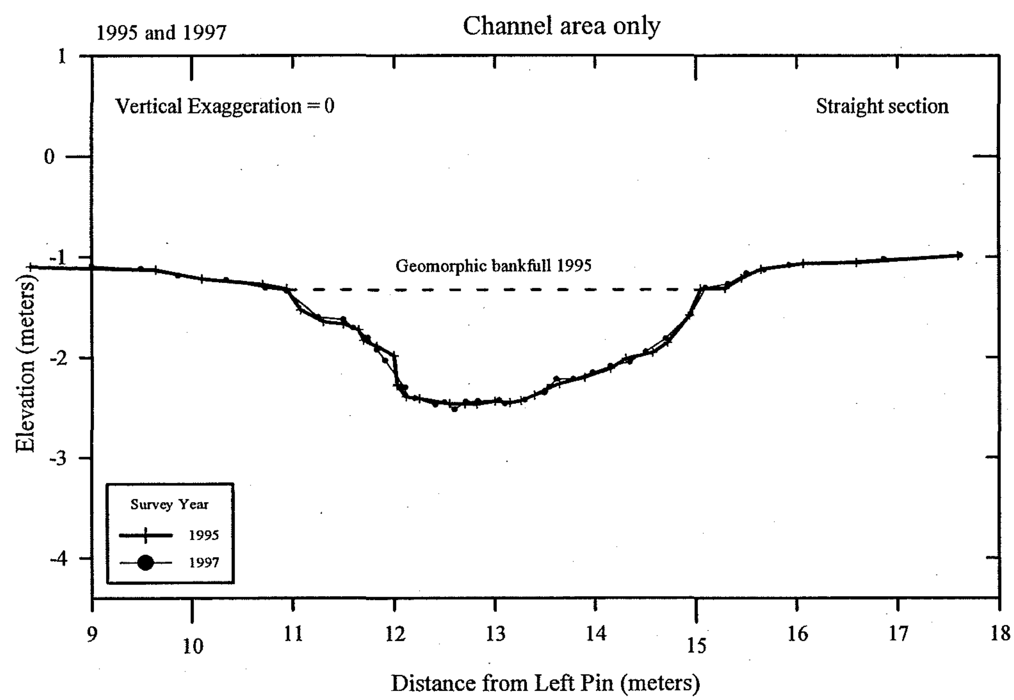
Basin Creek cross-section 14 (continued)
Riparian Guidelines
1995 and 1997





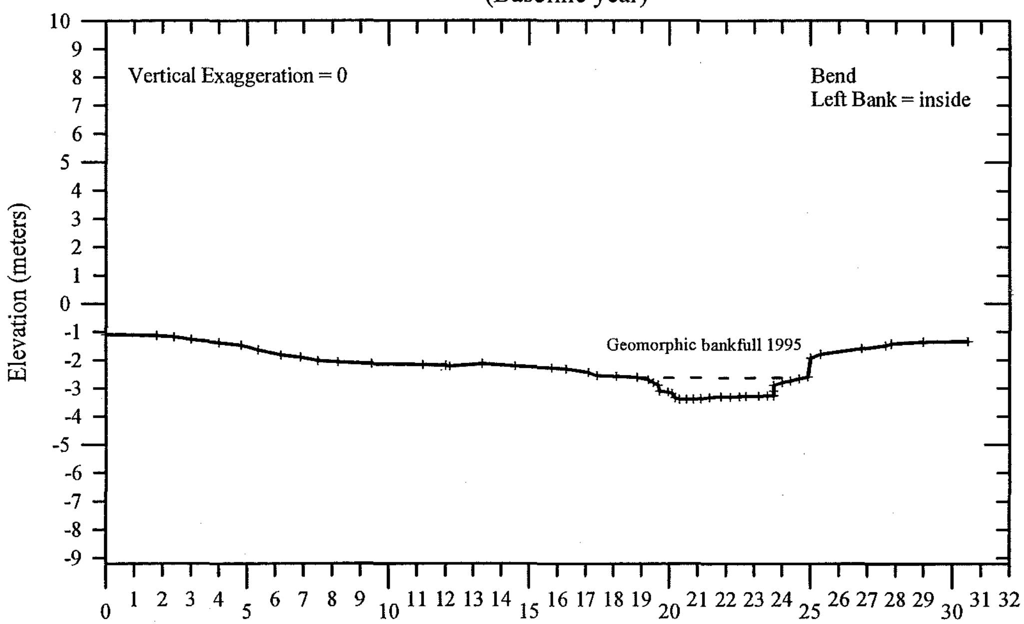
Basin Creek cross-section 15
Riparian Guidelines
1995 and 1997



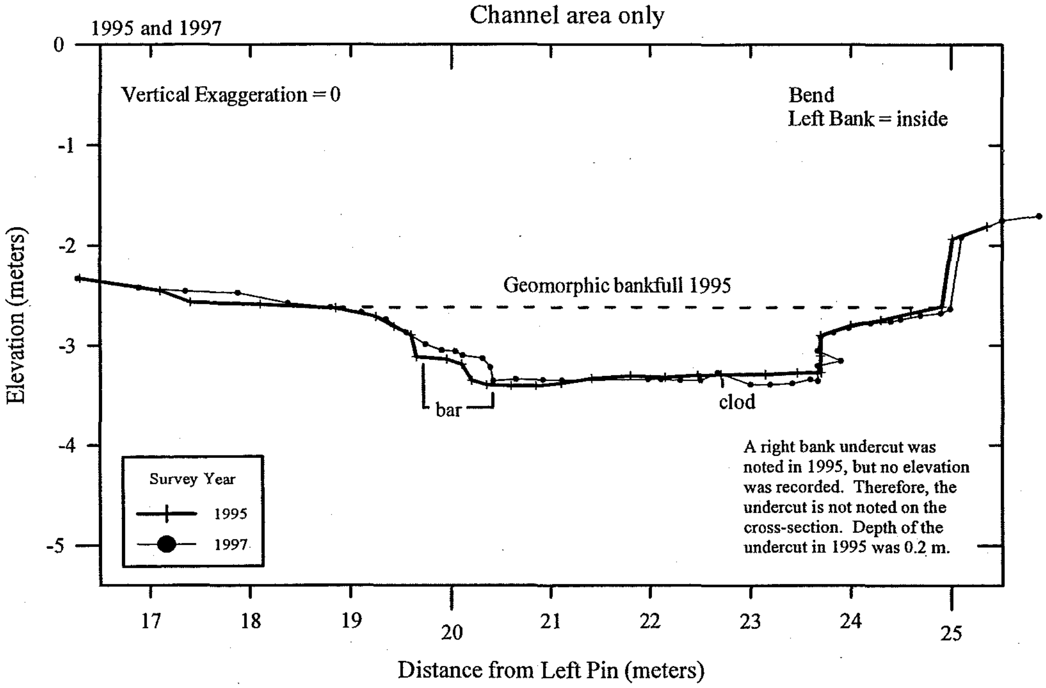


Basin Creek cross-section 16
Riparian Guidelines
1995 and 1997

Entire cross-section 1995
(Baseline year)



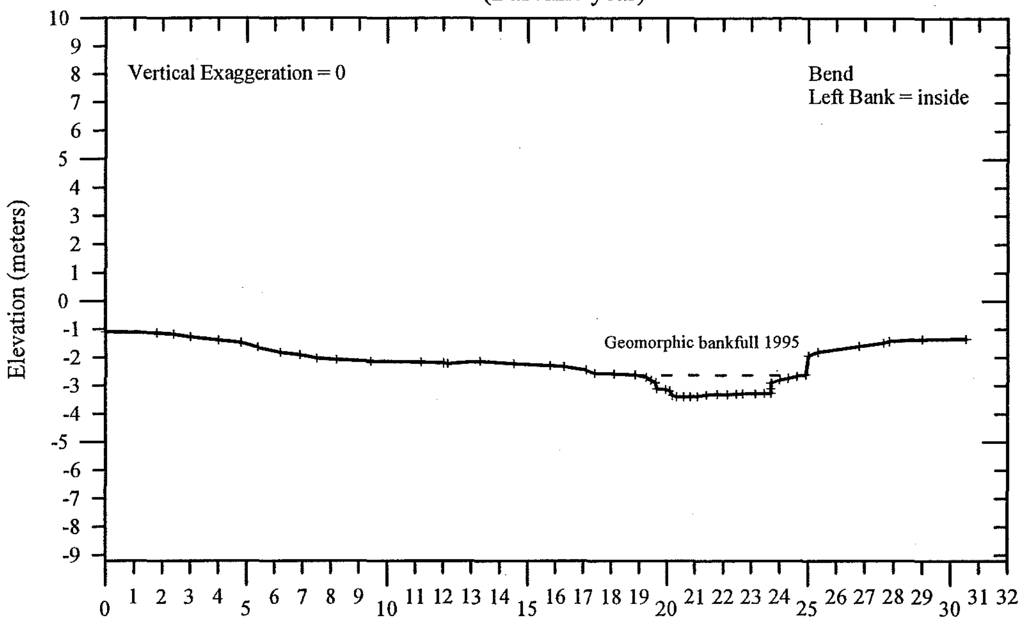
Channel area only



Basin Creek cross-section 16 (continued)
Riparian Guidelines
1995 and 1997

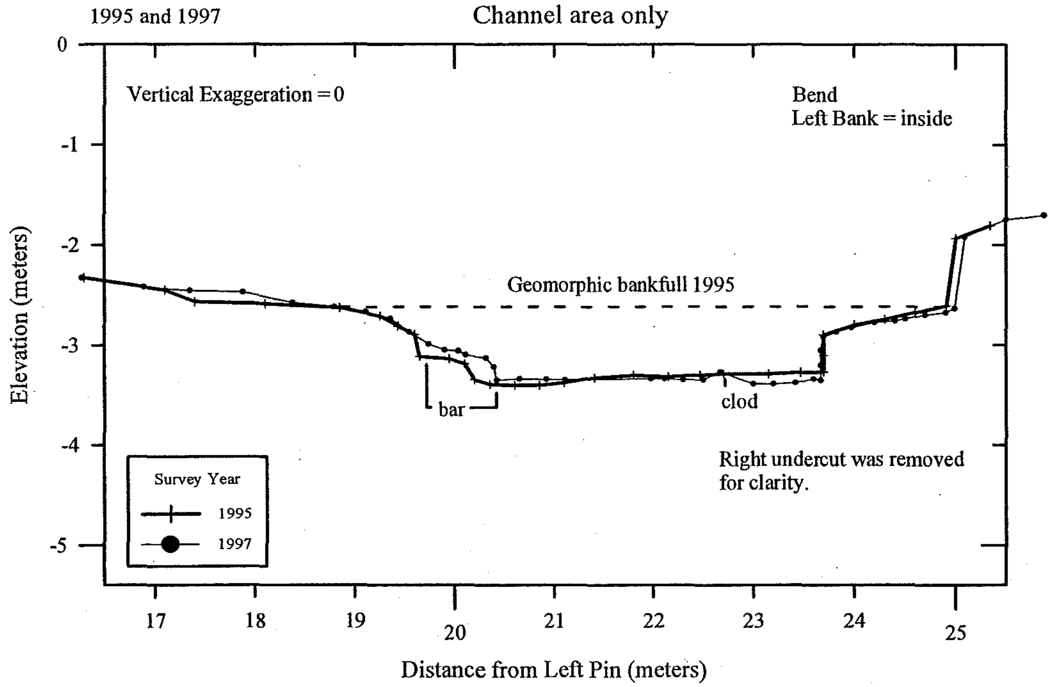
Undercuts removed for clarity.

Entire cross-section 1995
(Baseline year)

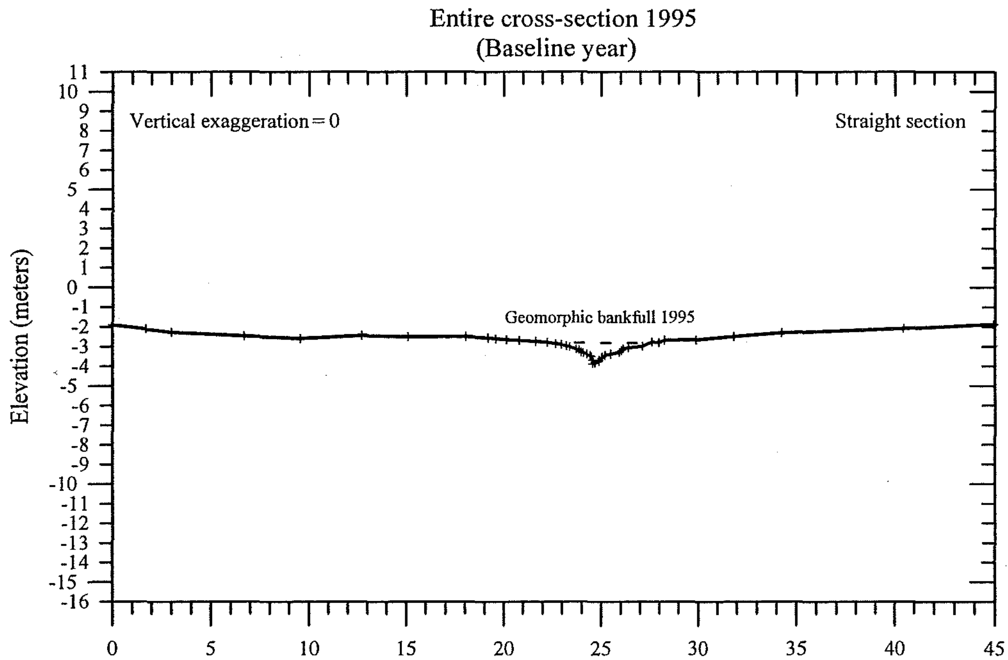


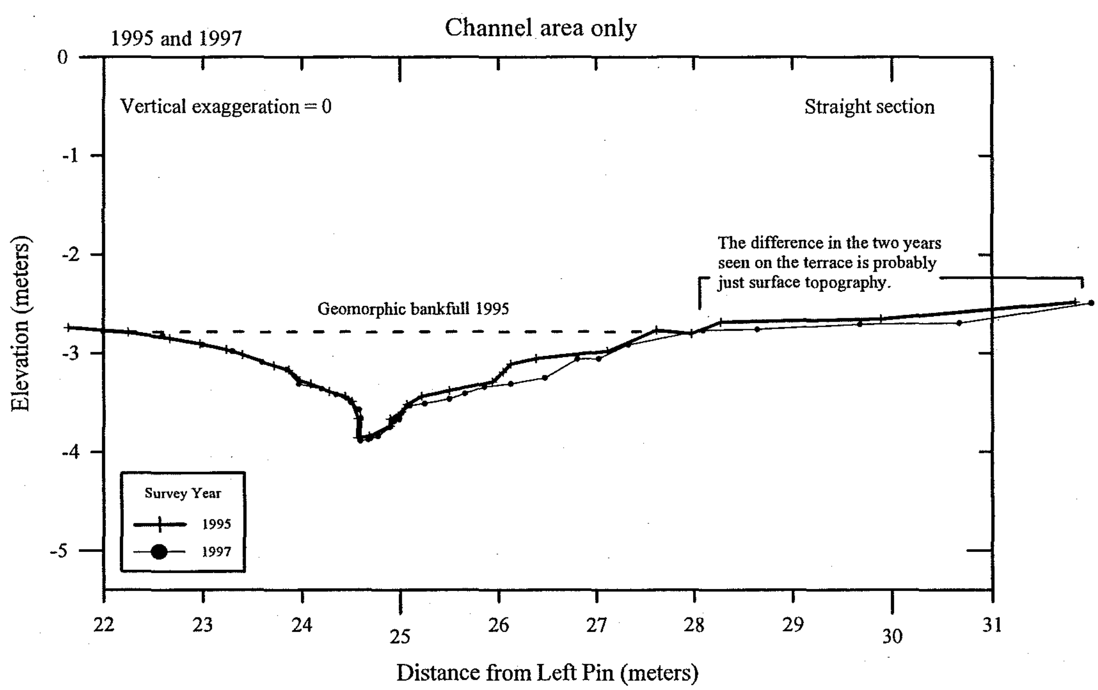
1995 and 1997

Channel area only

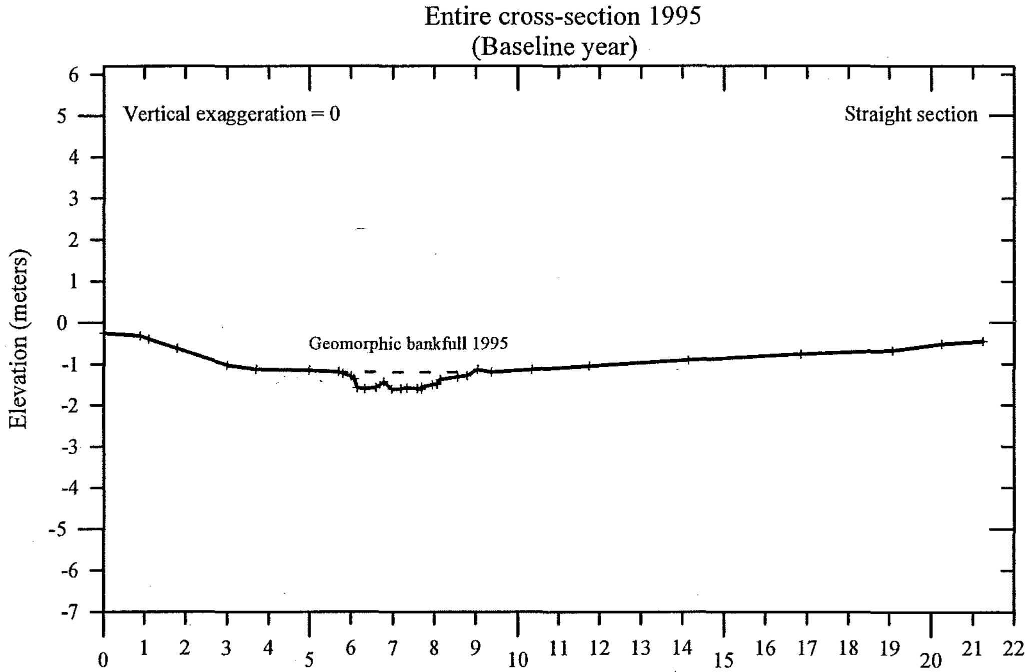


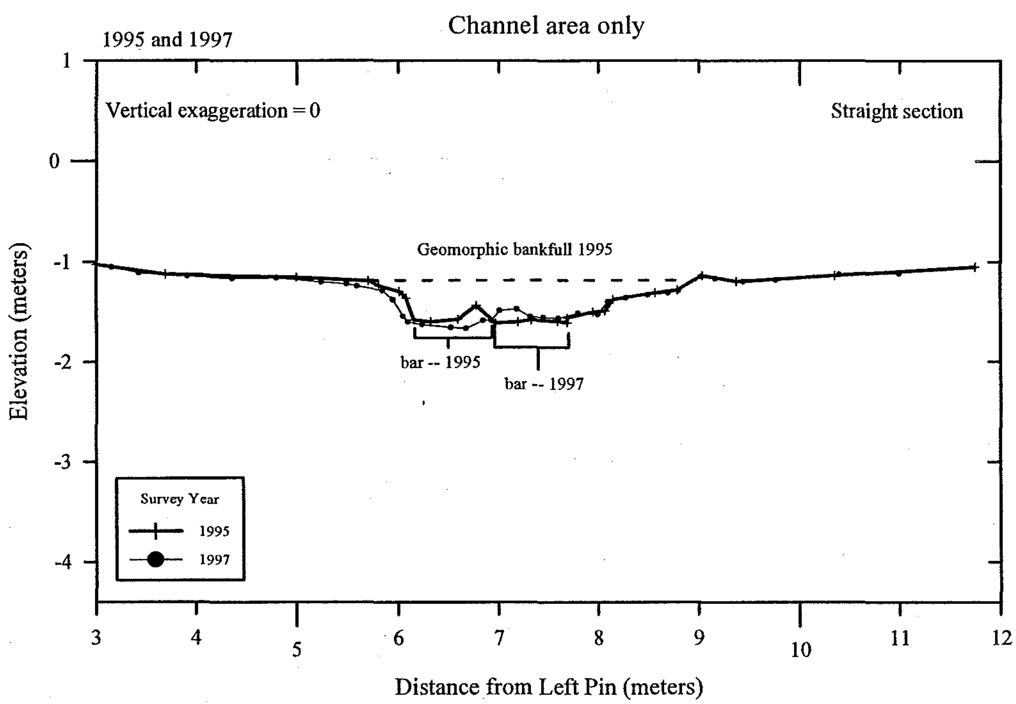
Basin Creek cross-section 17
Riparian Guidelines
1995 and 1997



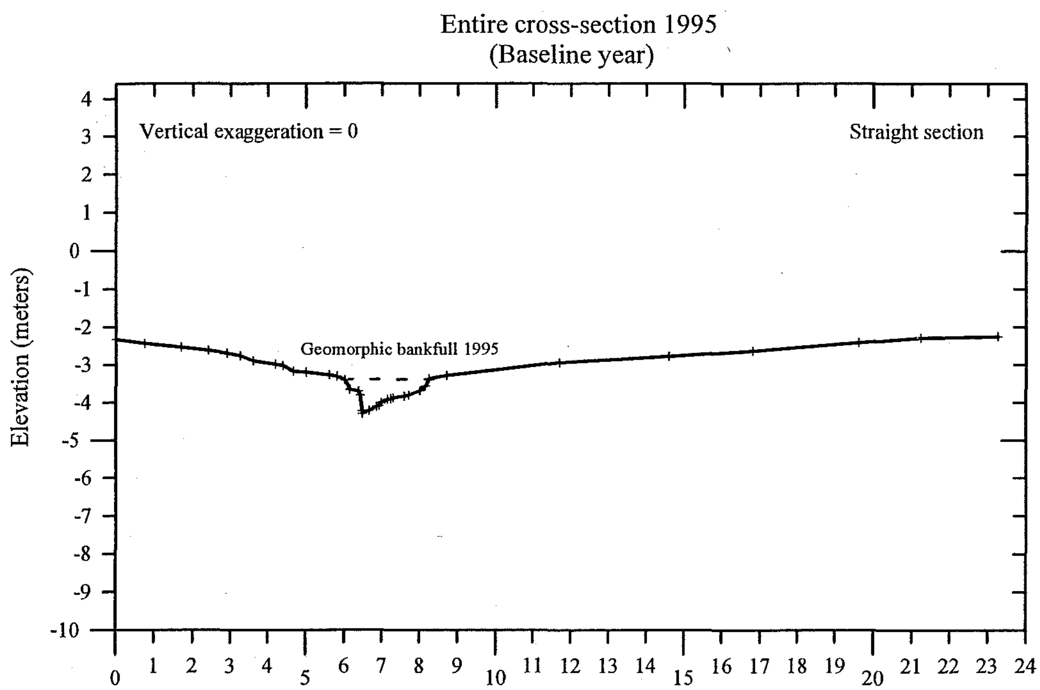


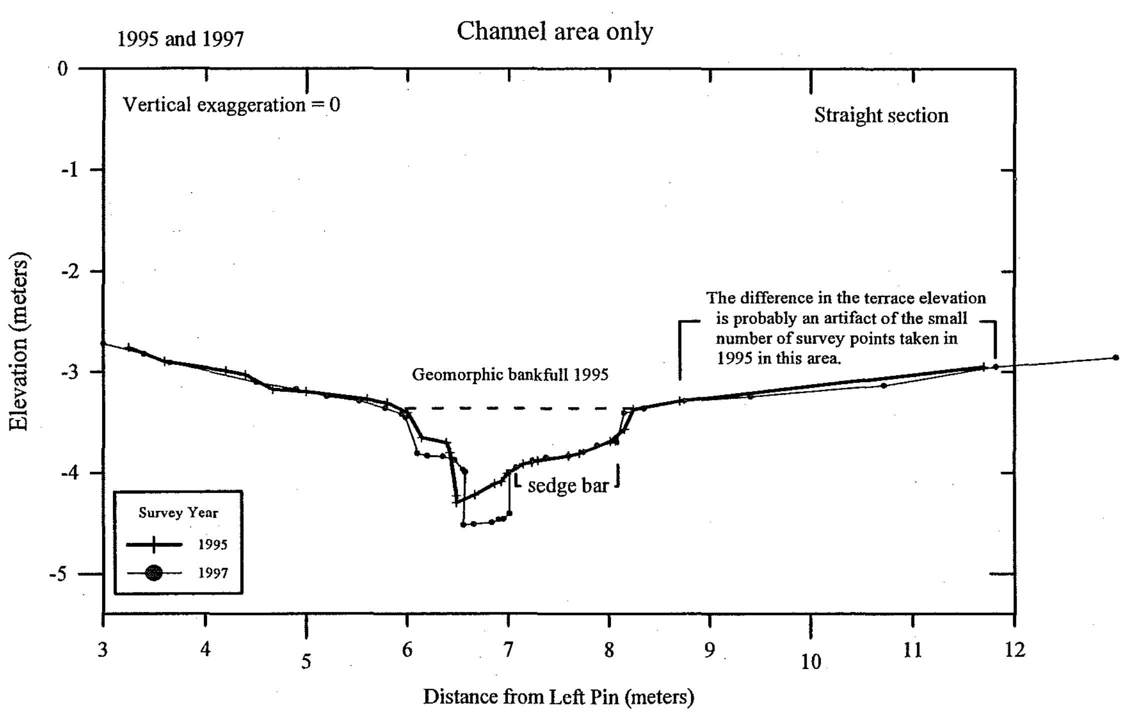
Basin Creek cross-section 18
Riparian Guidelines
1995 and 1997



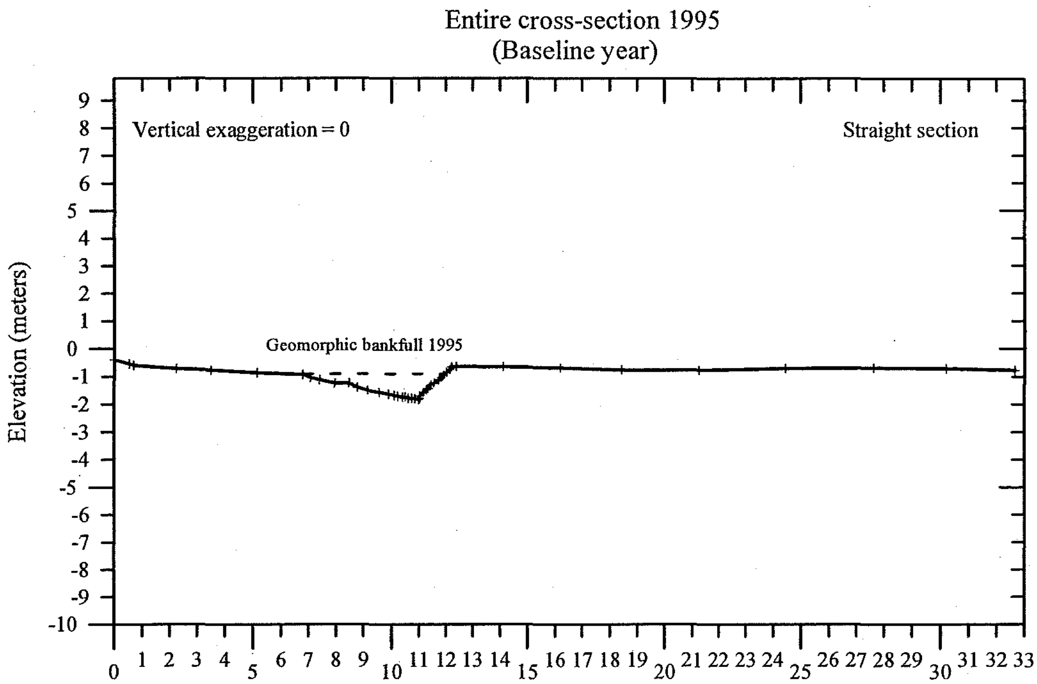


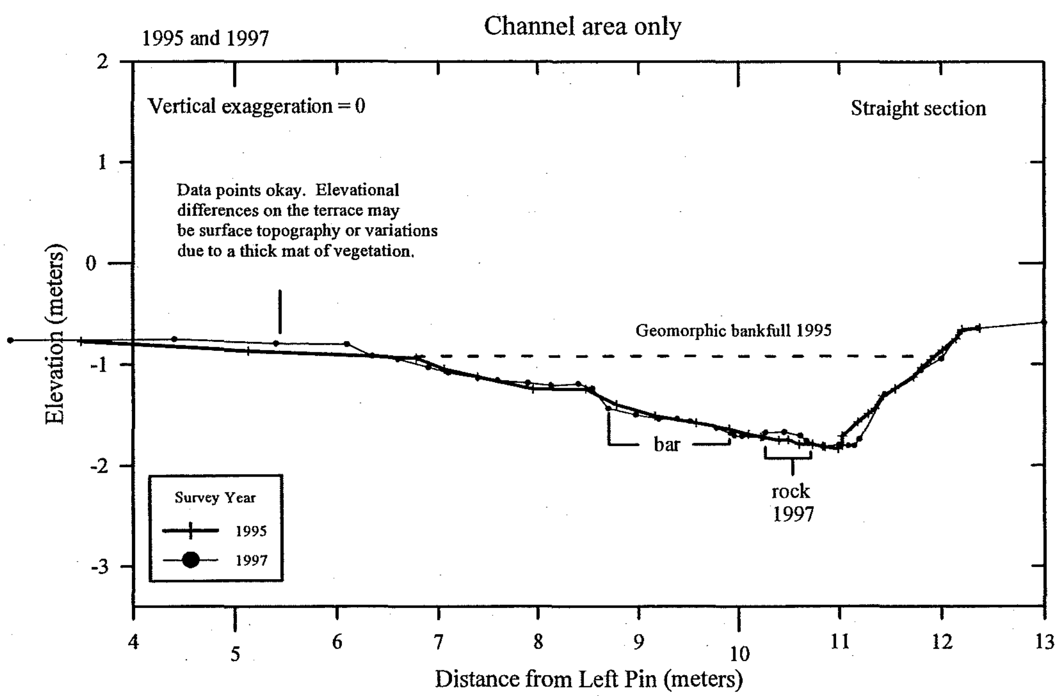
Basin Creek cross-section 19
Riparian Guidelines
1995 and 1997



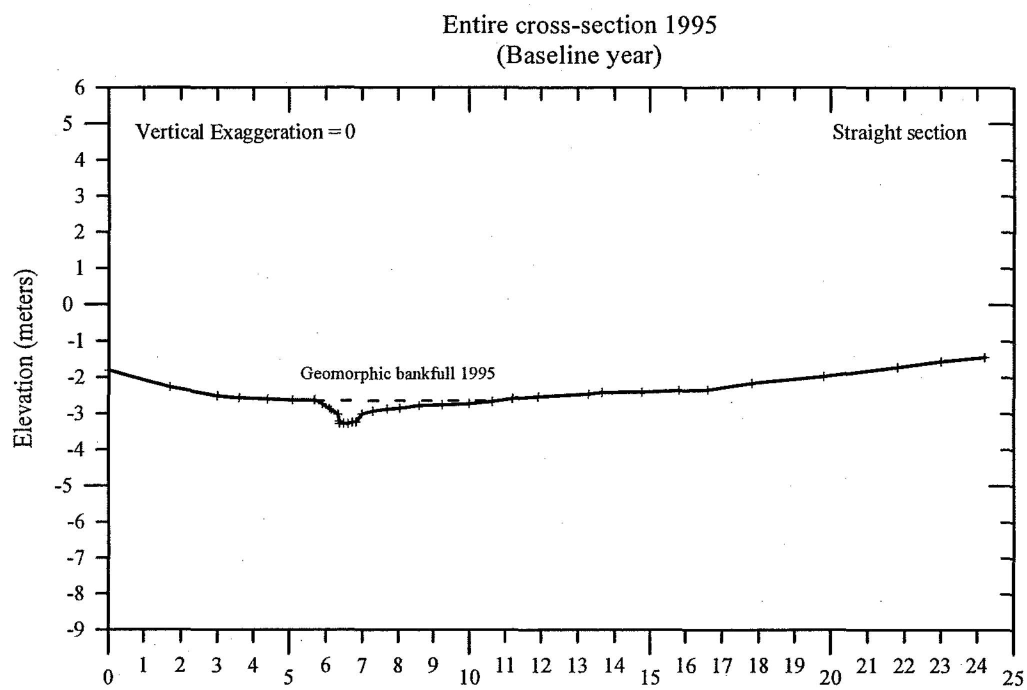


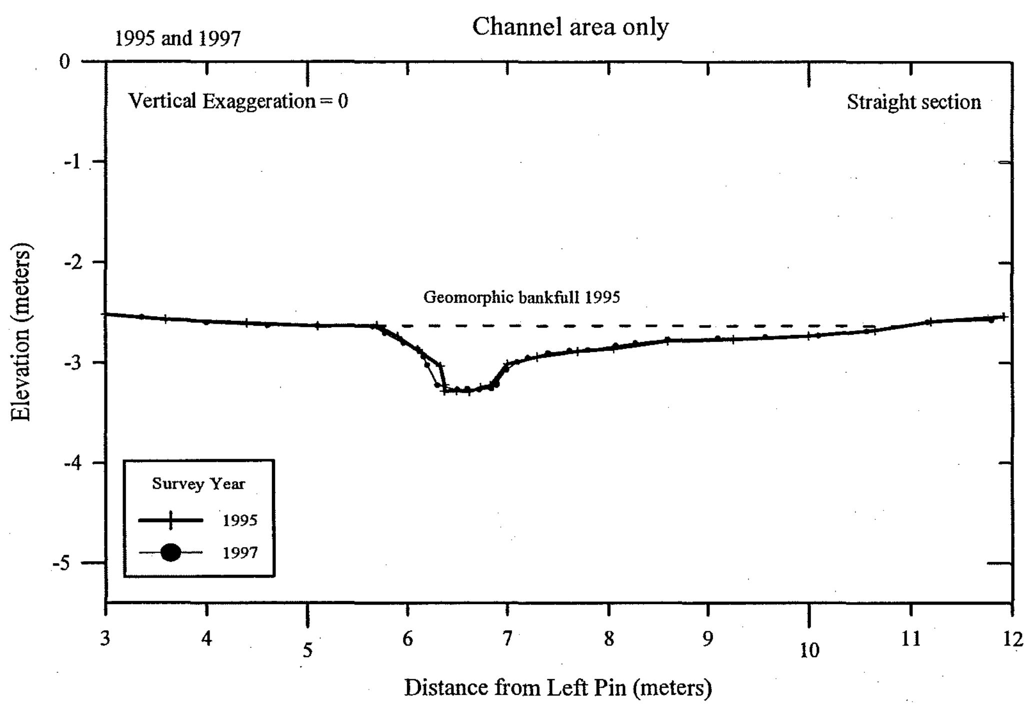
Basin Creek cross-section 20
Riparian Guidelines
1995 and 1997



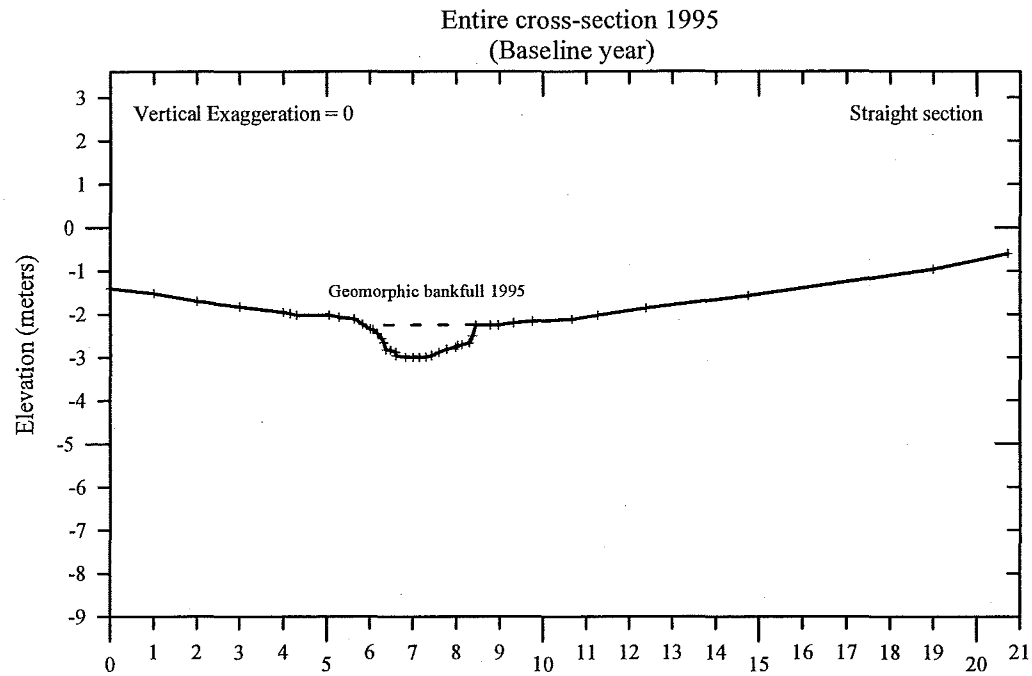


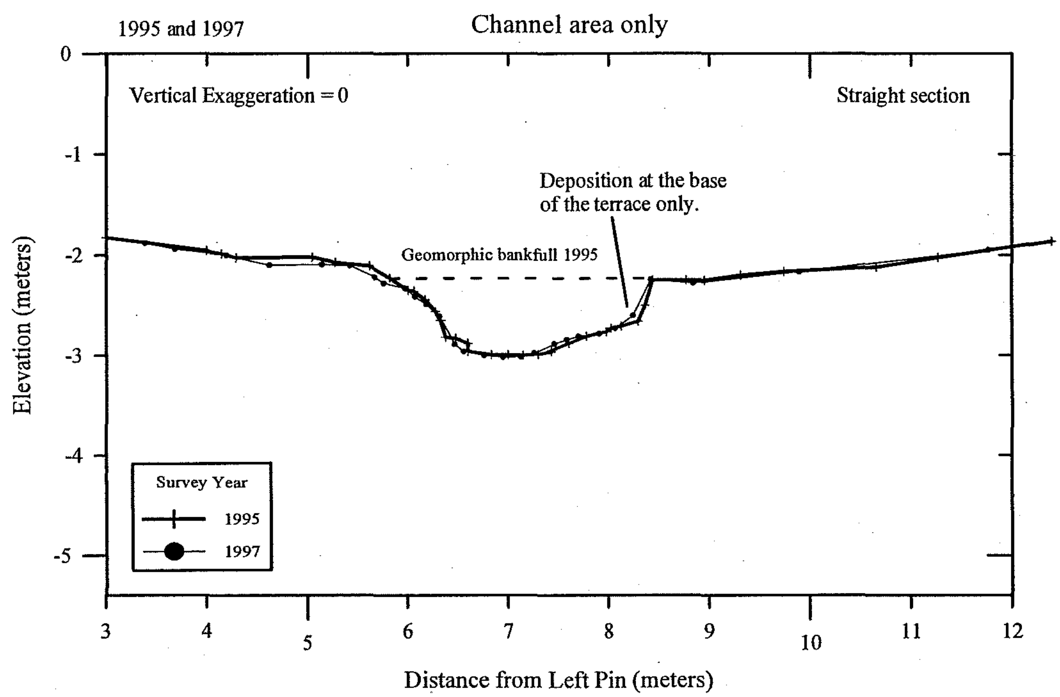
Basin Creek cross-section 21
Riparian Guidelines
1995 and 1997



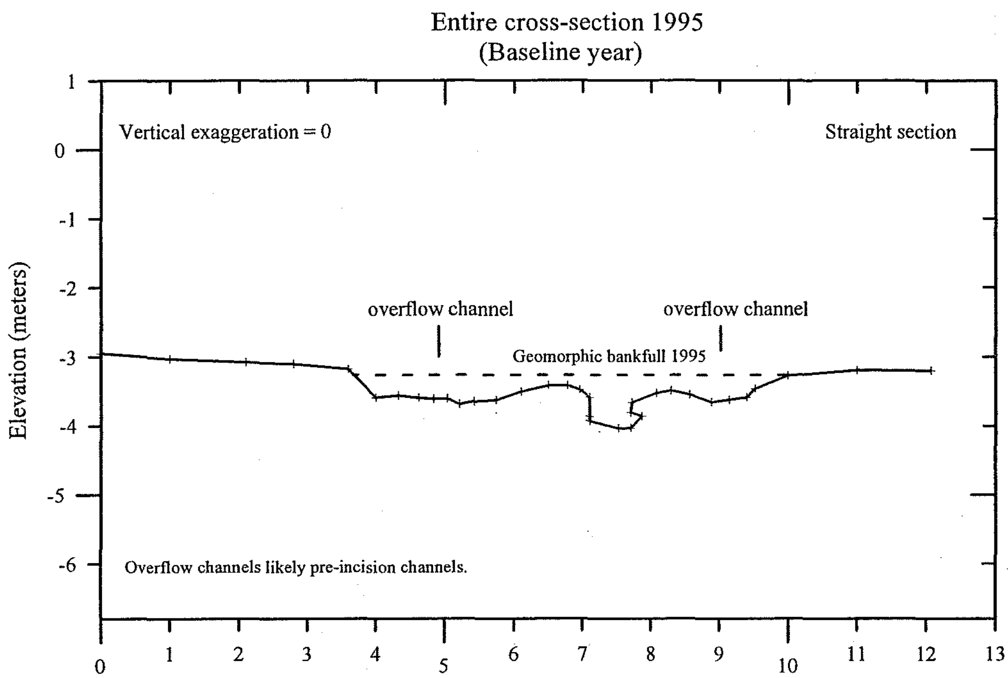


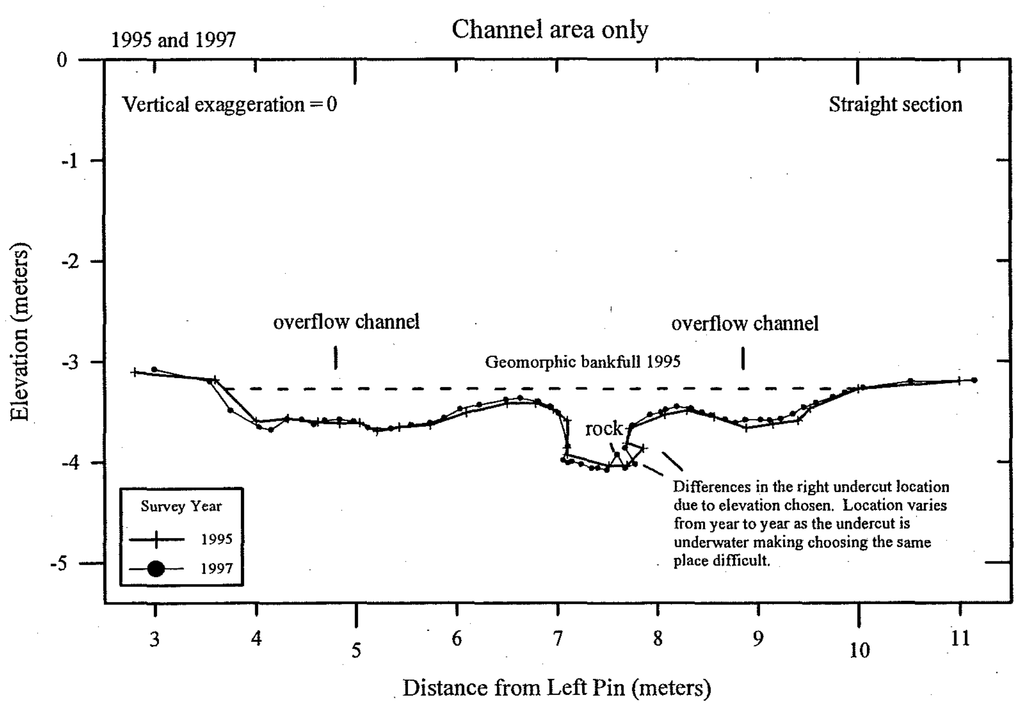
Basin Creek cross-section 22
Riparian Guidelines
1995 and 1997





Basin Creek cross-section 23
New Cattle Exclosure
1995 and 1997

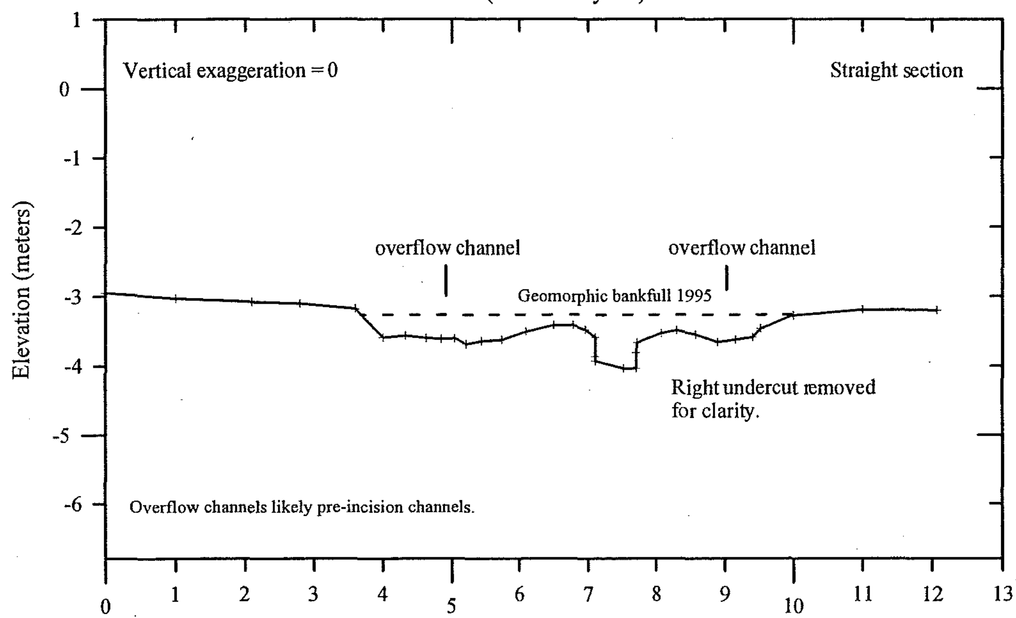




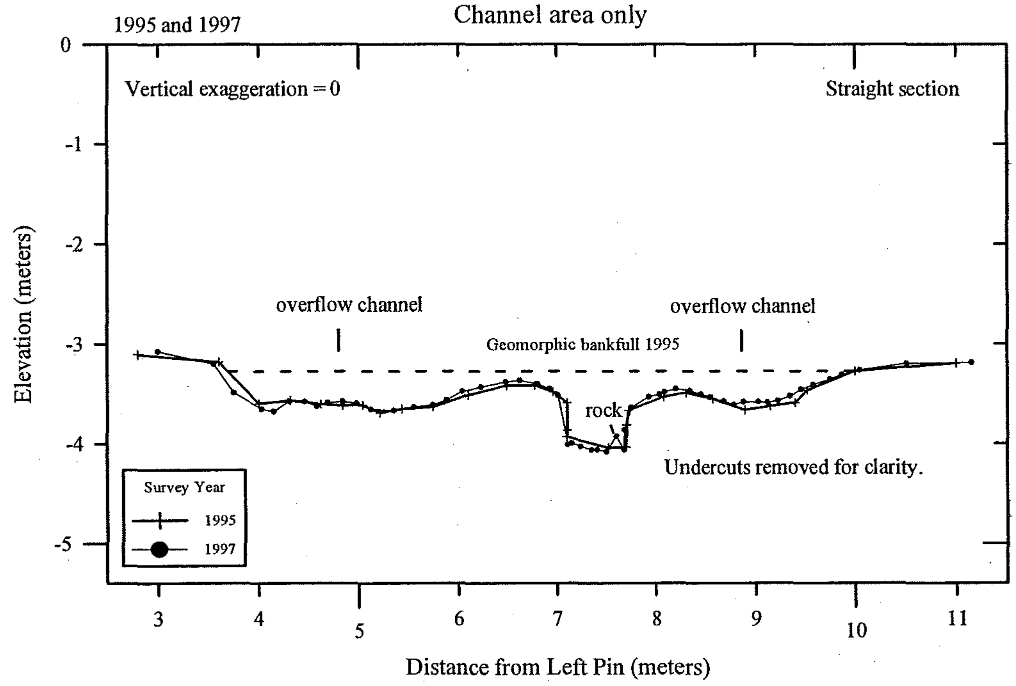
Basin Creek cross-section 23 (continued)
New Cattle Exclosure
1995 and 1997

Undercuts removed for clarity.

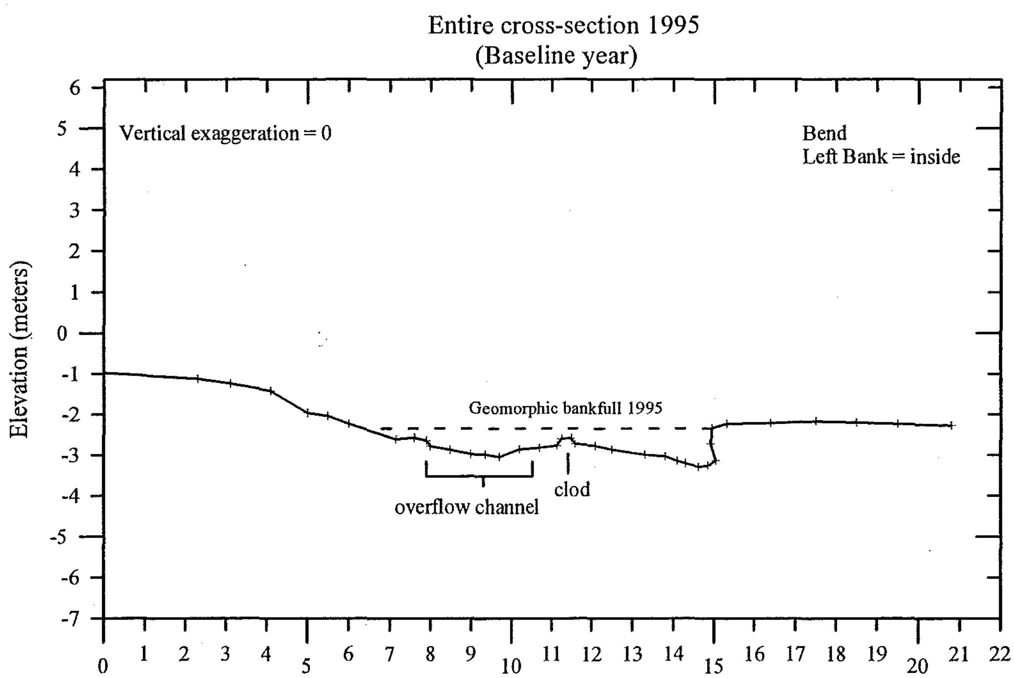
Entire cross-section 1995
(Baseline year)

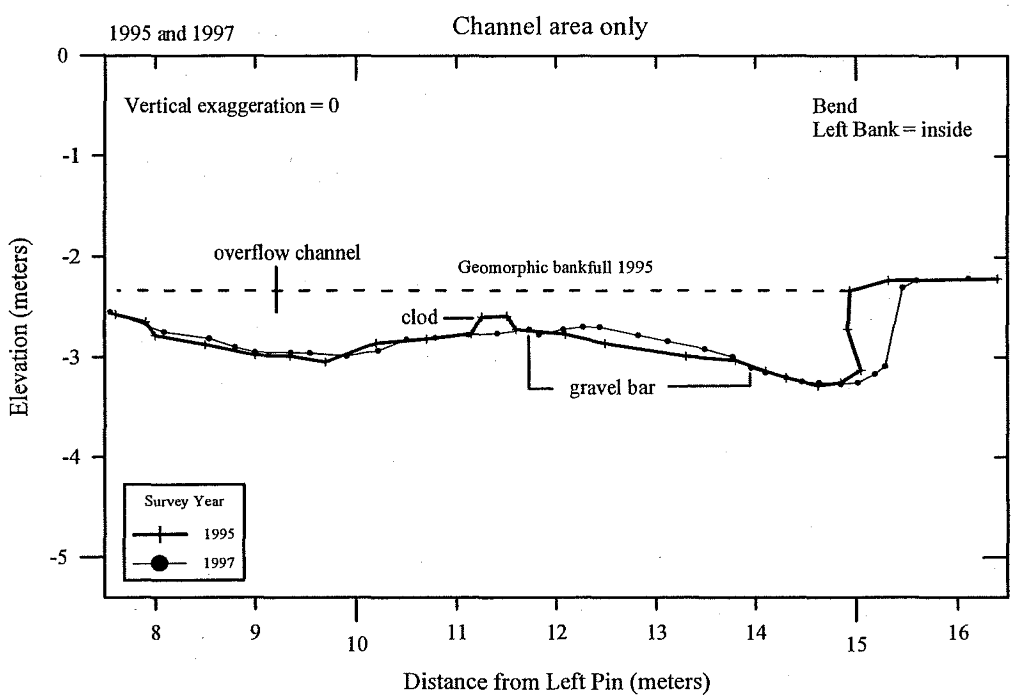


Channel area only

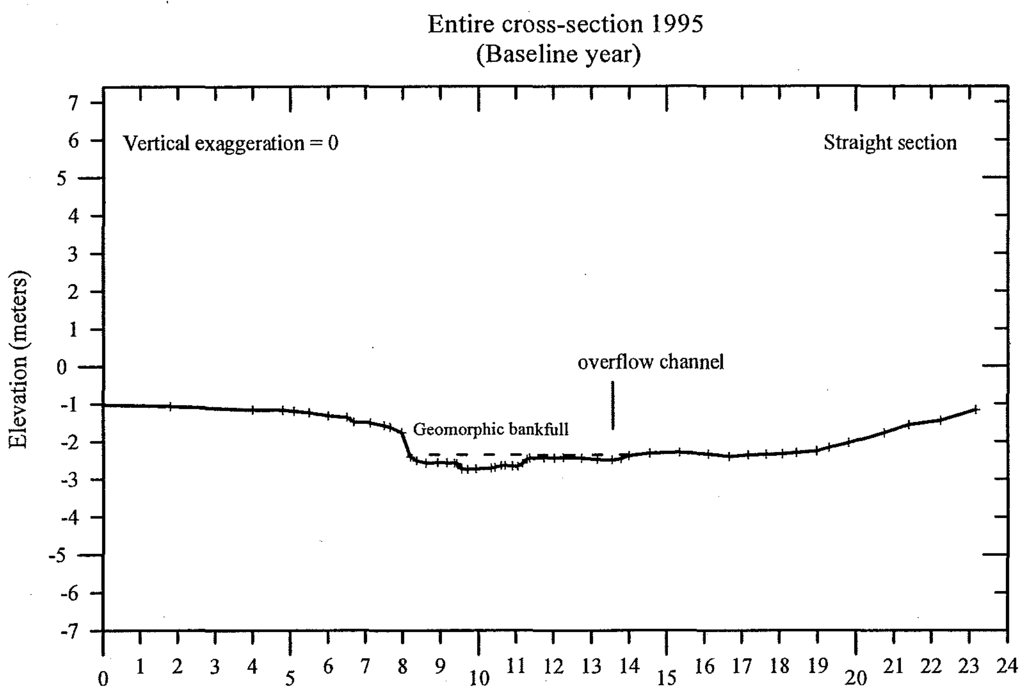


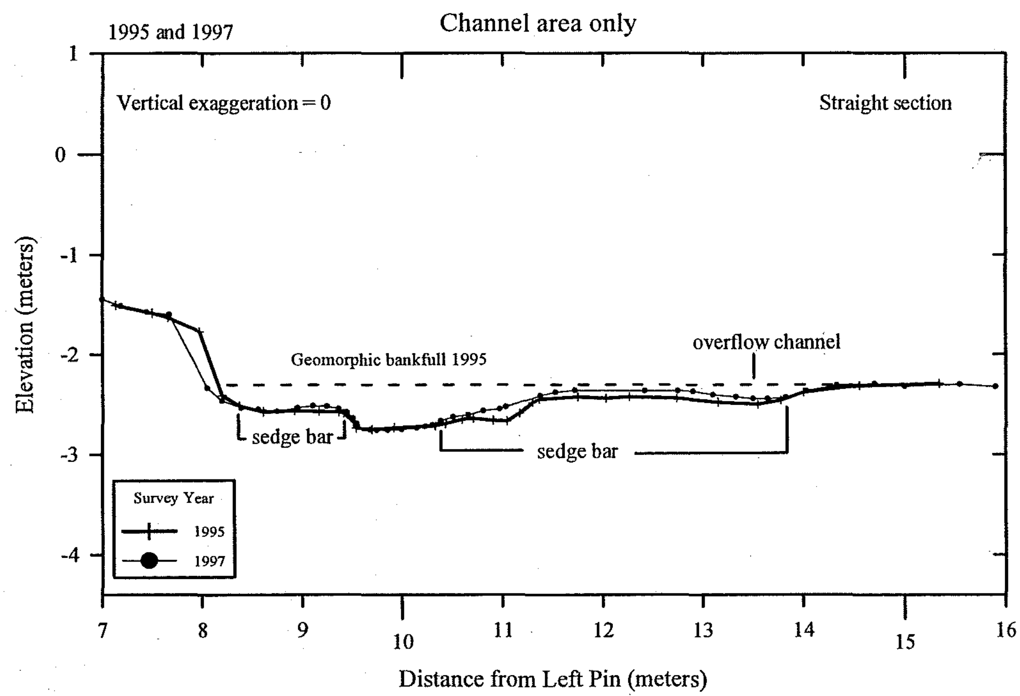
Basin Creek cross-section 24
New Cattle Exclosure
1995 and 1997



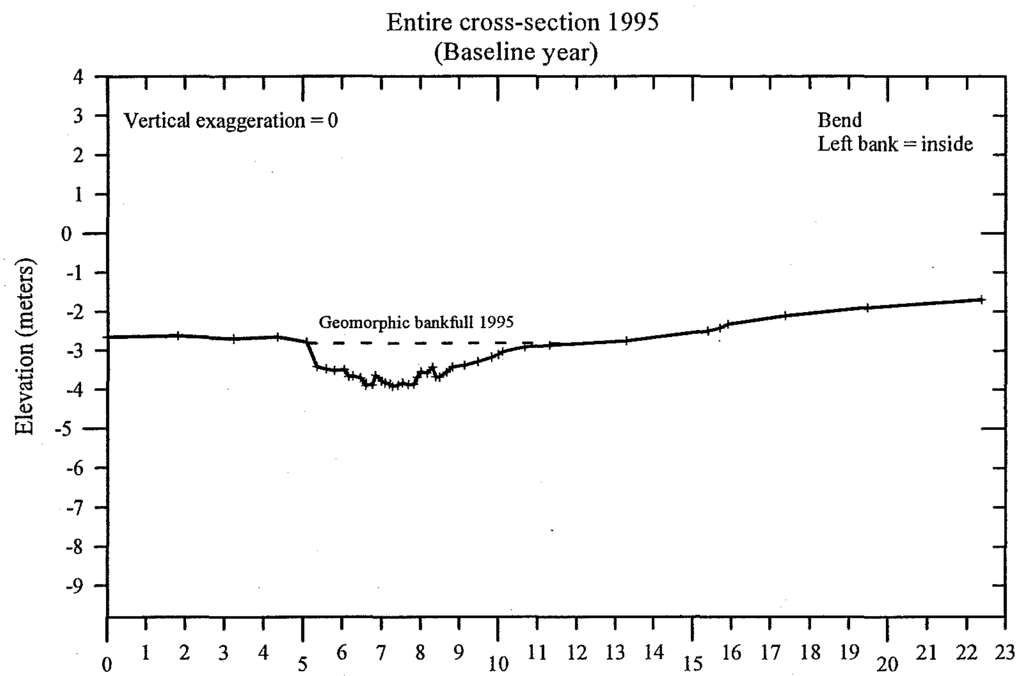


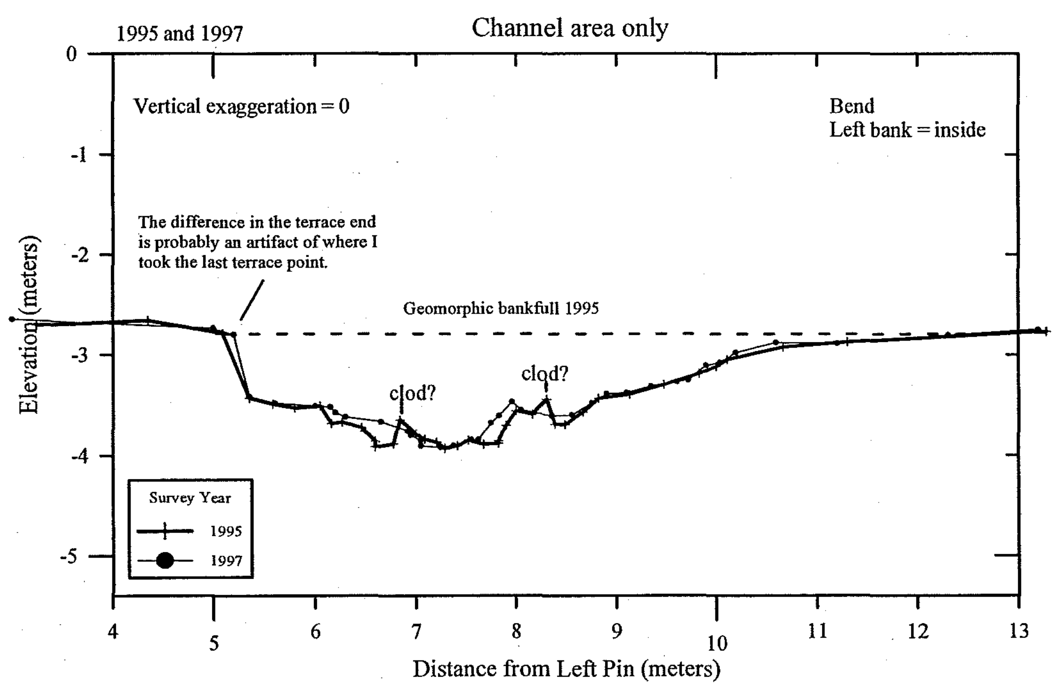
Basin Creek cross-section 25
New Elk Exclosure
1995 and 1997





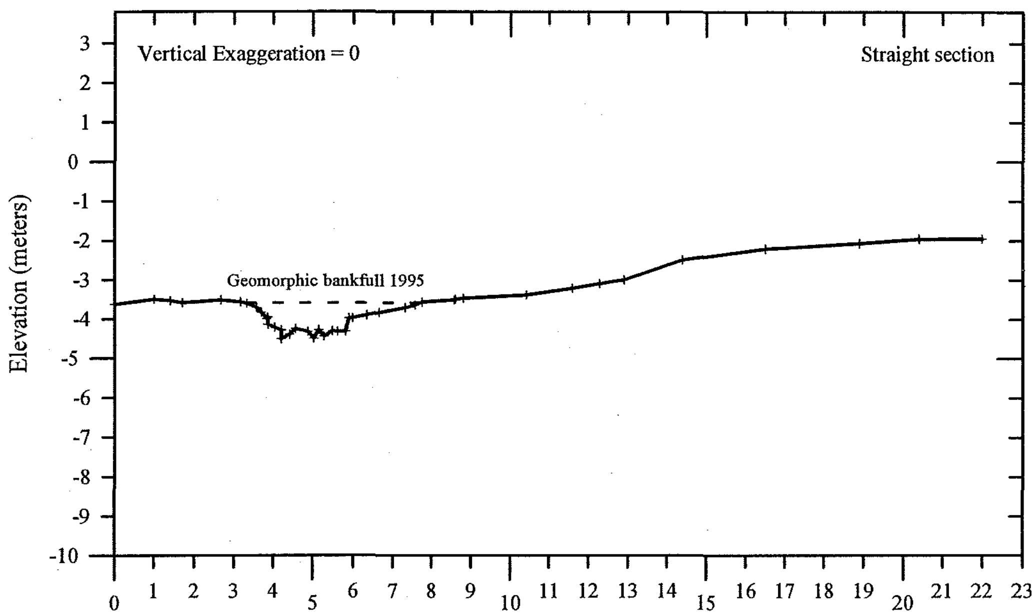
Basin Creek cross-section 26
Riparian Guidelines
1995 and 1997



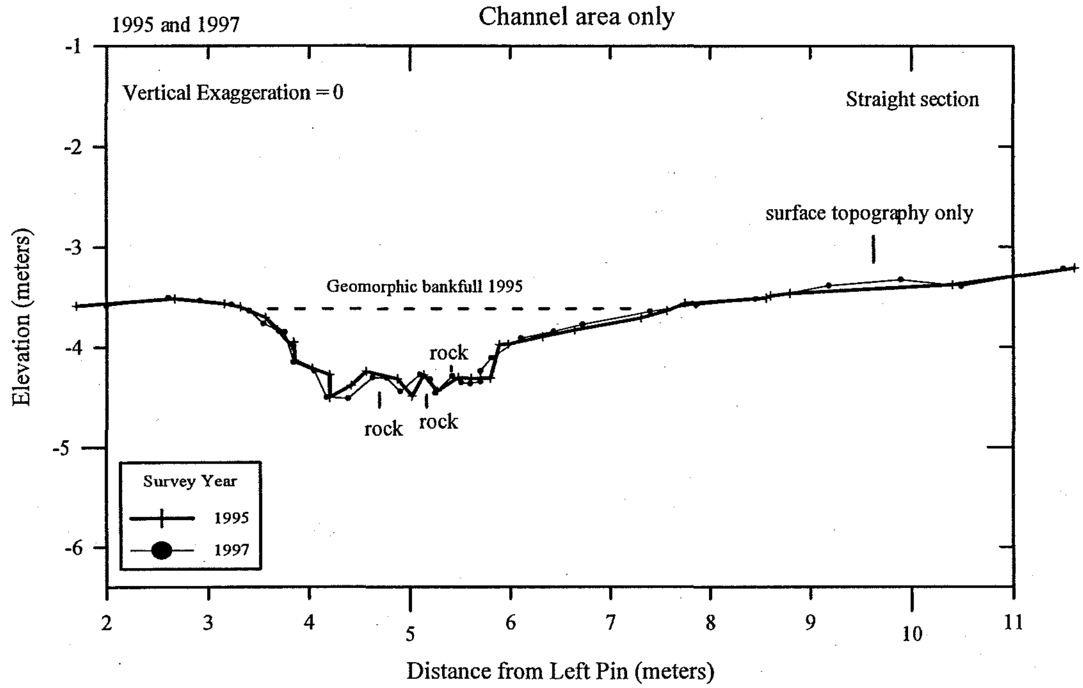


Basin Creek cross-section 27
Riparian Guidelines
1995 and 1997

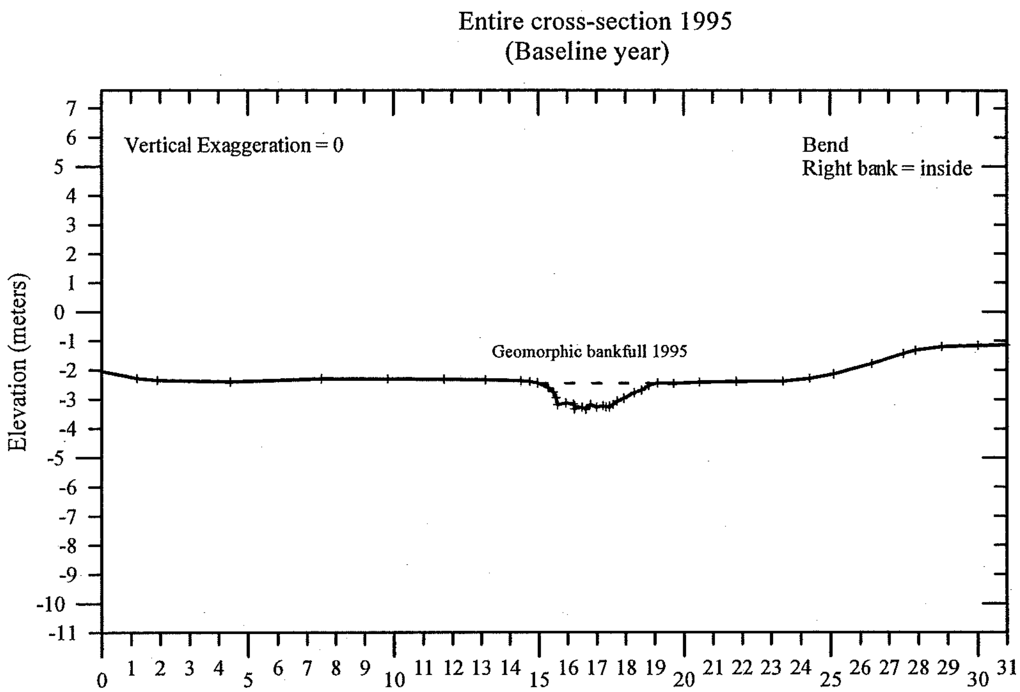
Entire cross-section 1995
(Baseline year)

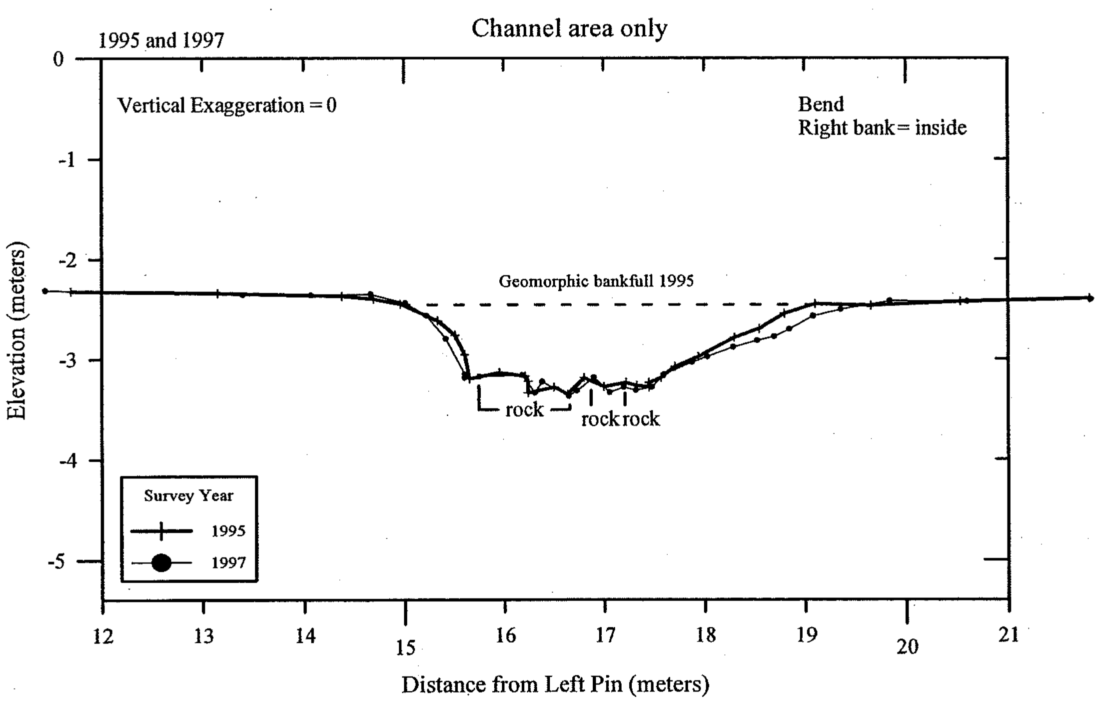


Channel area only

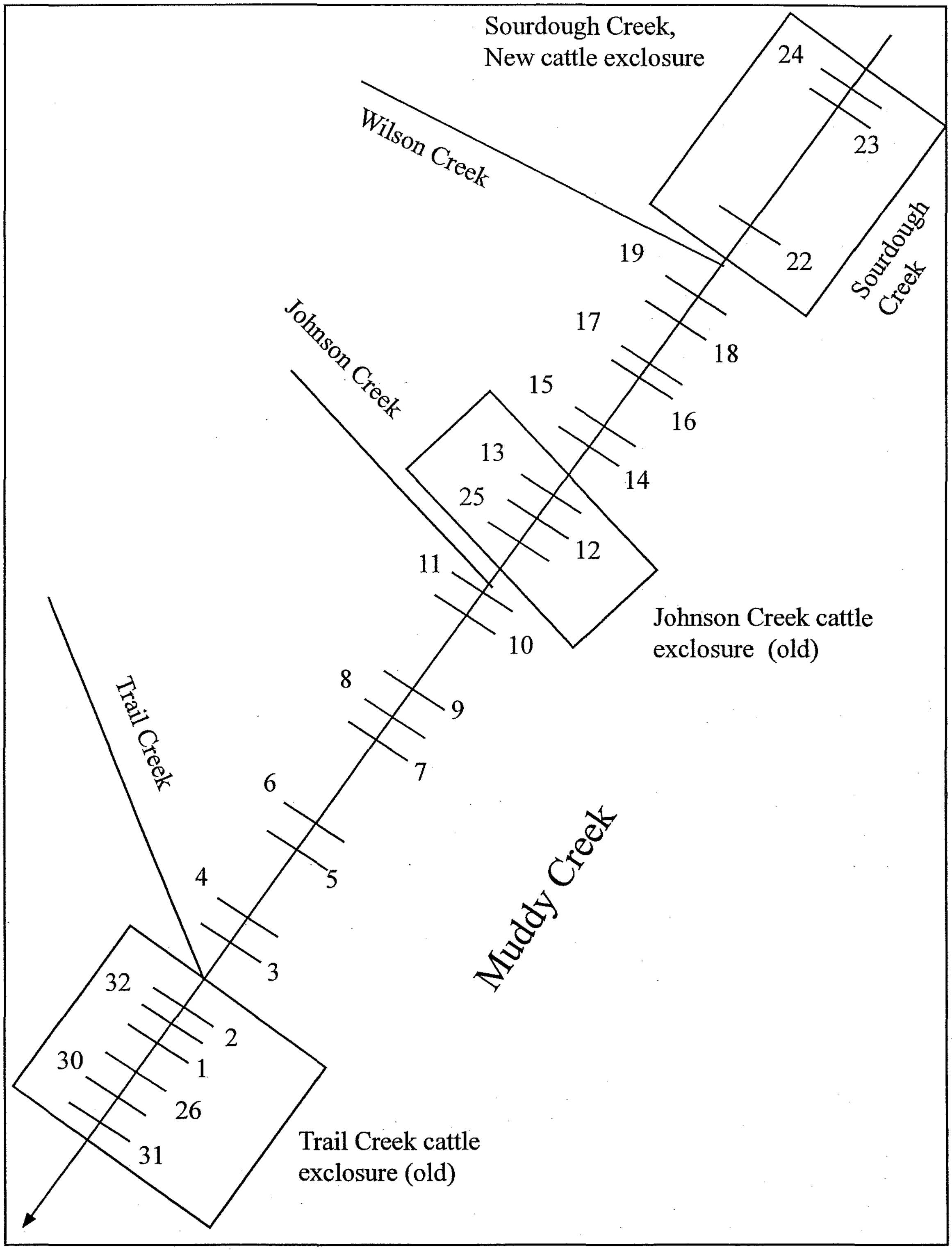


Basin Creek cross-section 28
Riparian Guidelines
1995 and 1997

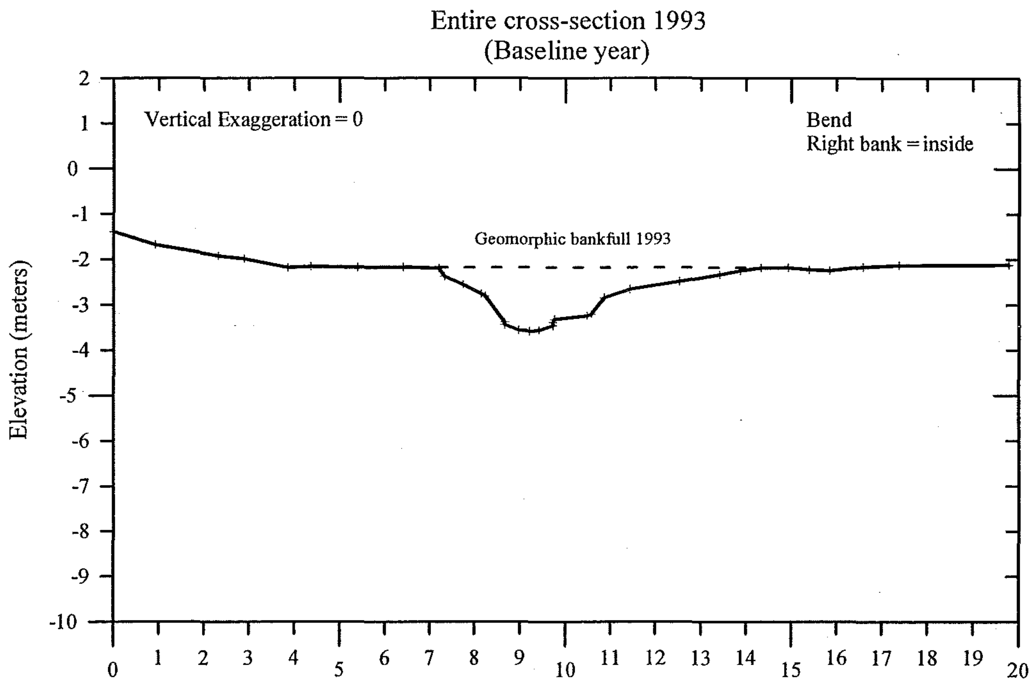


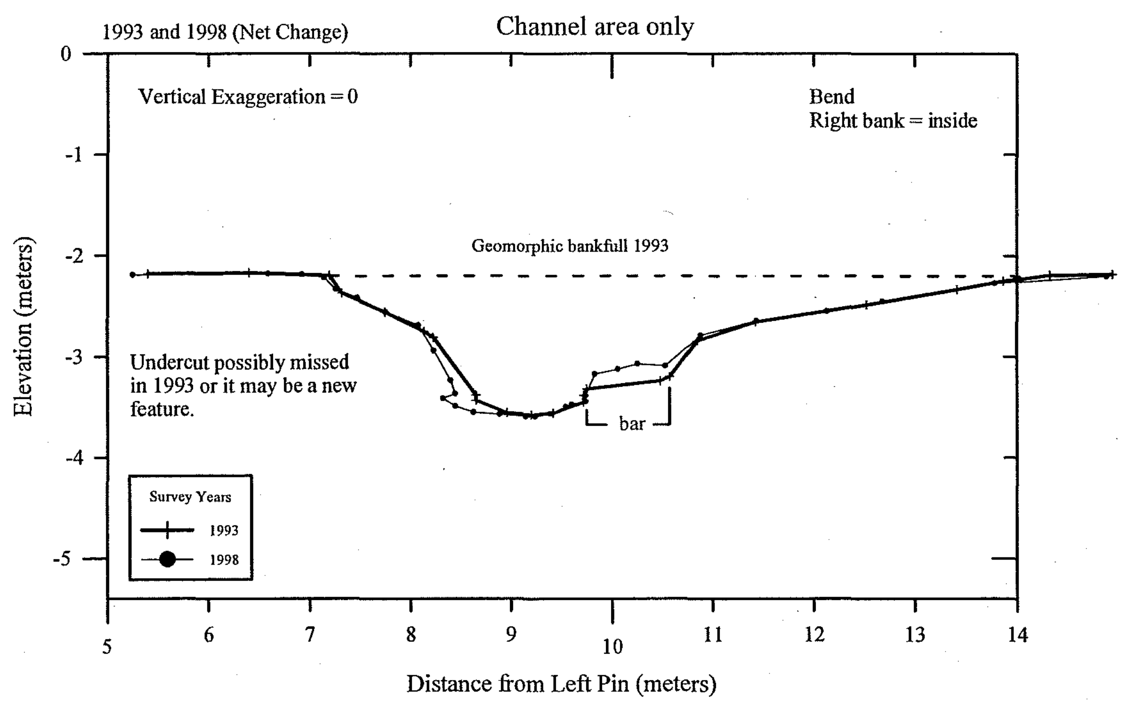


Muddy Creek, Montana
Relative location of cross-sections with respect to each other

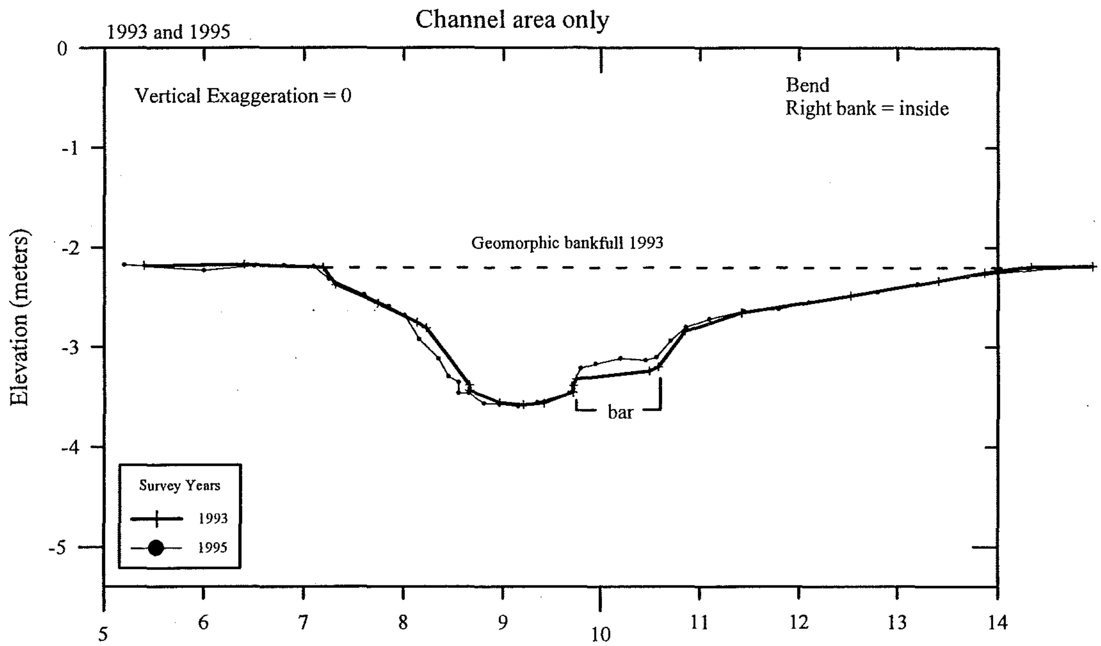


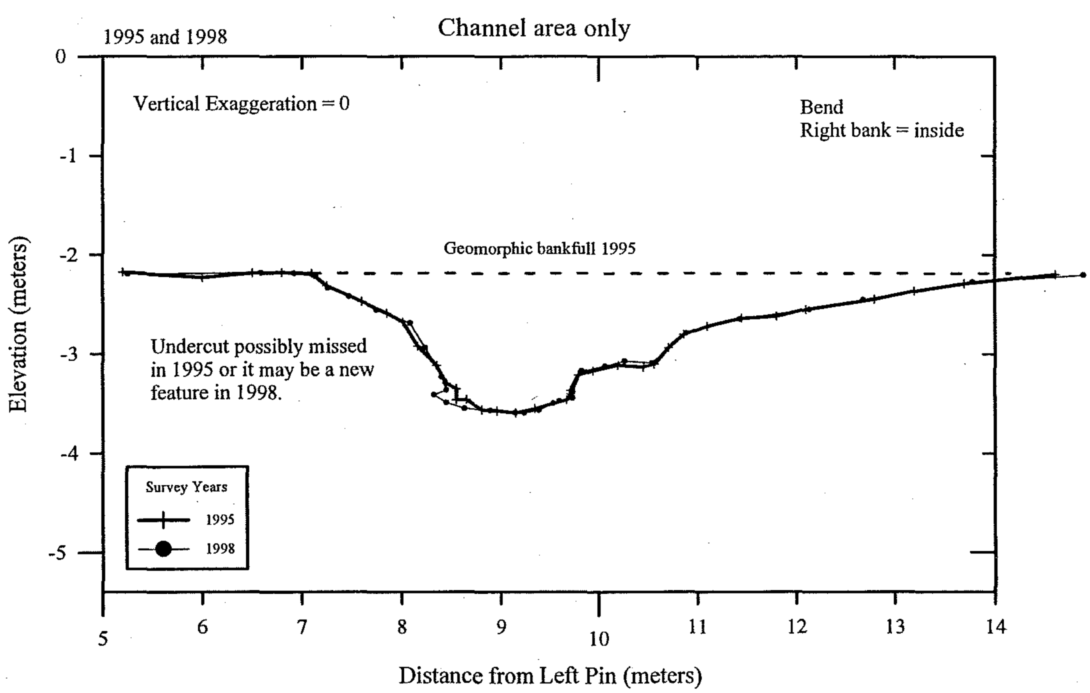
Muddy Creek cross-section 1
Old Cattle Exclosure
1993, 1995, and 1998





Muddy Creek cross-section 1 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

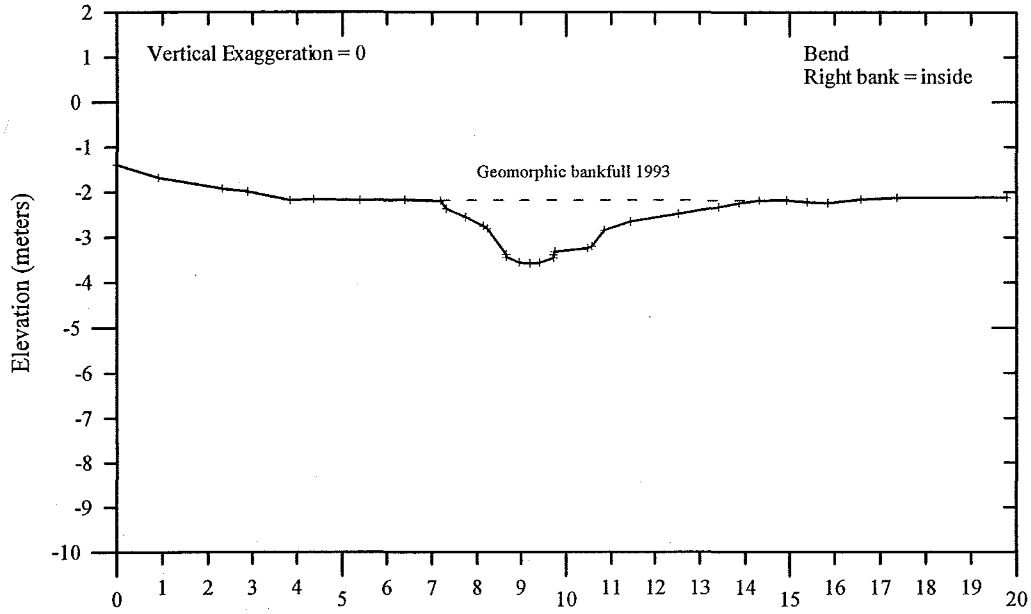




Muddy Creek cross-section 1 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

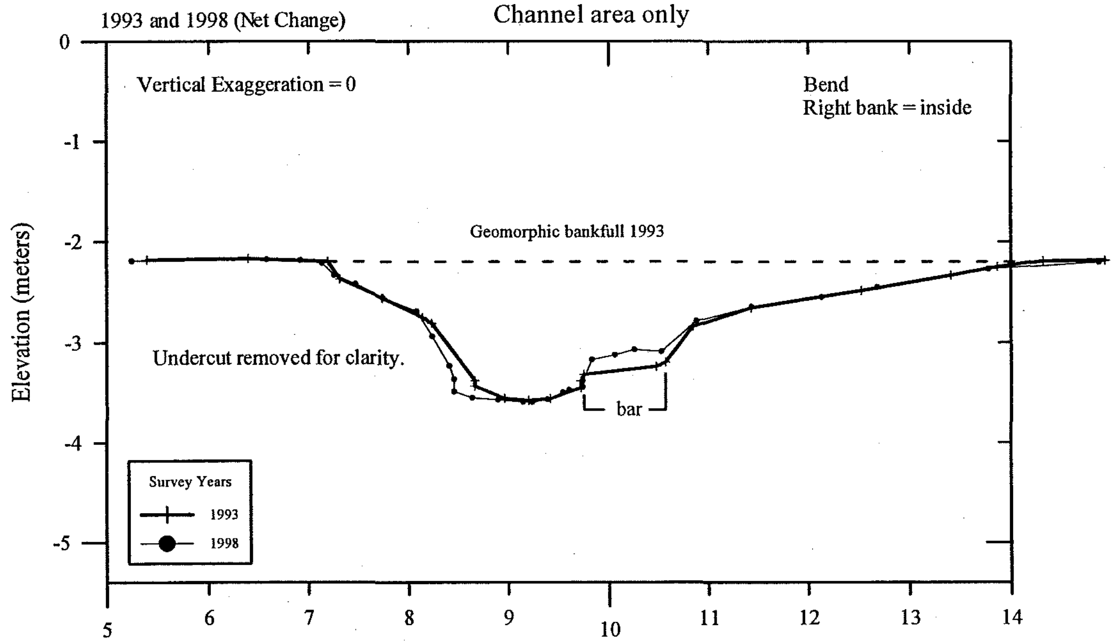
Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)



1993 and 1998 (Net Change)

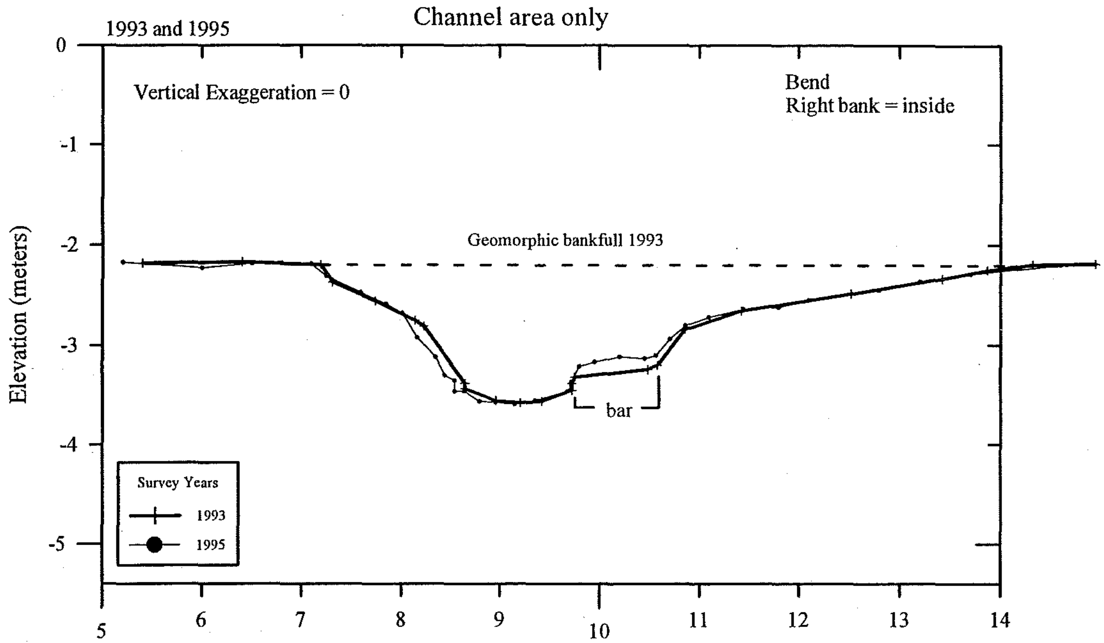
Channel area only

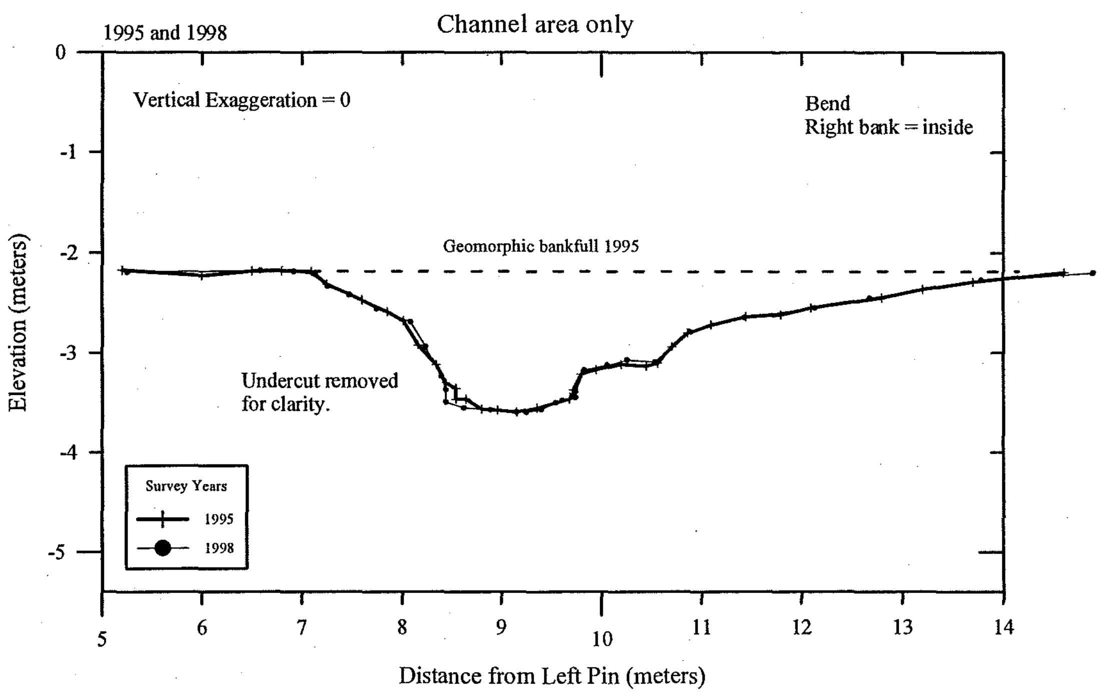


Distance from Left Pin (meters)

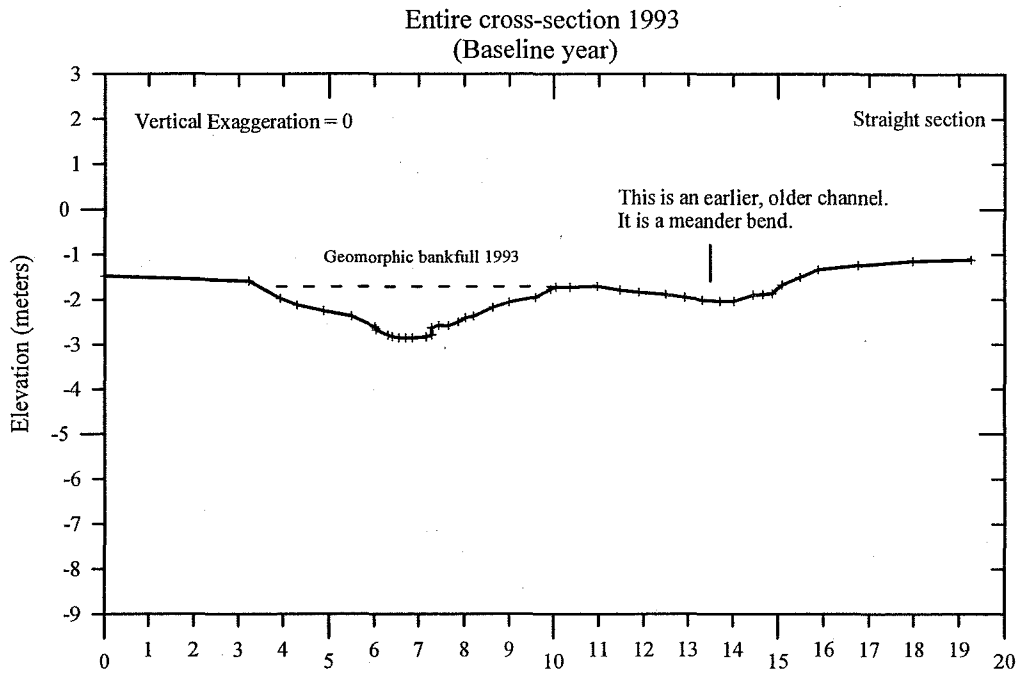
Muddy Creek cross-section 1 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

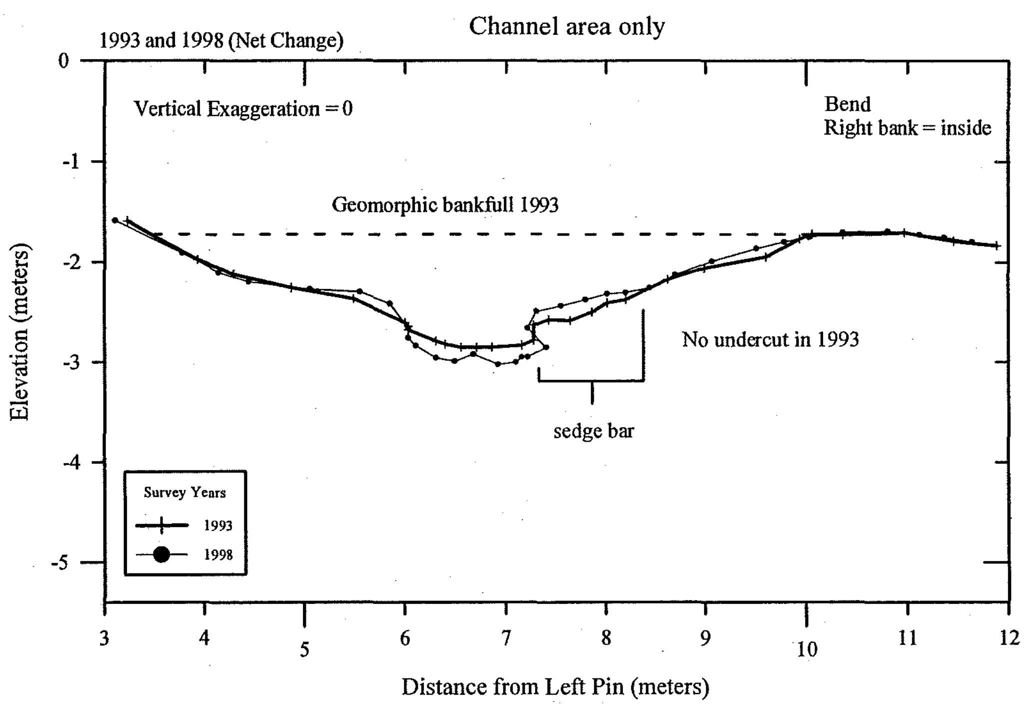
Undercut removed for clarity.



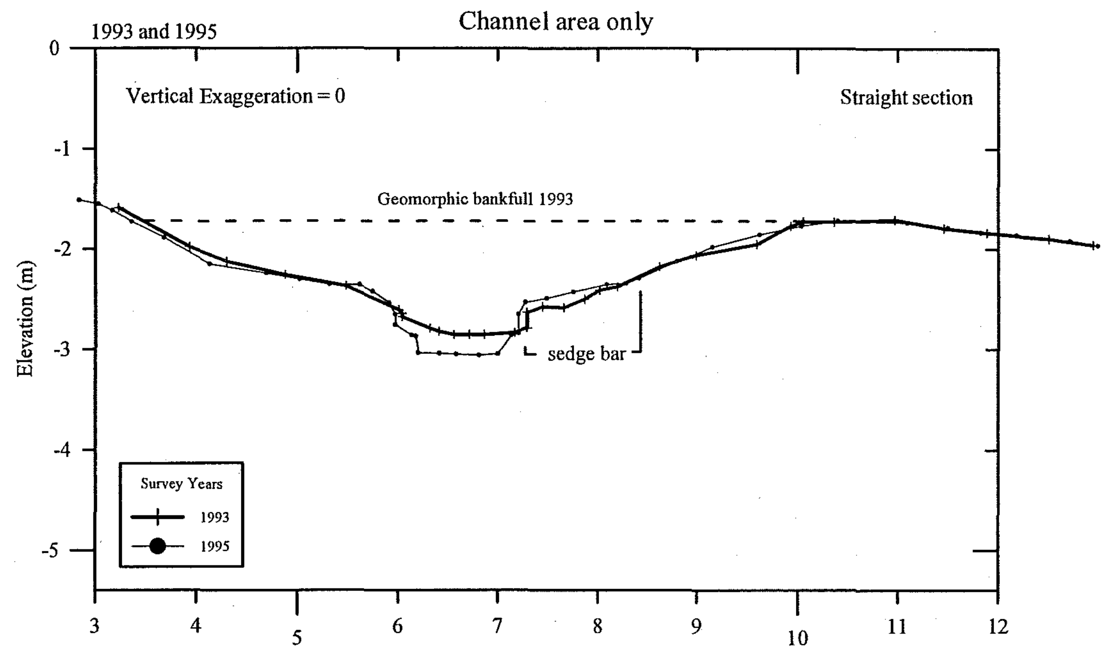


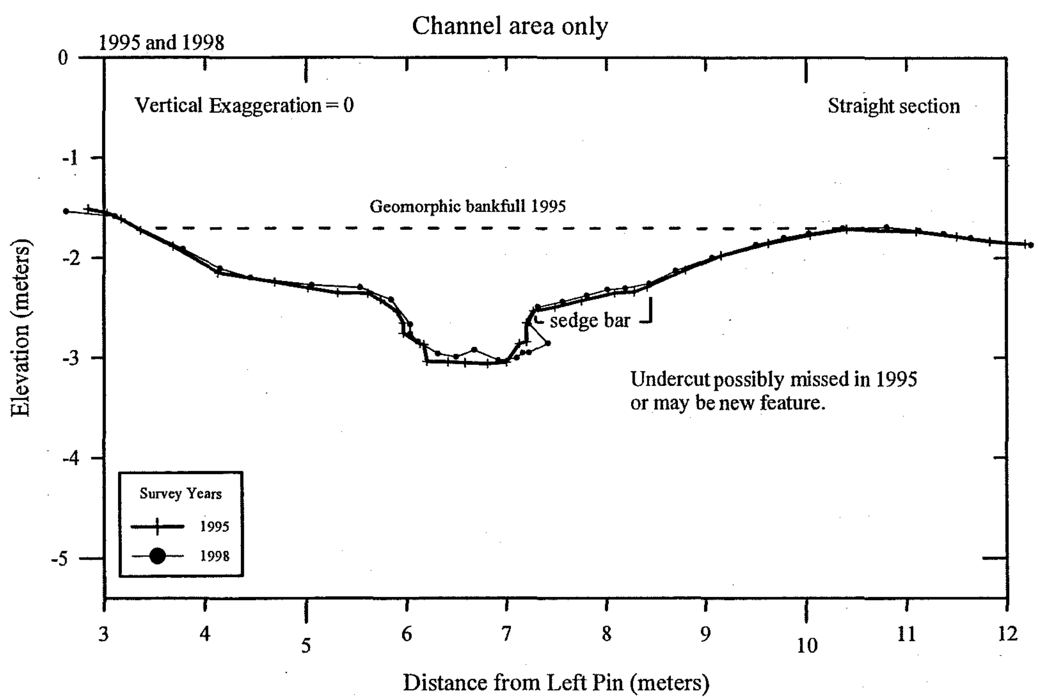
Muddy Creek cross-section 2
Old Cattle Exclosure
1993, 1995, and 1998





Muddy Creek cross-section 2 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

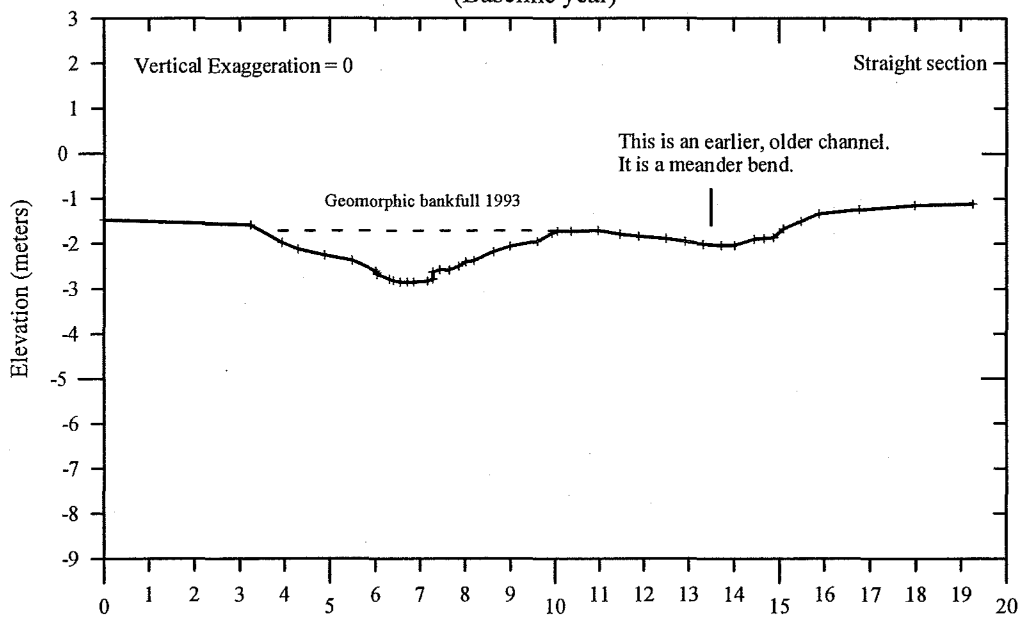




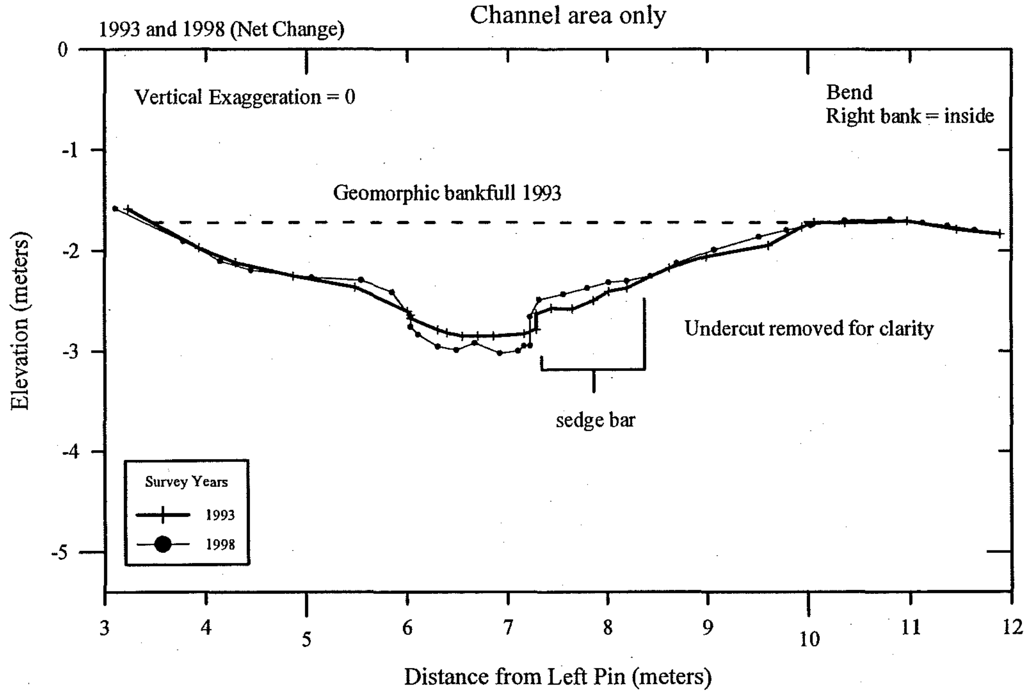
Muddy Creek cross-section 2 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)

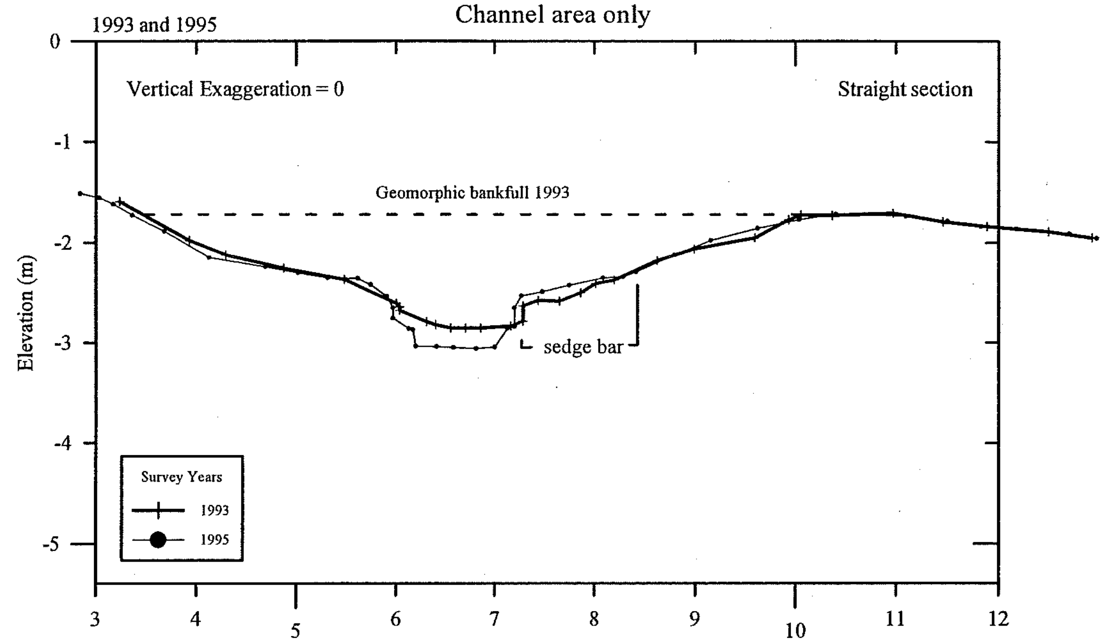


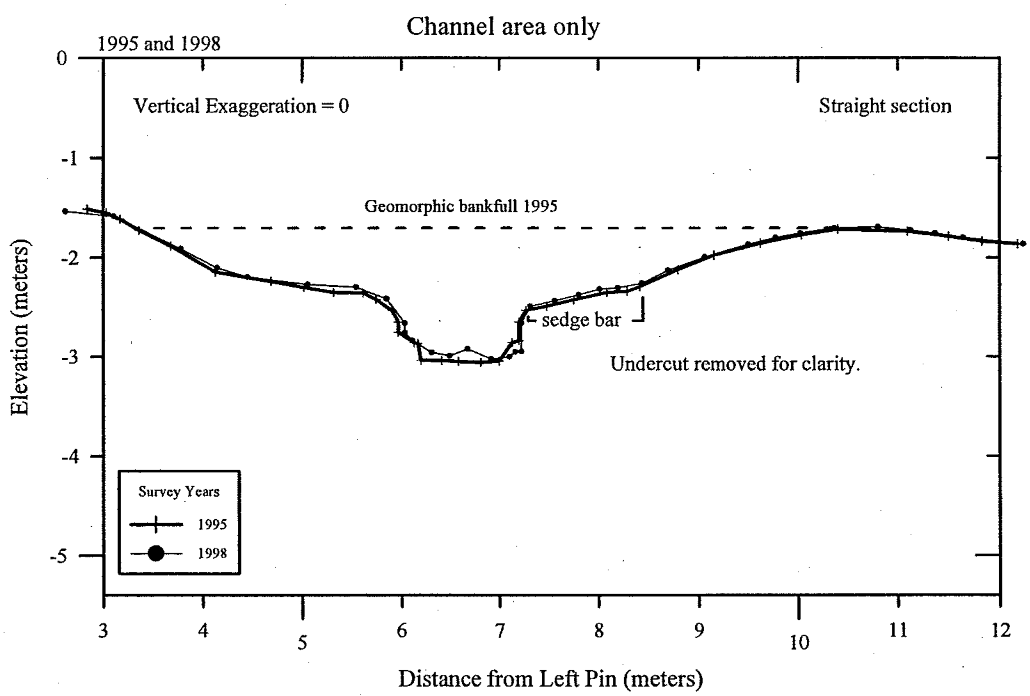
Channel area only



Muddy Creek cross-section 2 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

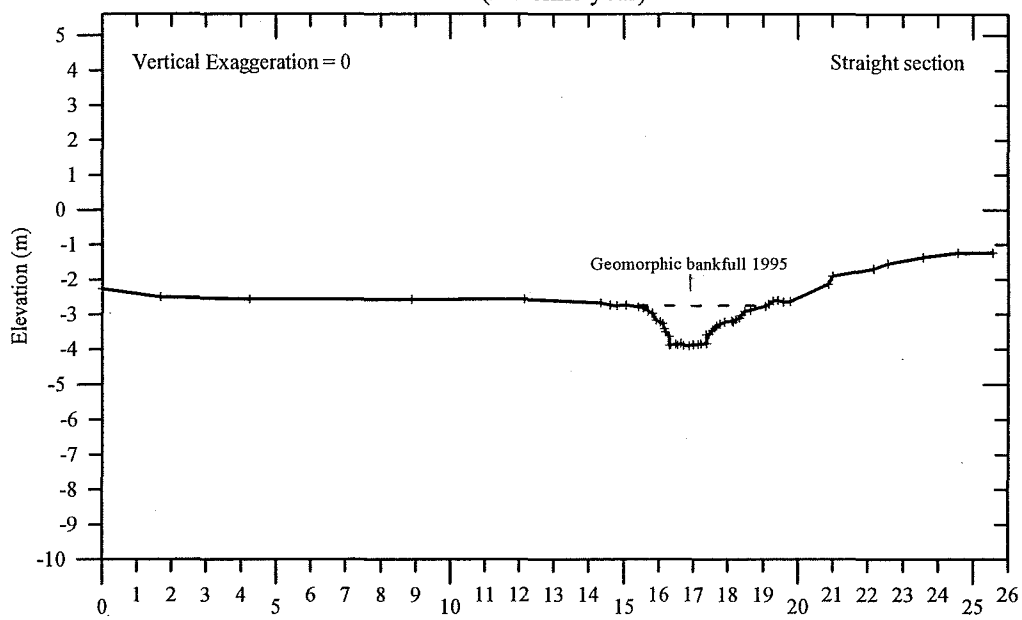
Undercut removed for clarity.



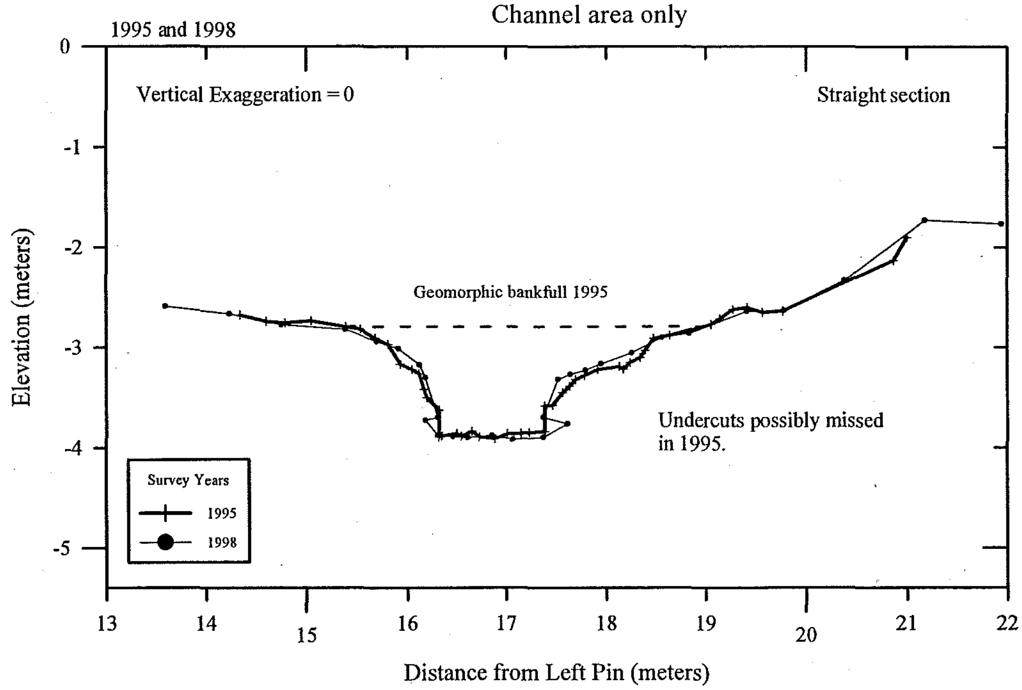


Muddy Creek cross-section 3
Riparian Guidelines
1995 and 1998

Entire cross-section 1995
(Baseline year)

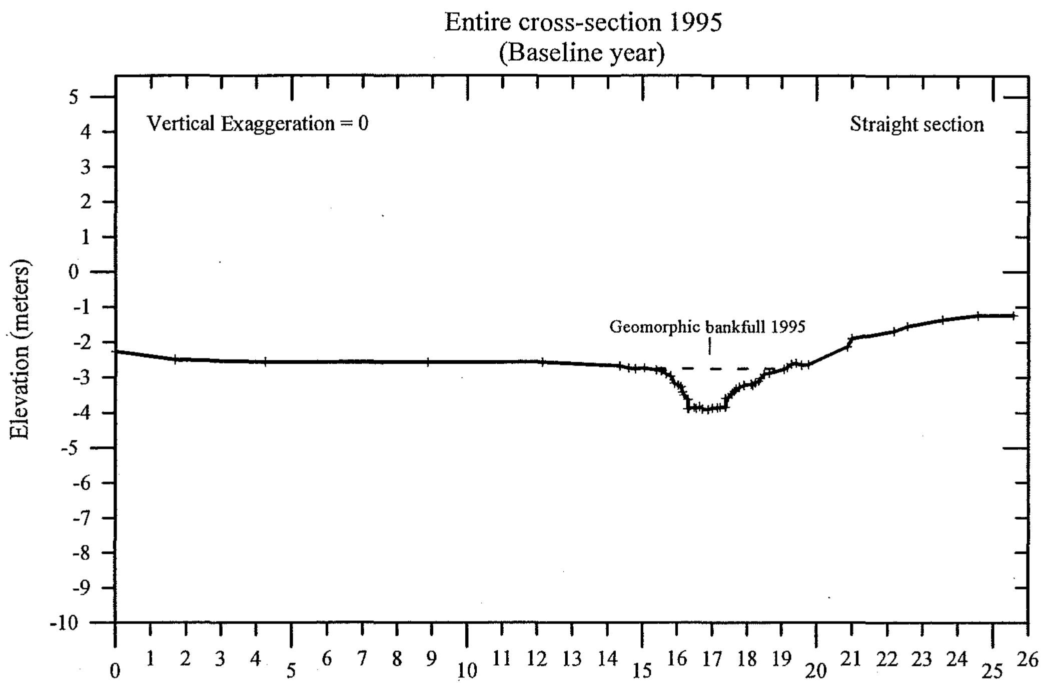


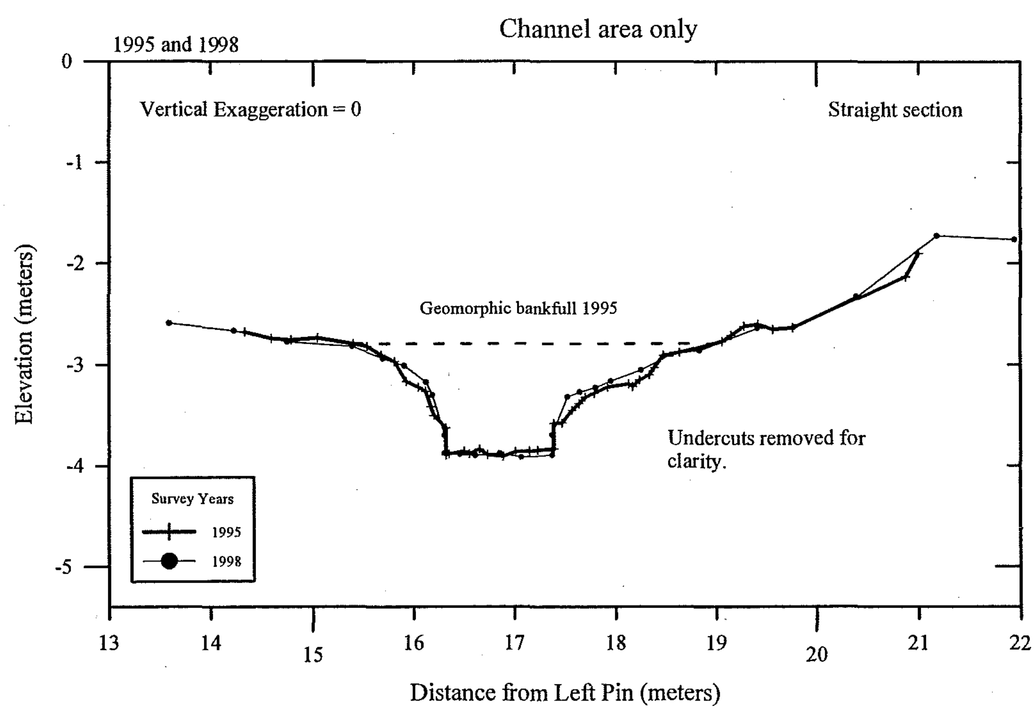
Channel area only



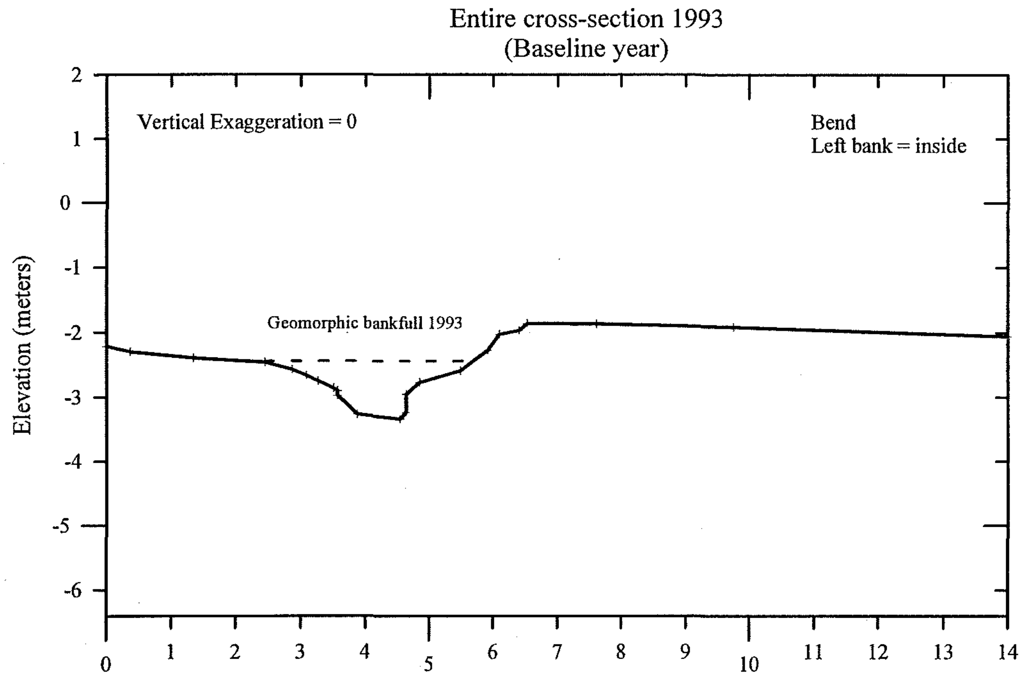
Muddy Creek cross-section 3 (continued)
Riparian Guidelines
1995 and 1998

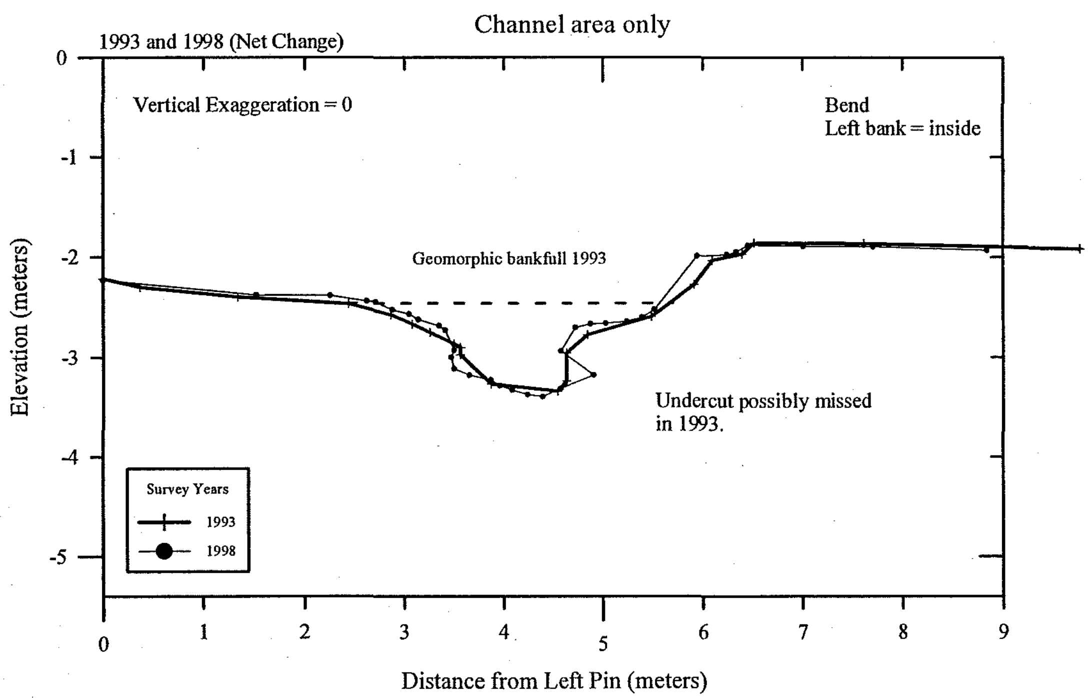
Undercuts removed for clarity.



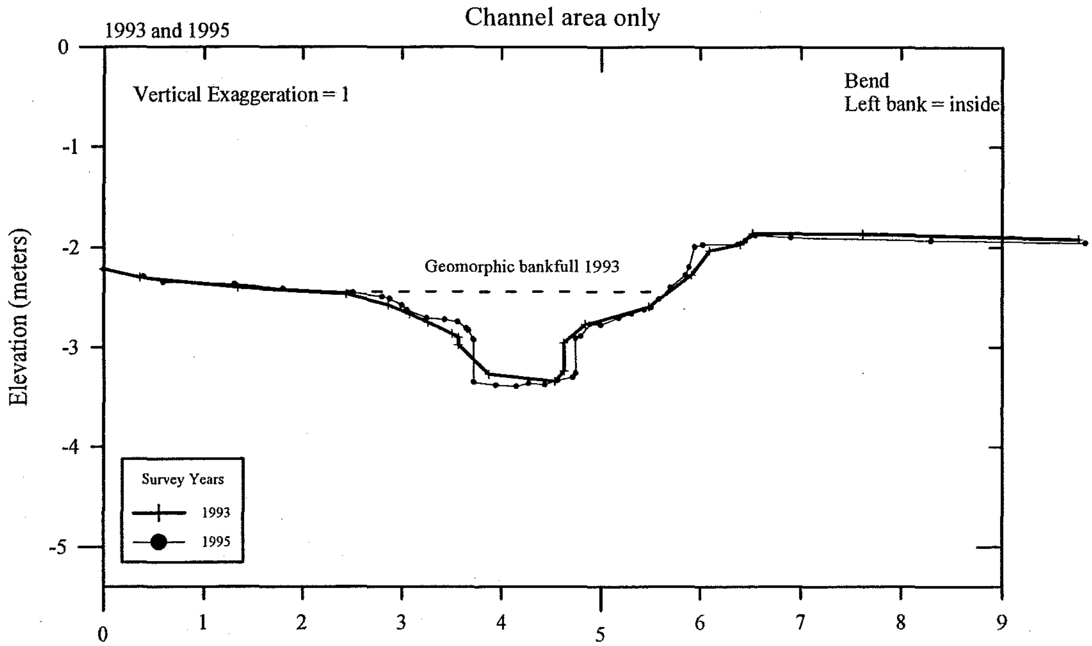


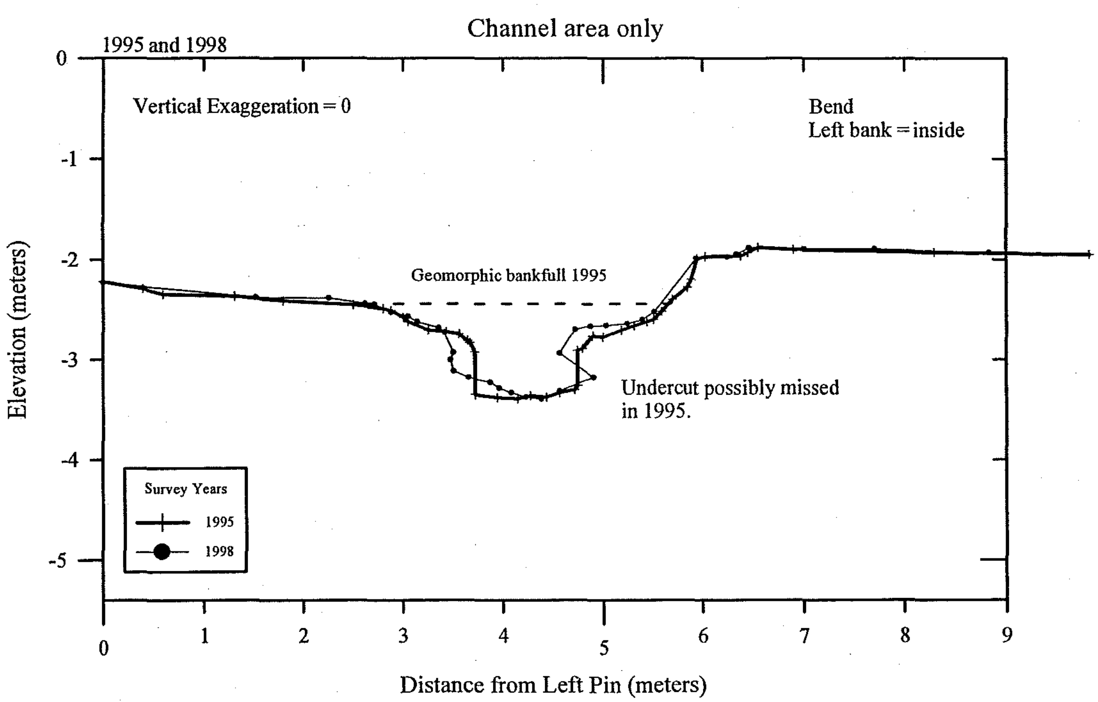
Muddy Creek cross-section 4
Riparian Guidelines
1993, 1995, and 1998





Muddy Creek cross-section 4 (continued)
Riparian Guidelines
1993, 1995, and 1998

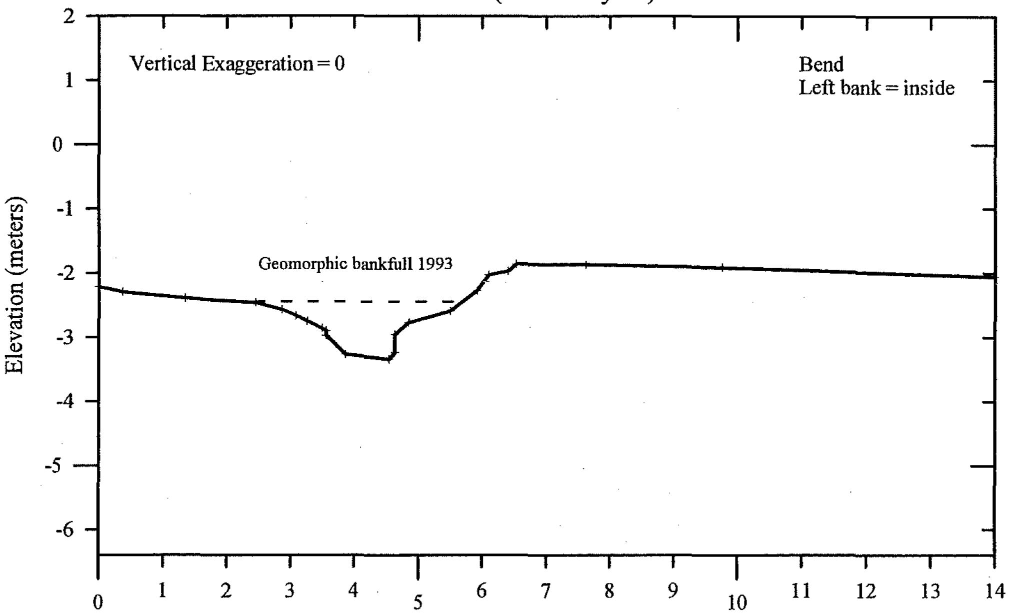




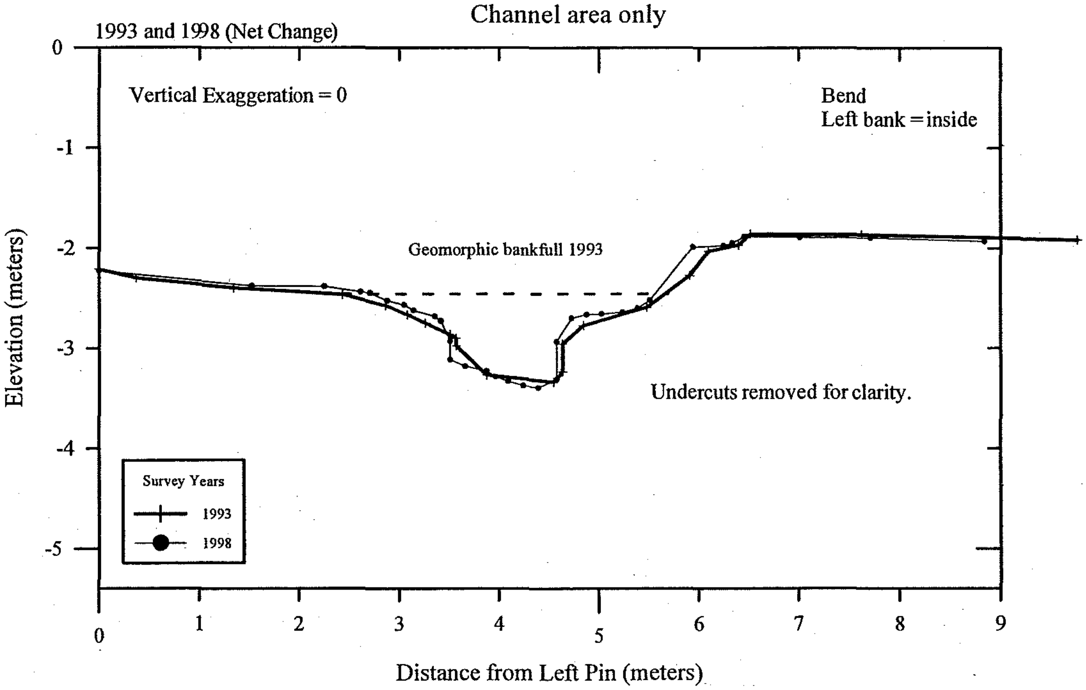
Muddy Creek cross-section 4 (continued)
Riparian Guidelines
1993, 1995, and 1998

Undercuts removed for clarity.

Entire cross-section 1993
(Baseline year)

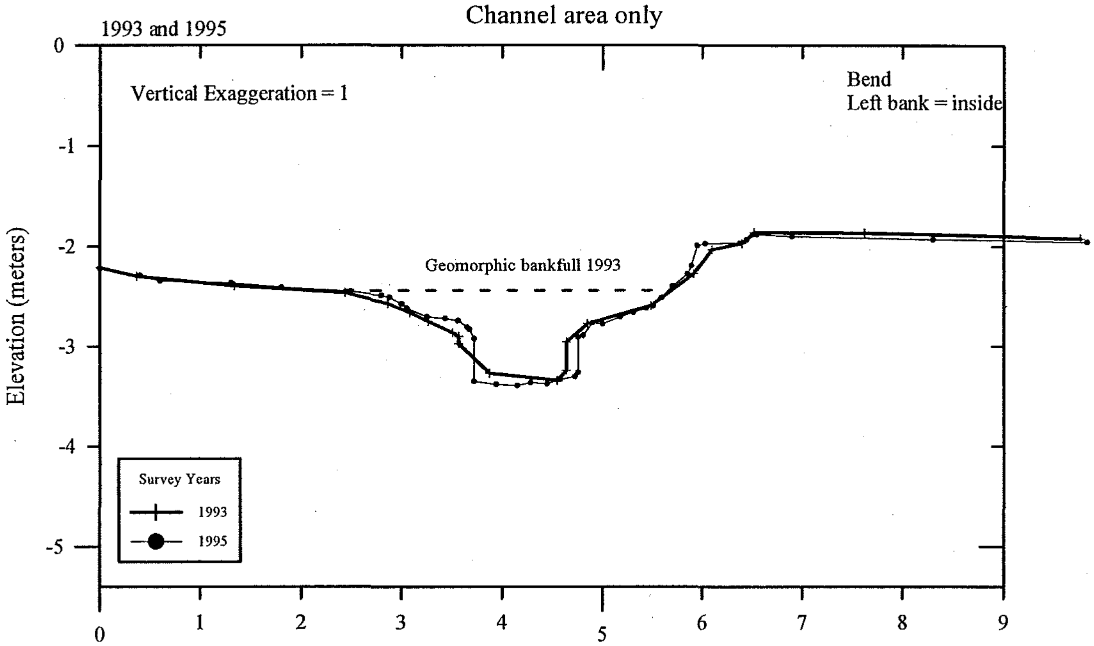


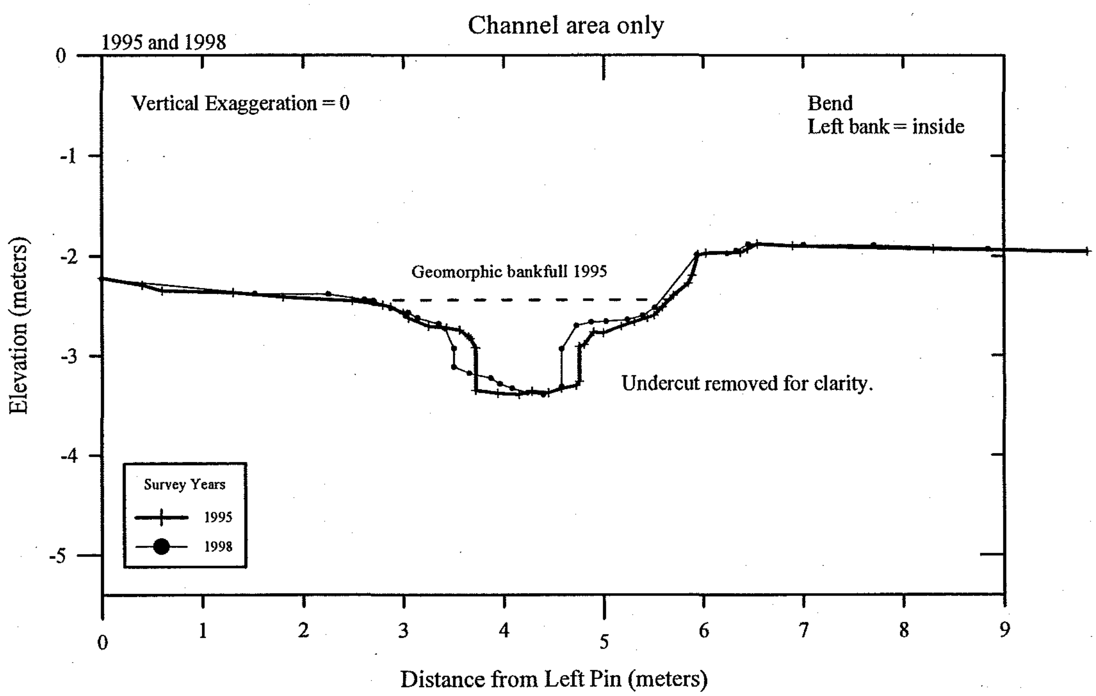
Channel area only



Muddy Creek cross-section 4 (continued)
Riparian Guidelines
1993, 1995, and 1998

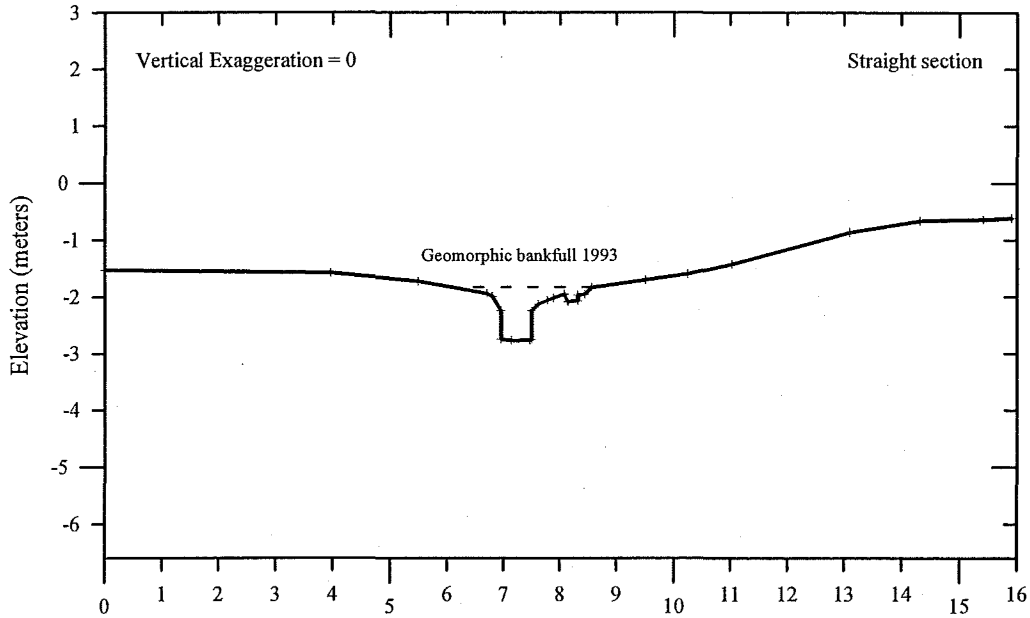
Undercut removed for clarity.



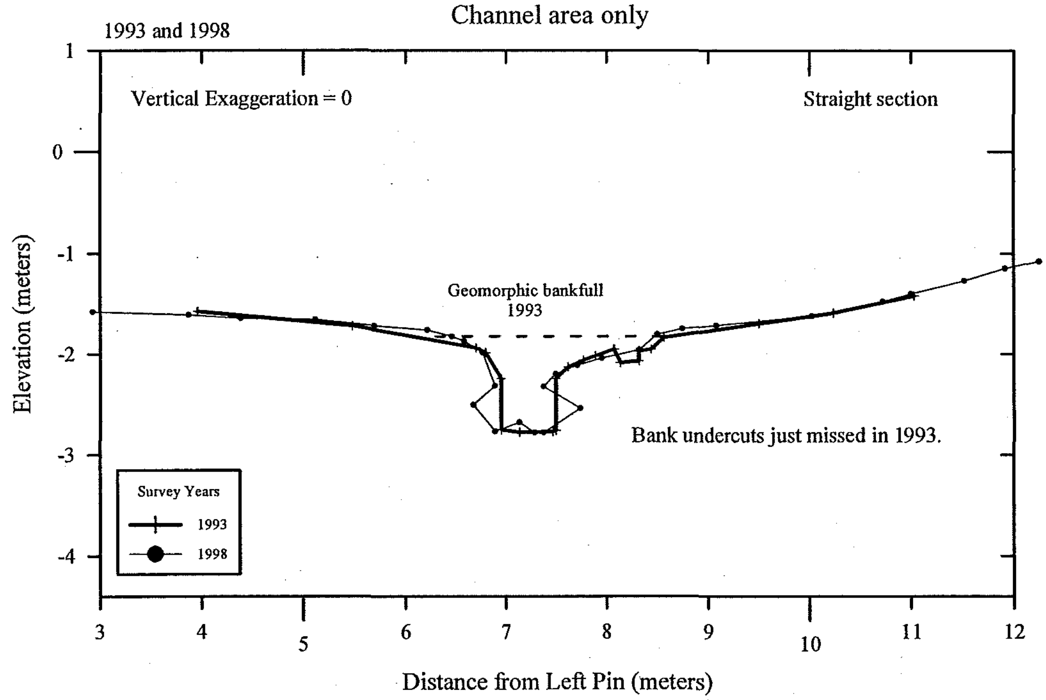


Muddy Creek cross-section 5
Riparian Guidelines
1993, 1995, and 1998

Entire cross-section 1993
(Baseline year)

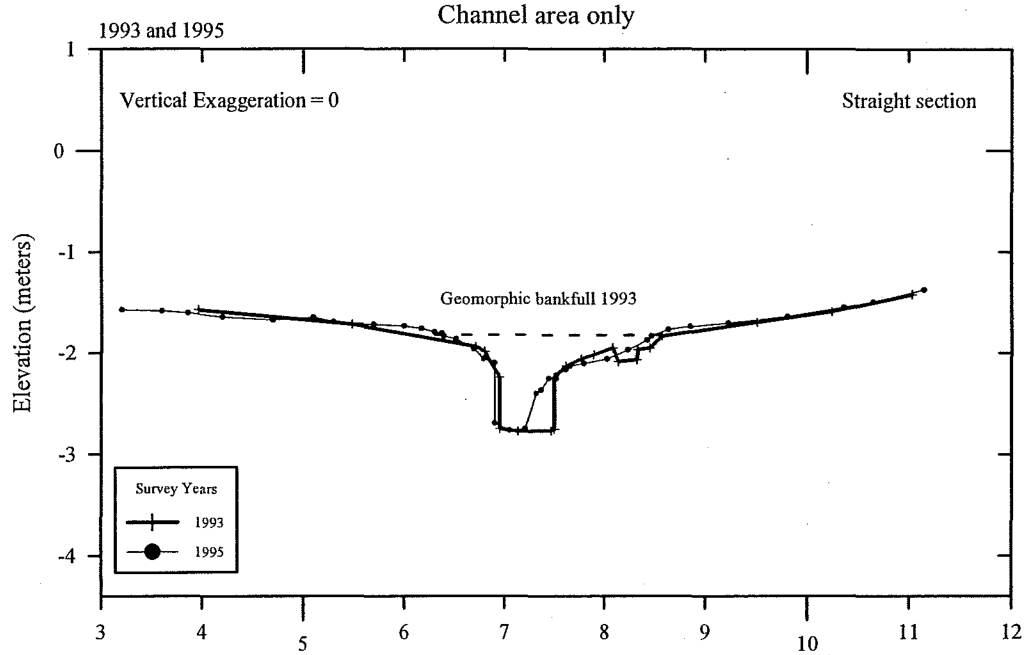


Channel area only

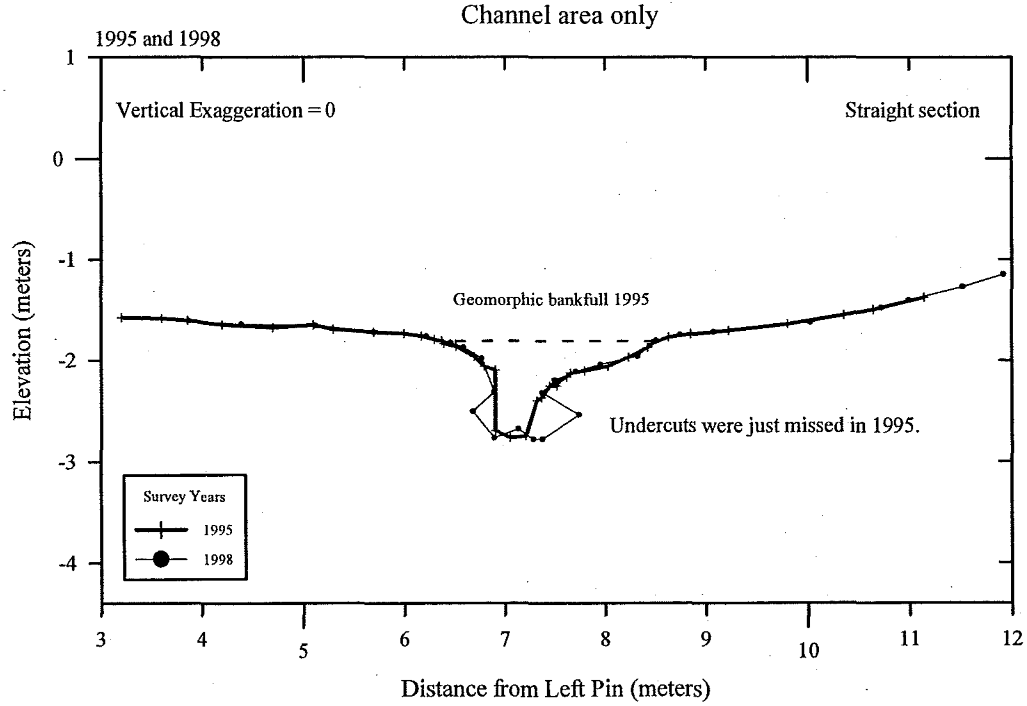


Muddy Creek cross-section 5 (continued)
Riparian Guidelines
1993, 1995, and 1998

Channel area only



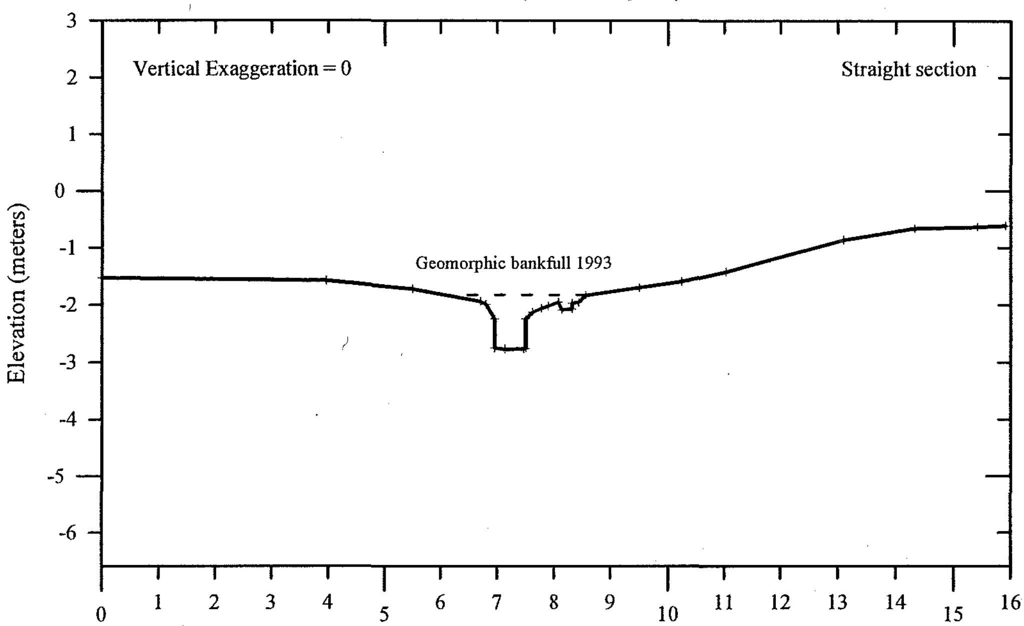
Channel area only



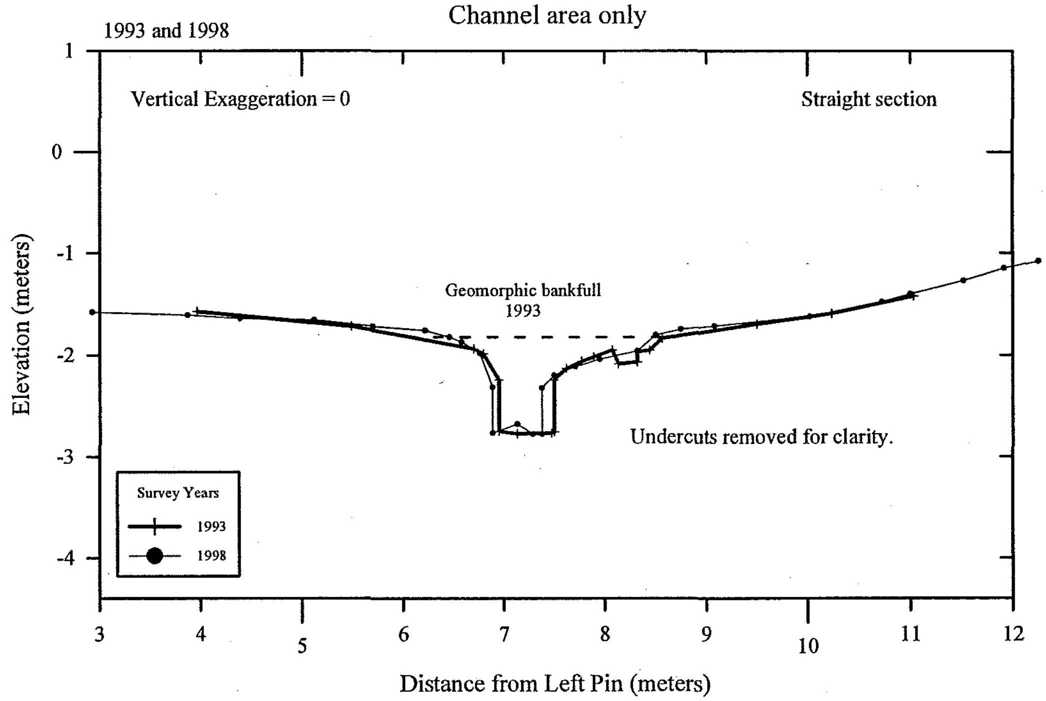
Muddy Creek cross-section 5 (continued)
Riparian Guidelines
1993, 1995, and 1998

Undercuts removed for clarity.

Entire cross-section 1993
(Baseline year)

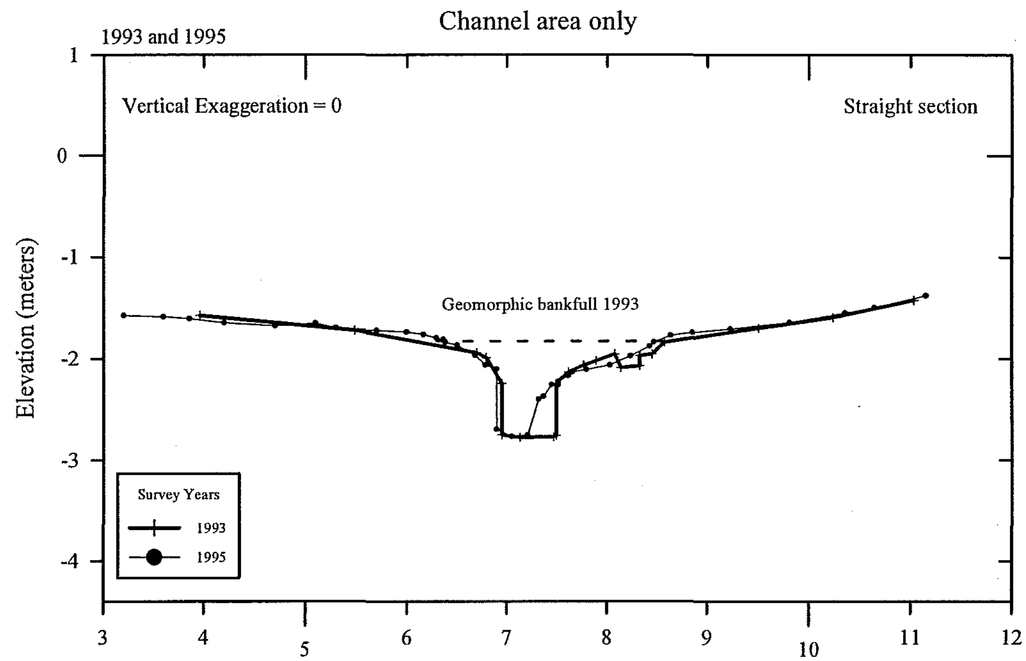


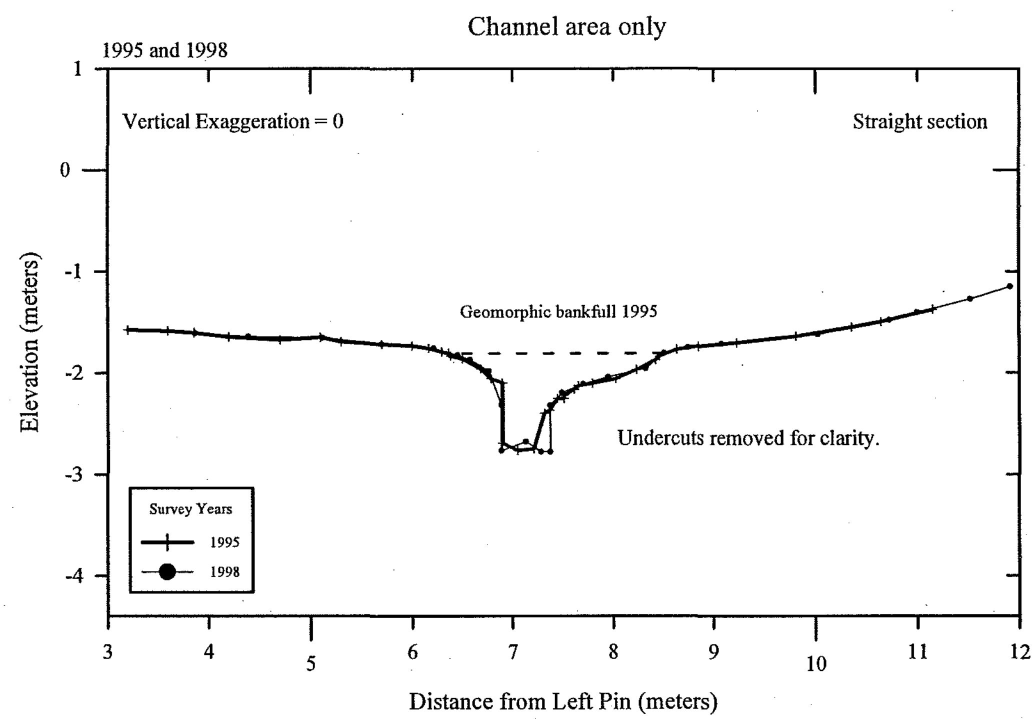
Channel area only



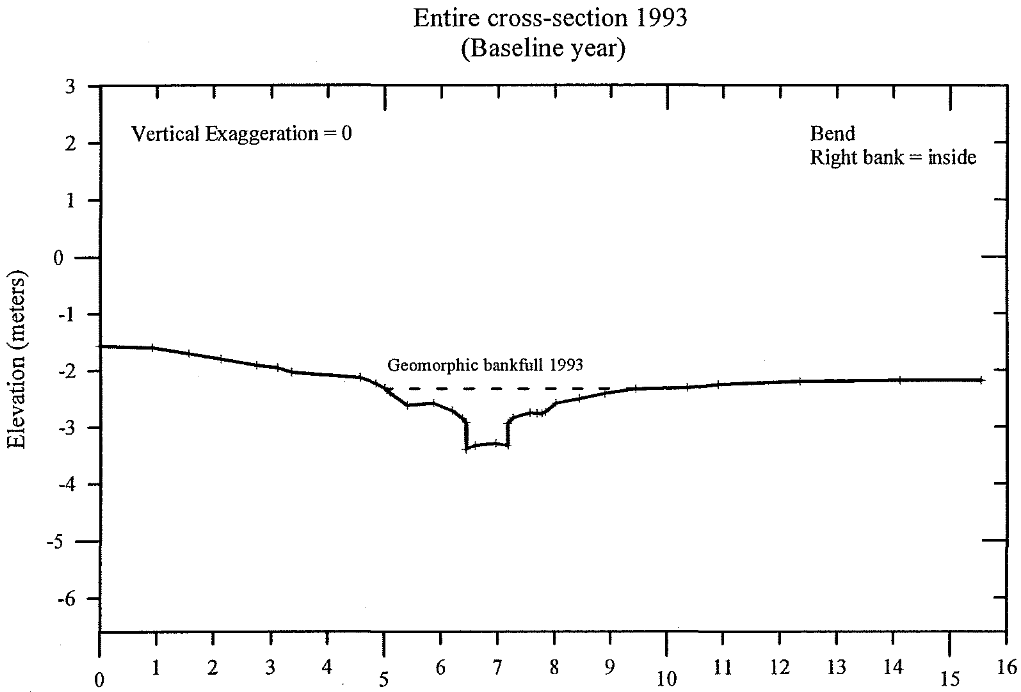
Muddy Creek cross-section 5 (continued)
Riparian Guidelines
1993, 1995, and 1998

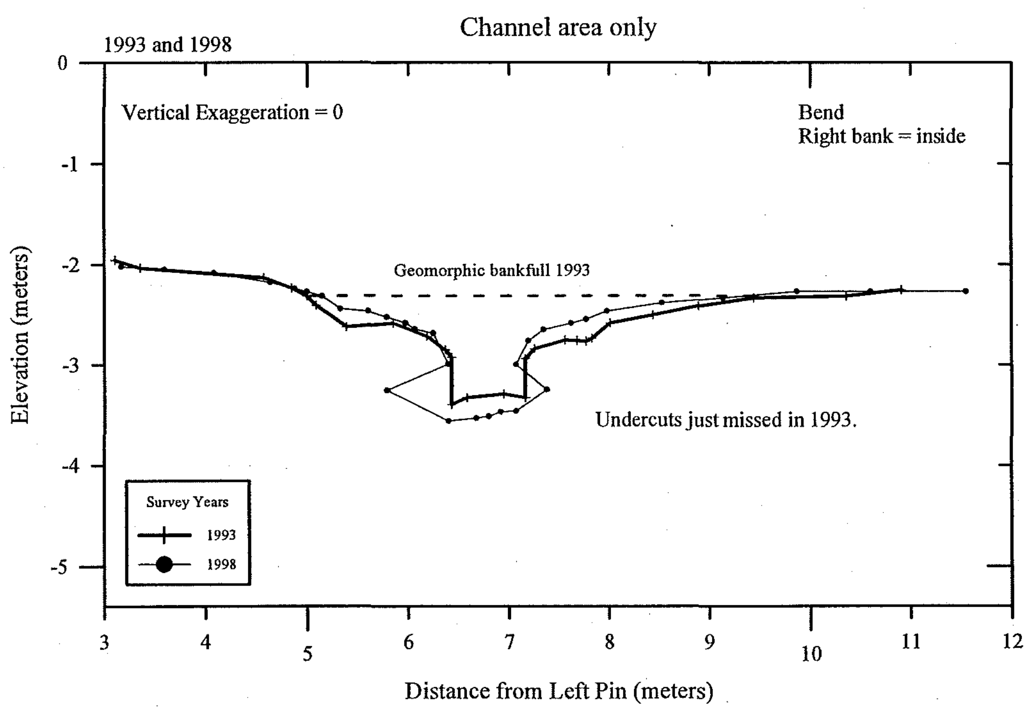
Undercuts removed for clarity.



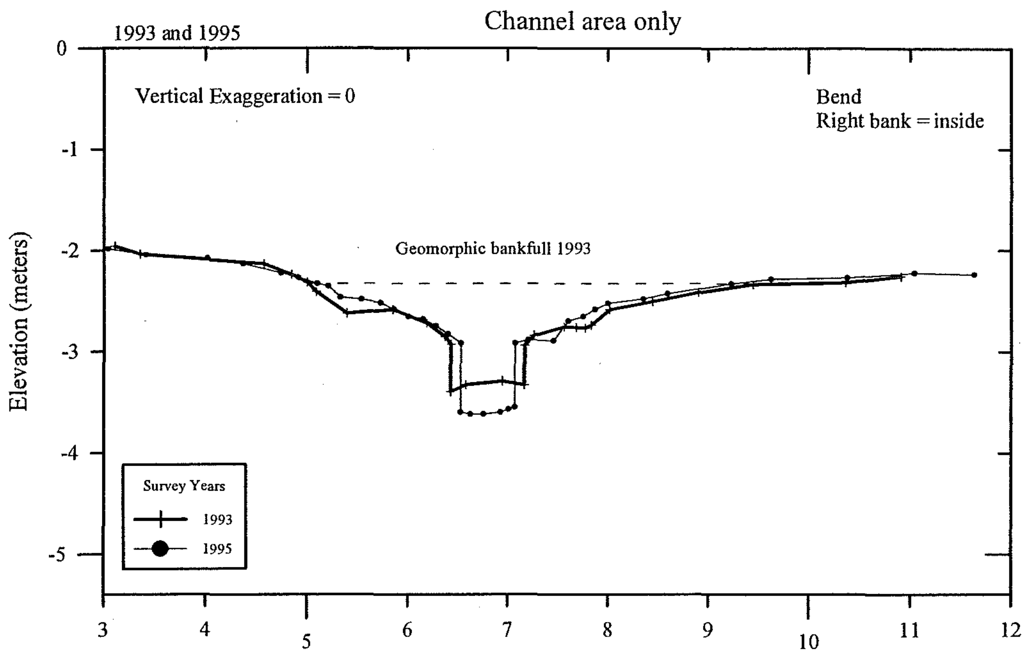


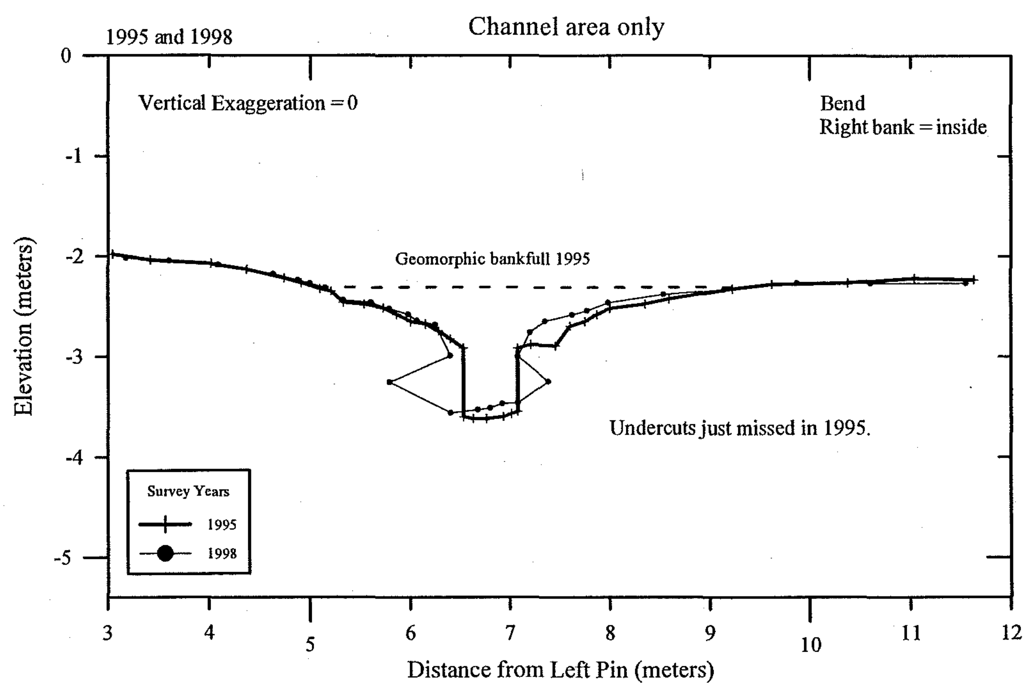
Muddy Creek cross-section 6
Riparian Guidelines
1993, 1995, and 1998





Muddy Creek cross-section 6 (continued)
Riparian Guidelines
1993, 1995, and 1998

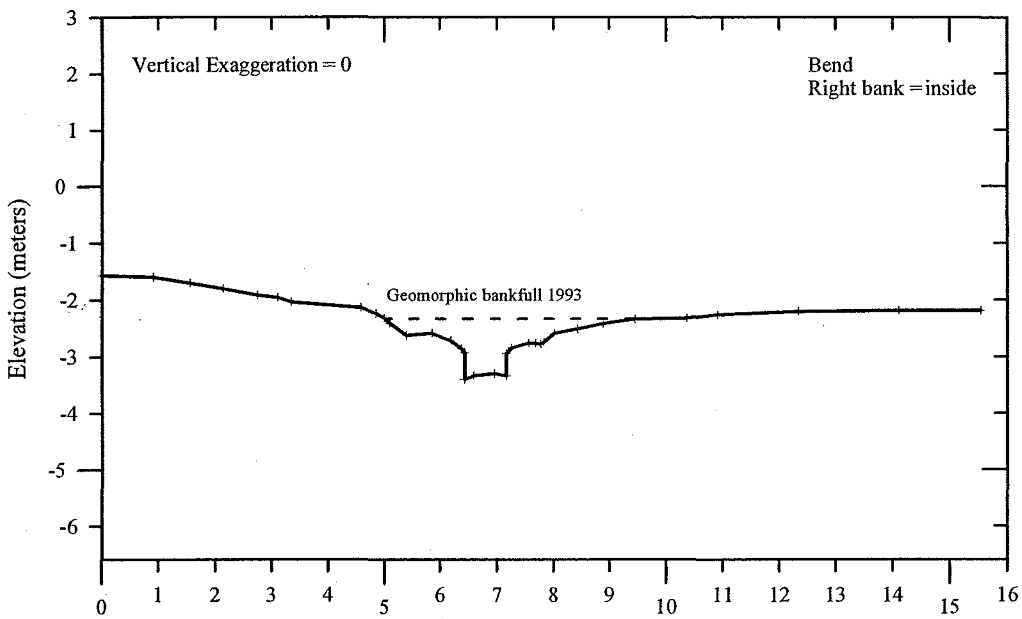




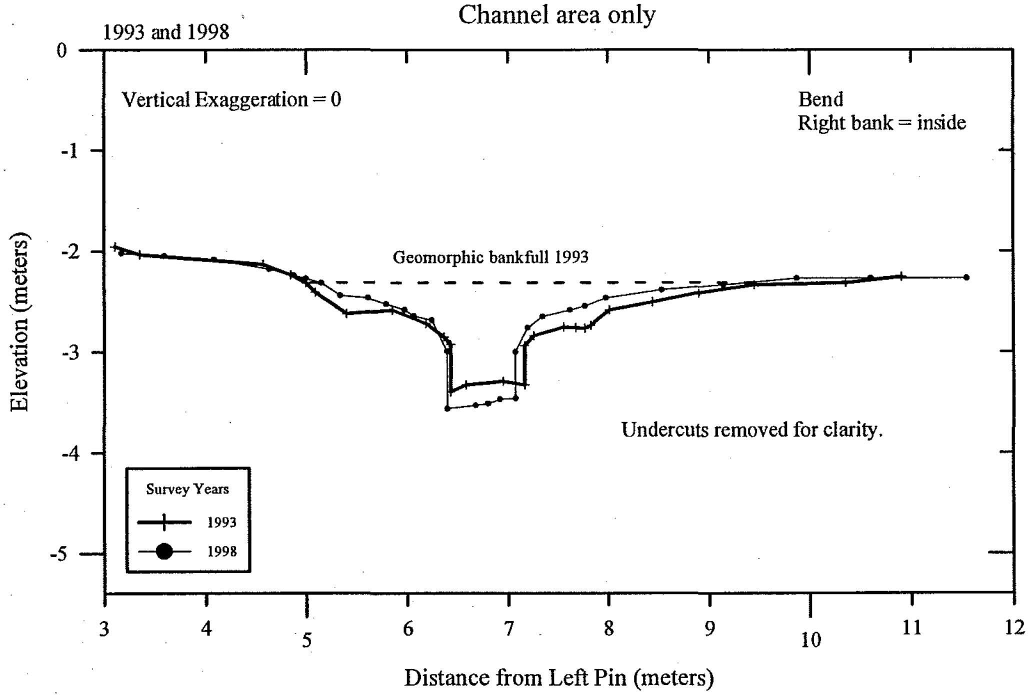
Muddy Creek cross-section 6 (continued)
Riparian Guidelines
1993, 1995, and 1998

Undercuts removed for clarity.

Entire cross-section 1993
(Baseline year)

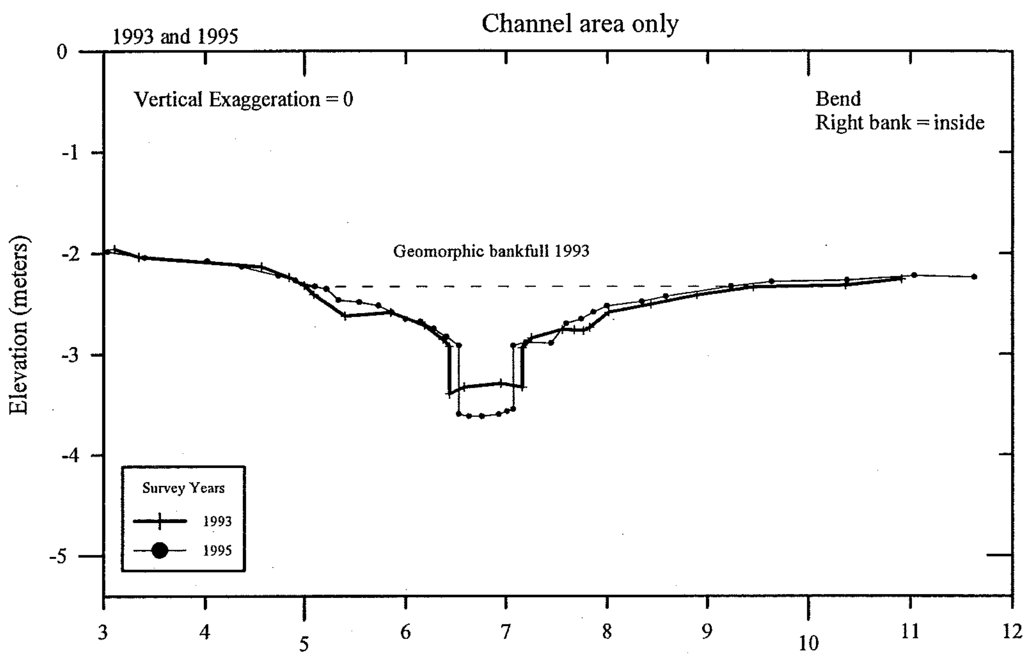


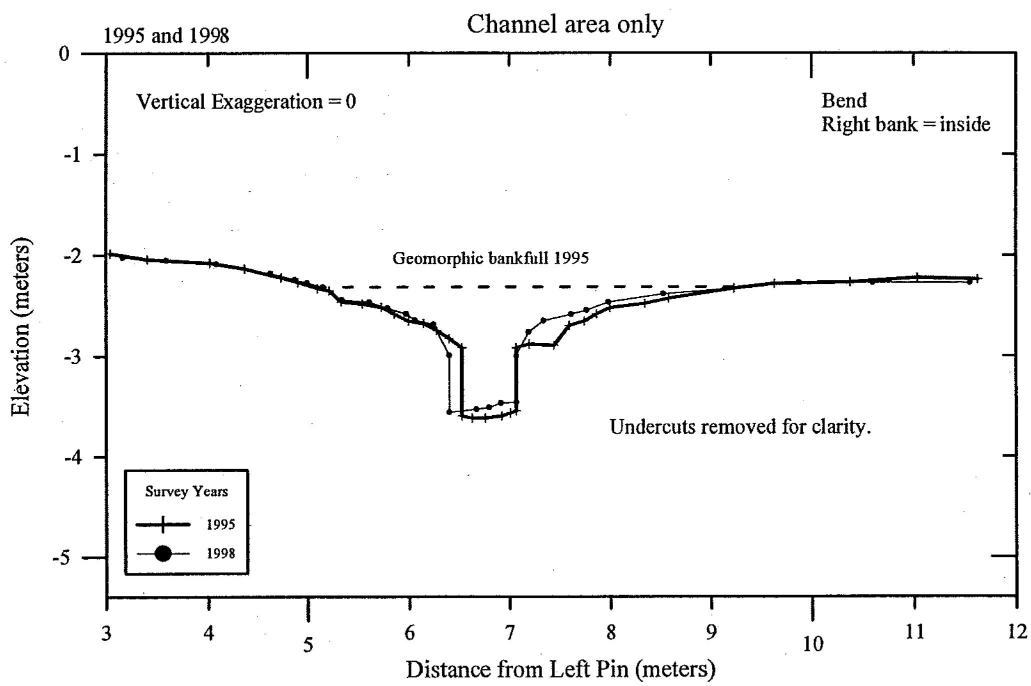
Channel area only



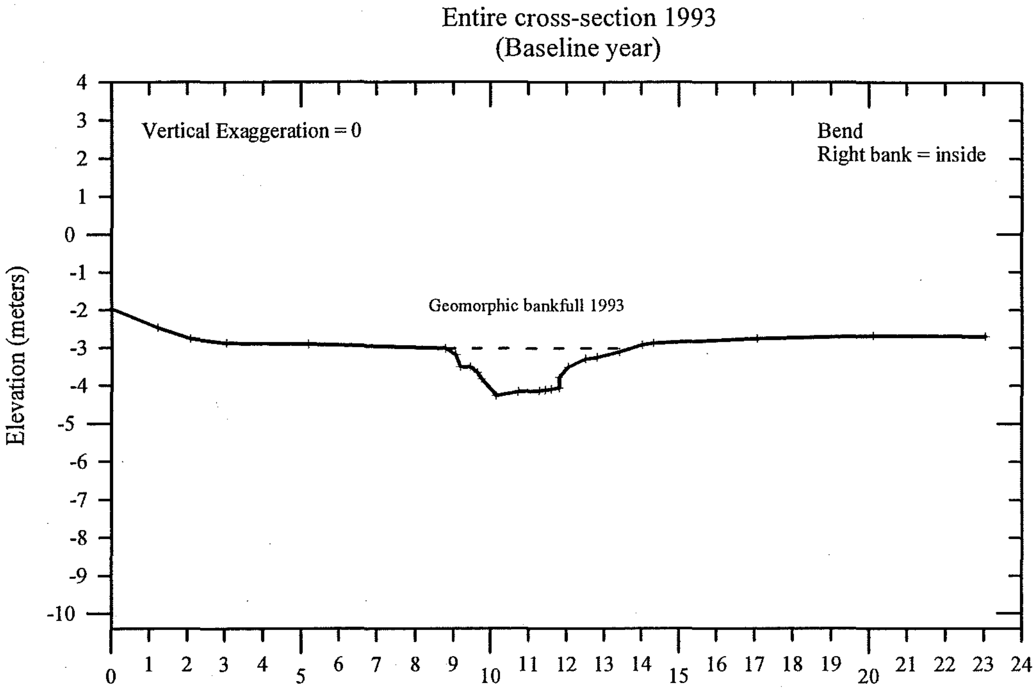
Muddy Creek cross-section 6 (continued)
Riparian Guidelines
1993, 1995, and 1998

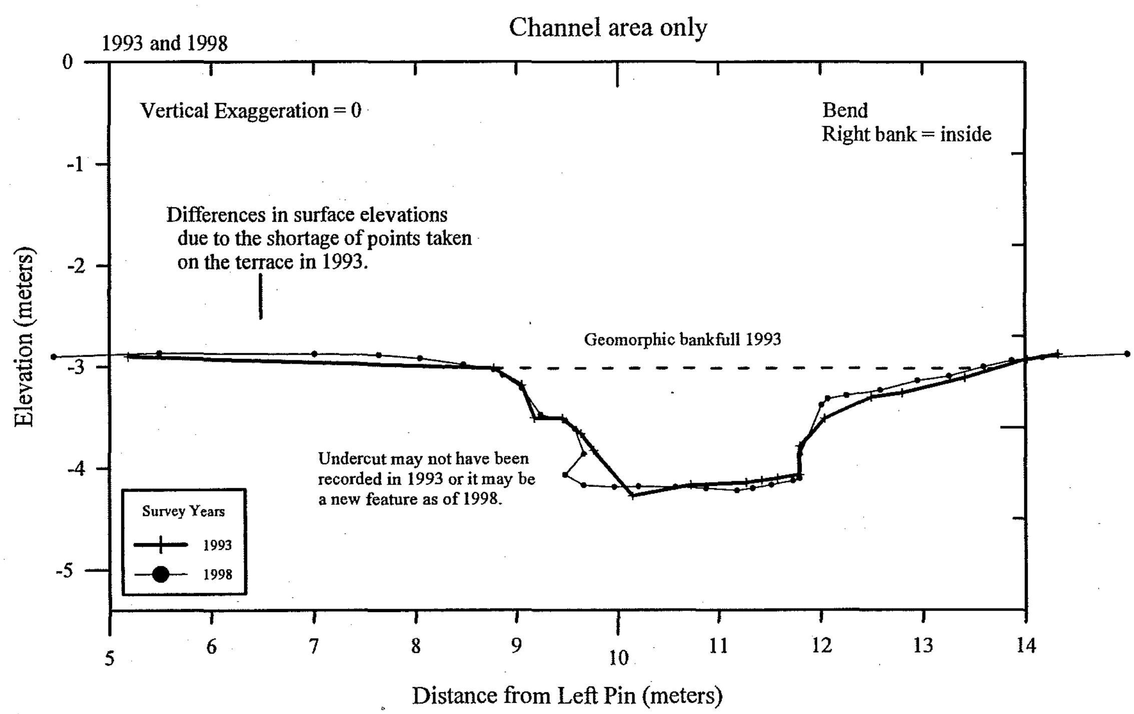
Undercuts removed for clarity.





Muddy Creek cross-section 7
Riparian Guidelines
1993 and 1998

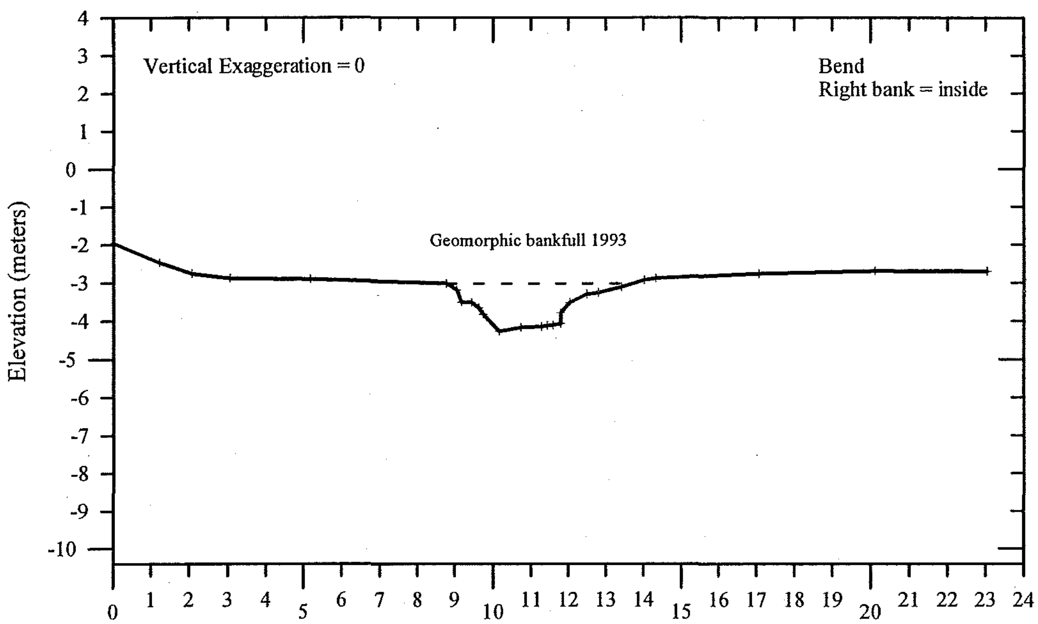




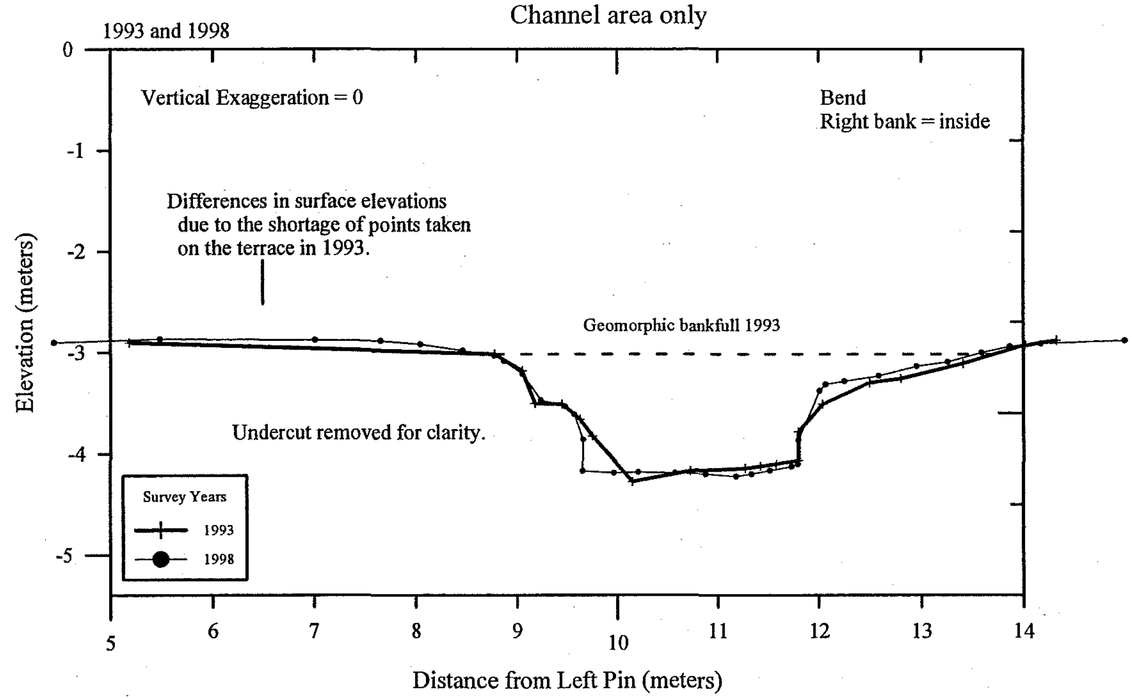
Muddy Creek cross-section 7 (continued)
Riparian Guidelines
1993 and 1998

Undercut removed for clarity.

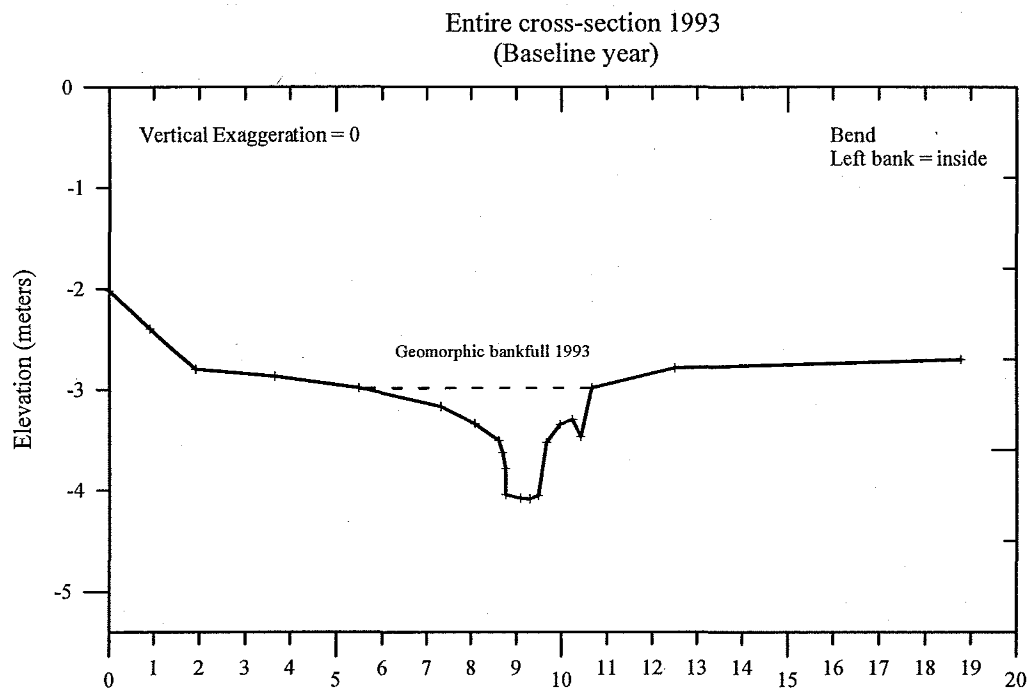
Entire cross-section 1993
(Baseline year)

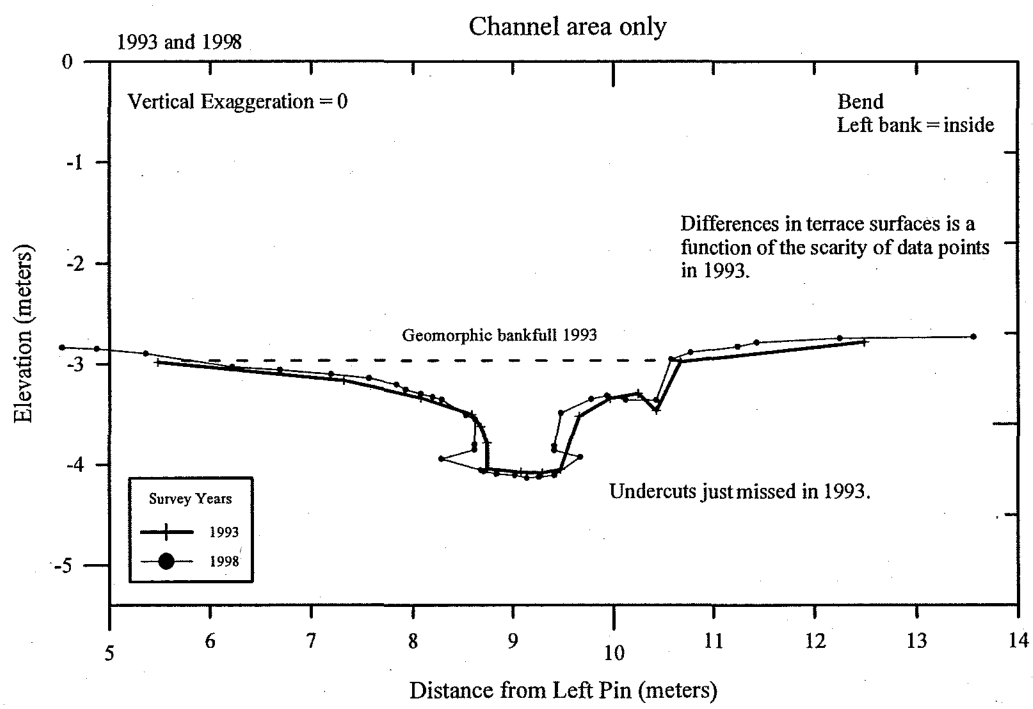


Channel area only



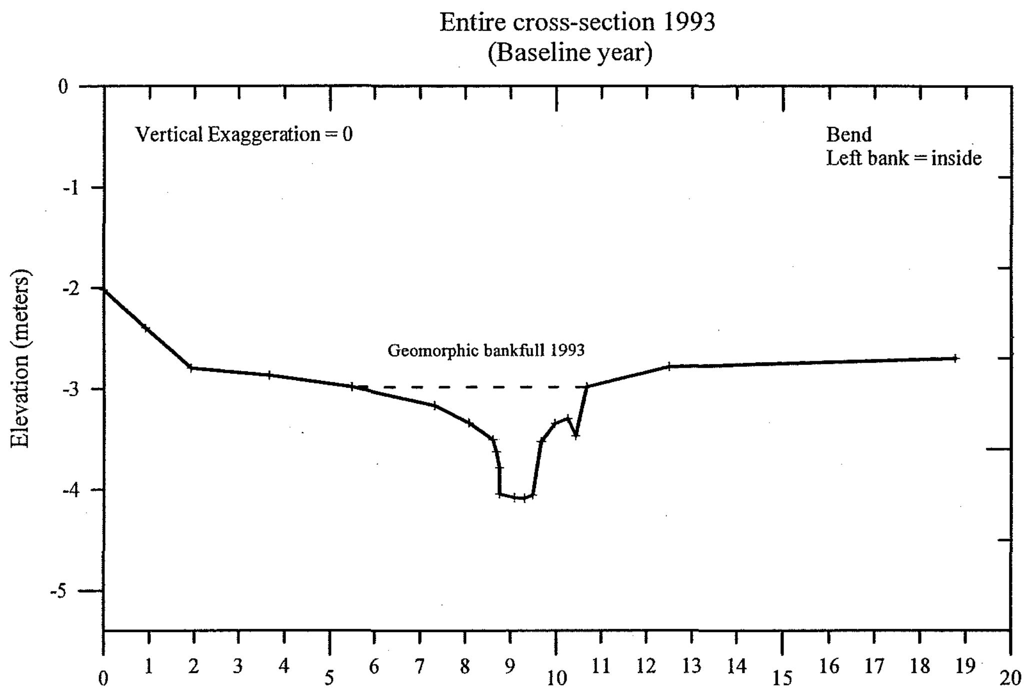
Muddy Creek cross-section 8
Riparian Guidelines
1993 and 1998

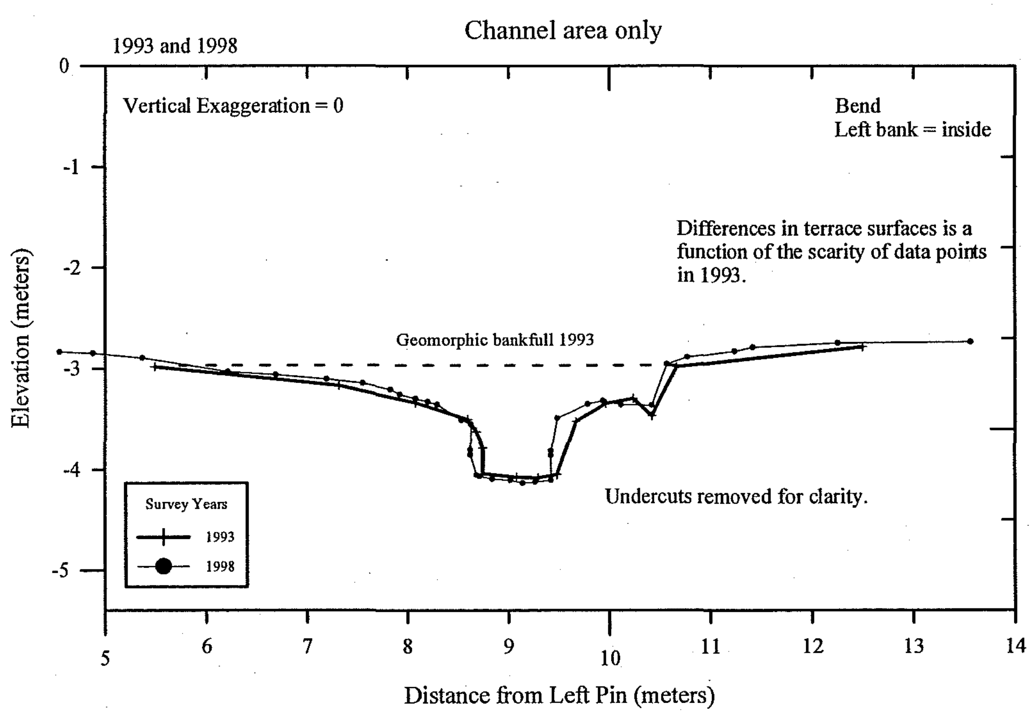




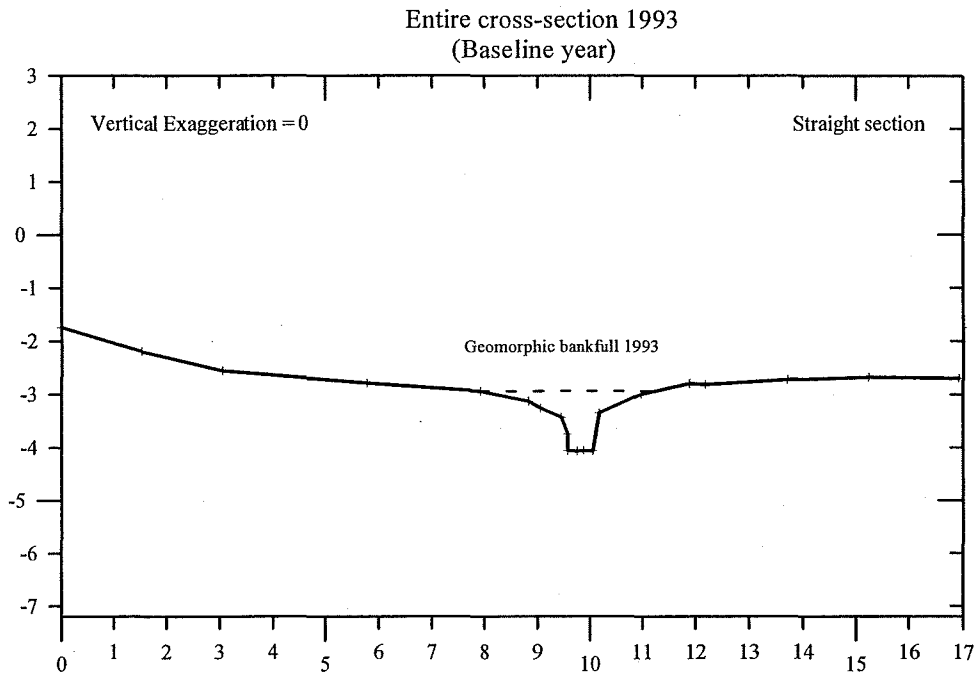
Muddy Creek cross-section 8 (continued)
Riparian Guidelines
1993 and 1998

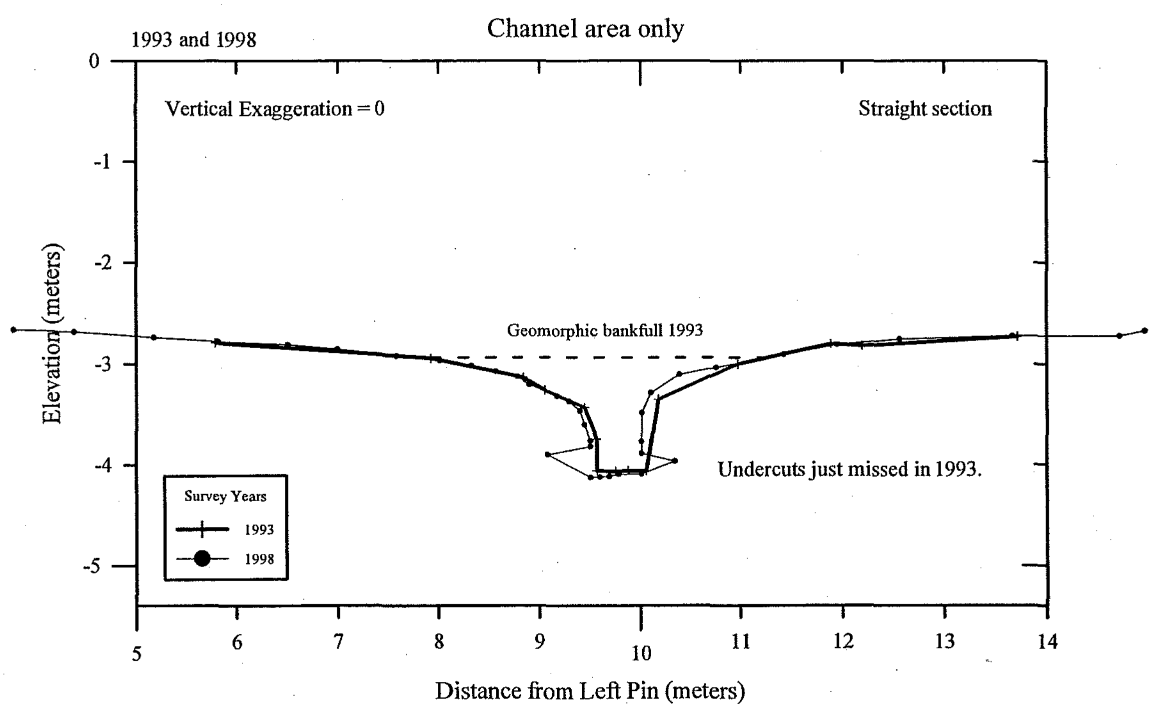
Undercuts removed for clarity.





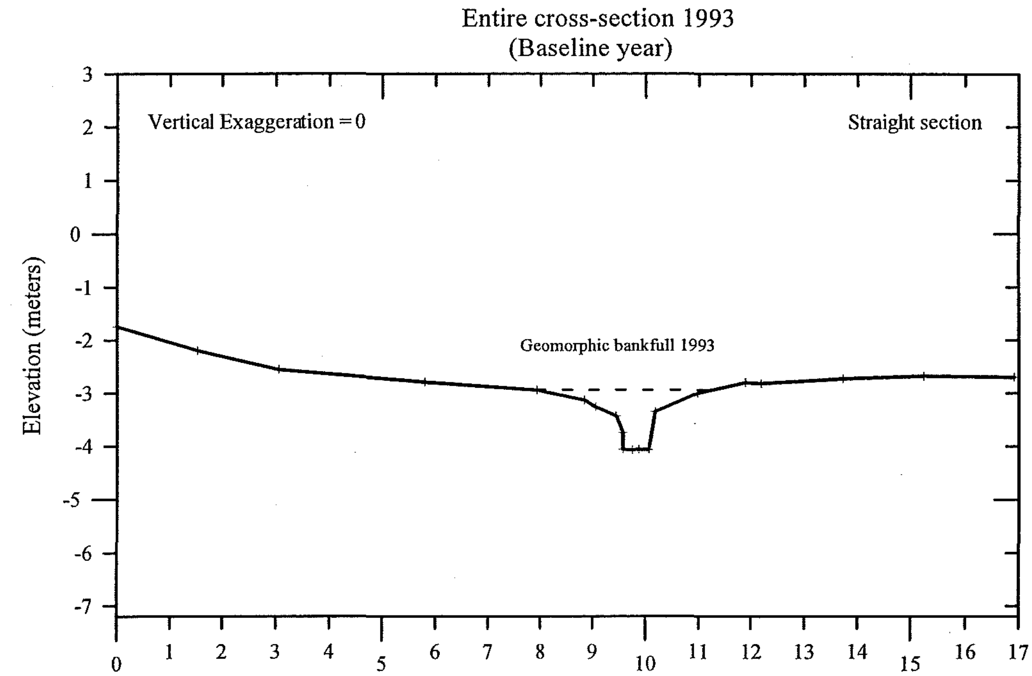
Muddy Creek cross-section 9
Riparian Guidelines
1993 and 1998

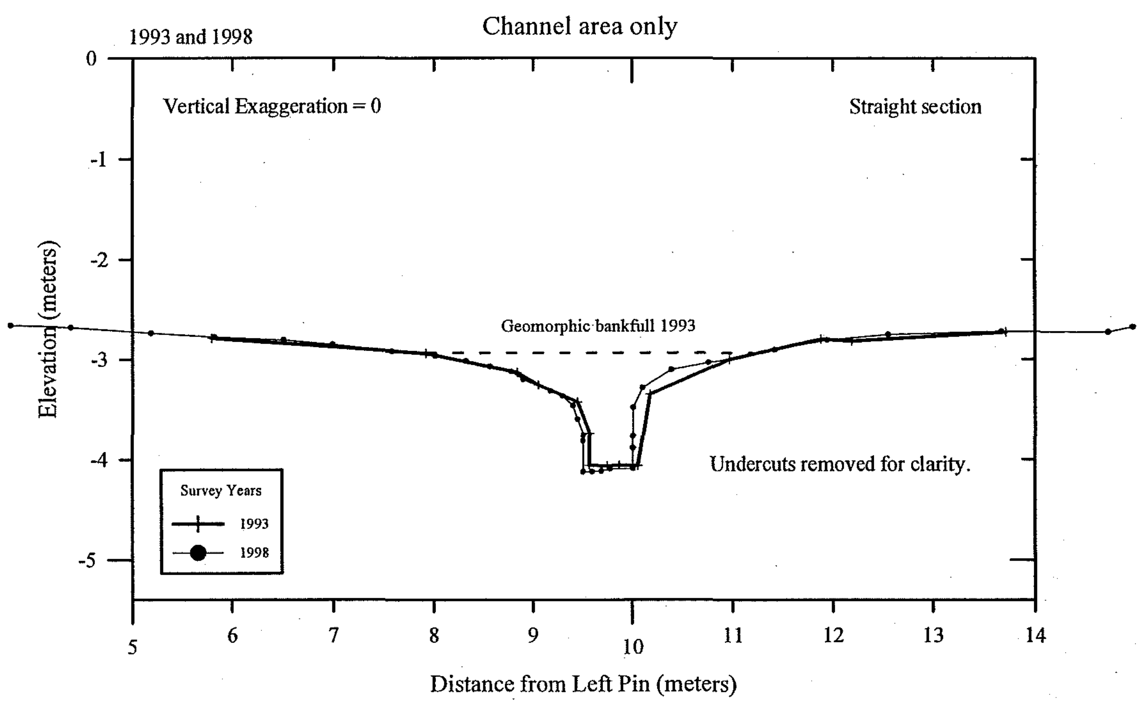




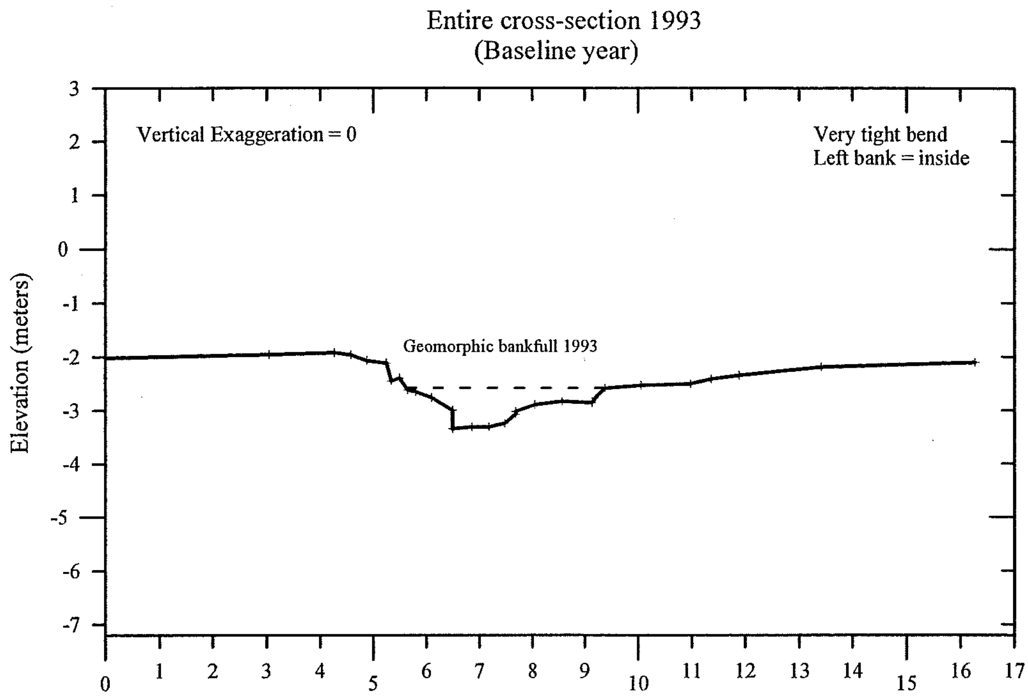
Muddy Creek cross-section 9 (continued)
Riparian Guidelines
1993 and 1998

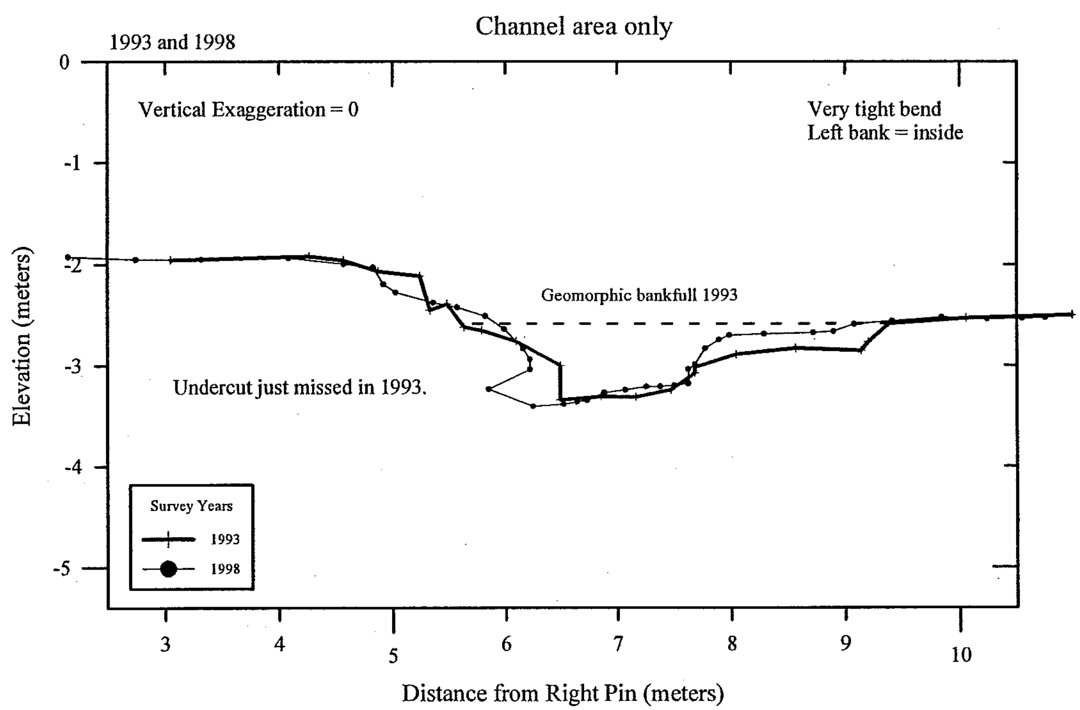
Undercuts removed for clarity.





Muddy Creek cross-section 10
Riparian Guidelines
1993 and 1998

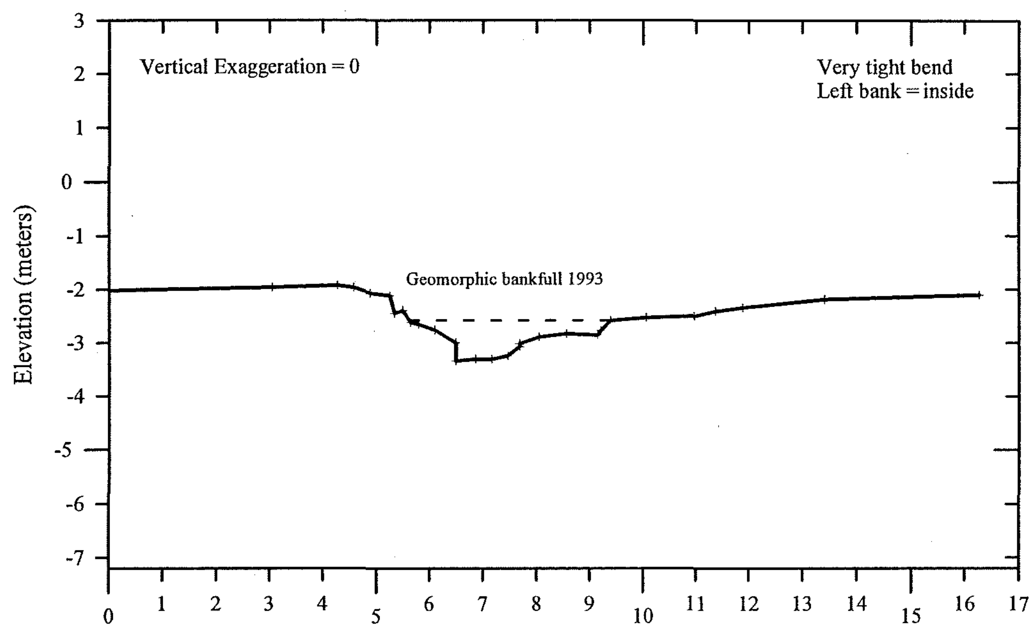




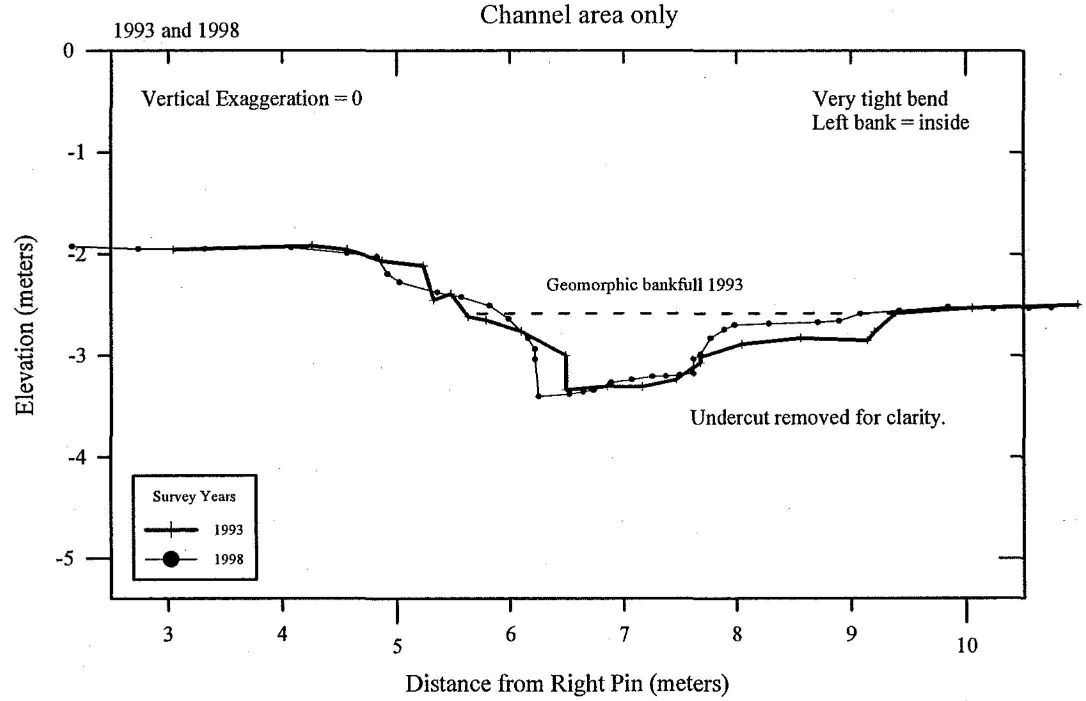
Muddy Creek cross-section 10 (continued)
Riparian Guidelines
1993 and 1998

Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)

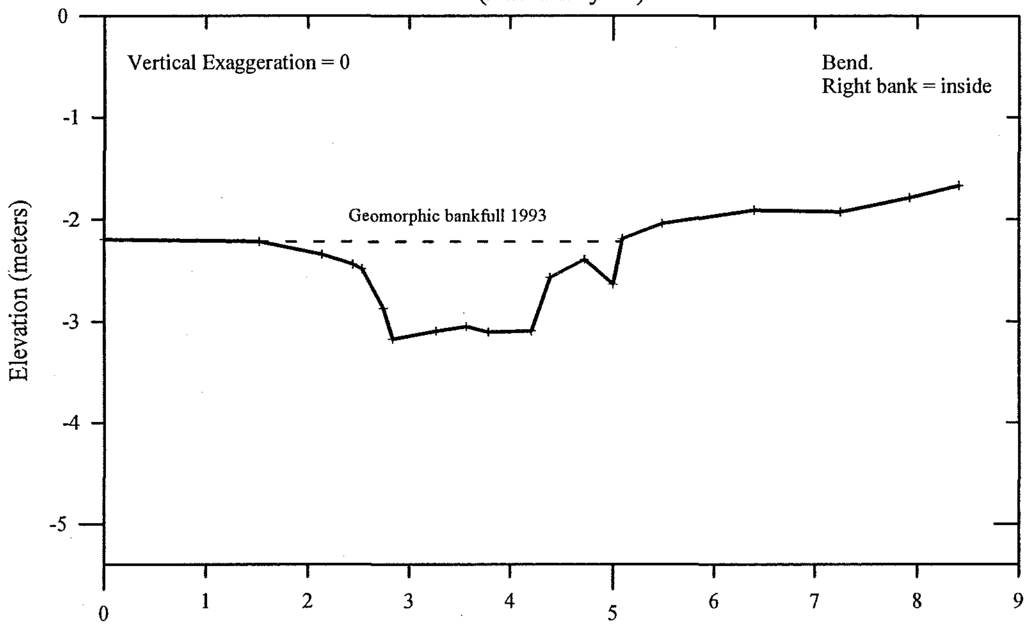


Channel area only

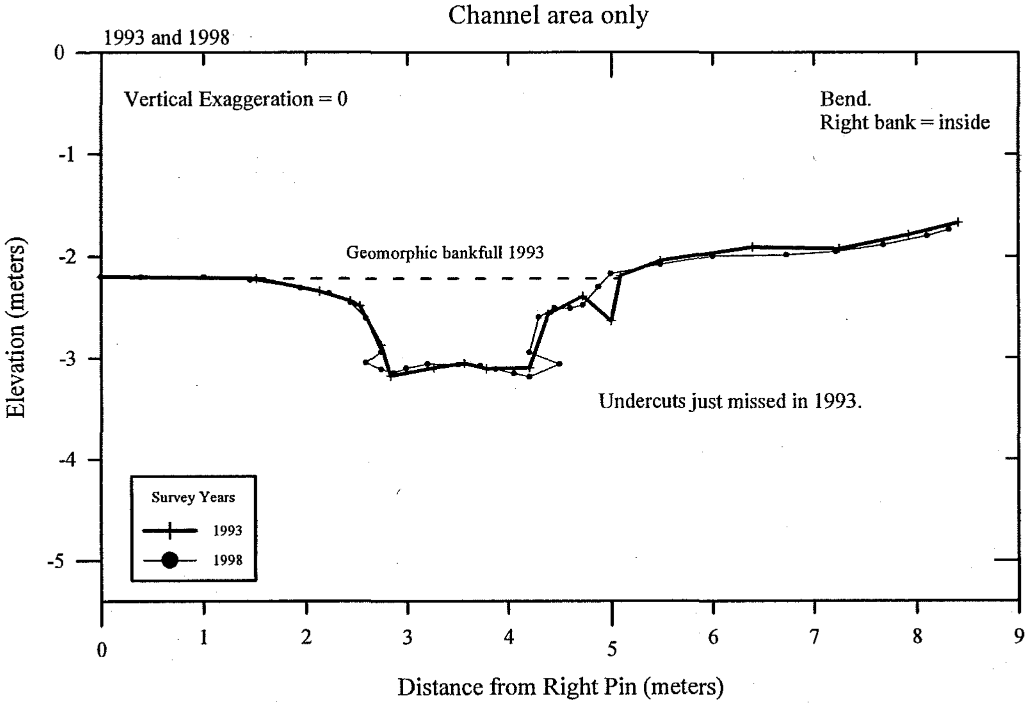


Muddy Creek cross-section 11
Riparian Guidelines
1993 and 1998

Entire cross-section 1993
(Baseline year)



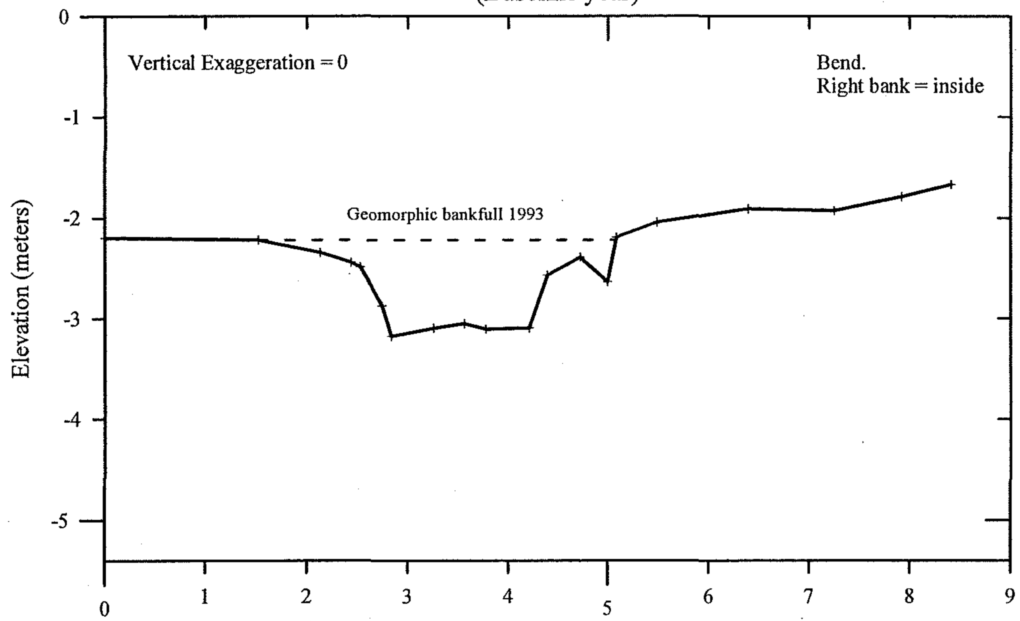
Channel area only



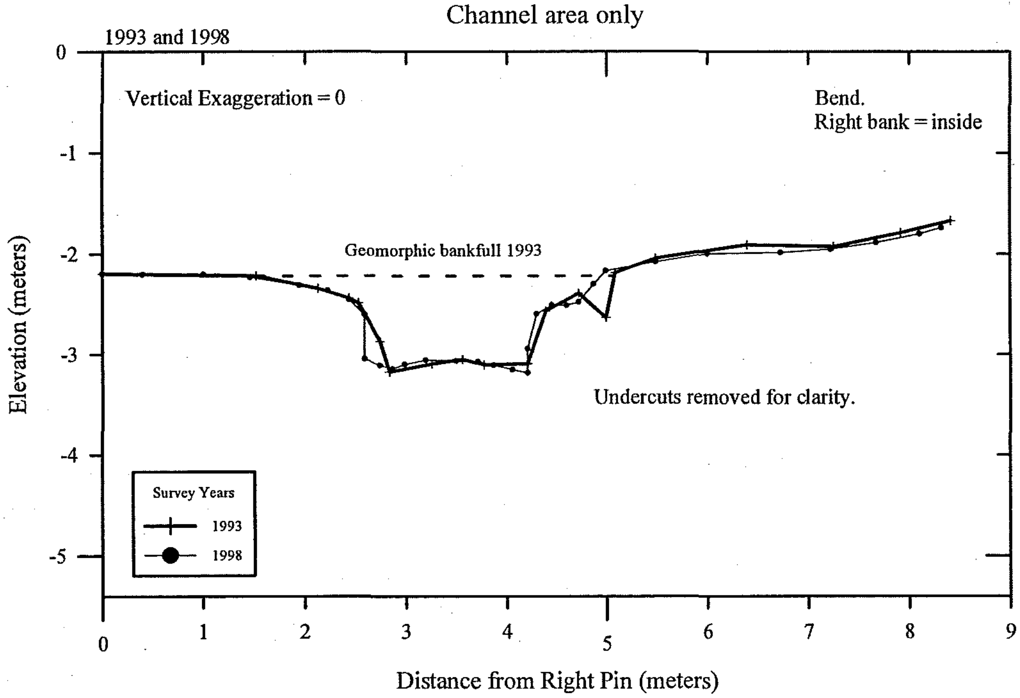
Muddy Creek cross-section 11 (continued)
Riparian Guidelines
1993 and 1998

Undercuts removed for clarity.

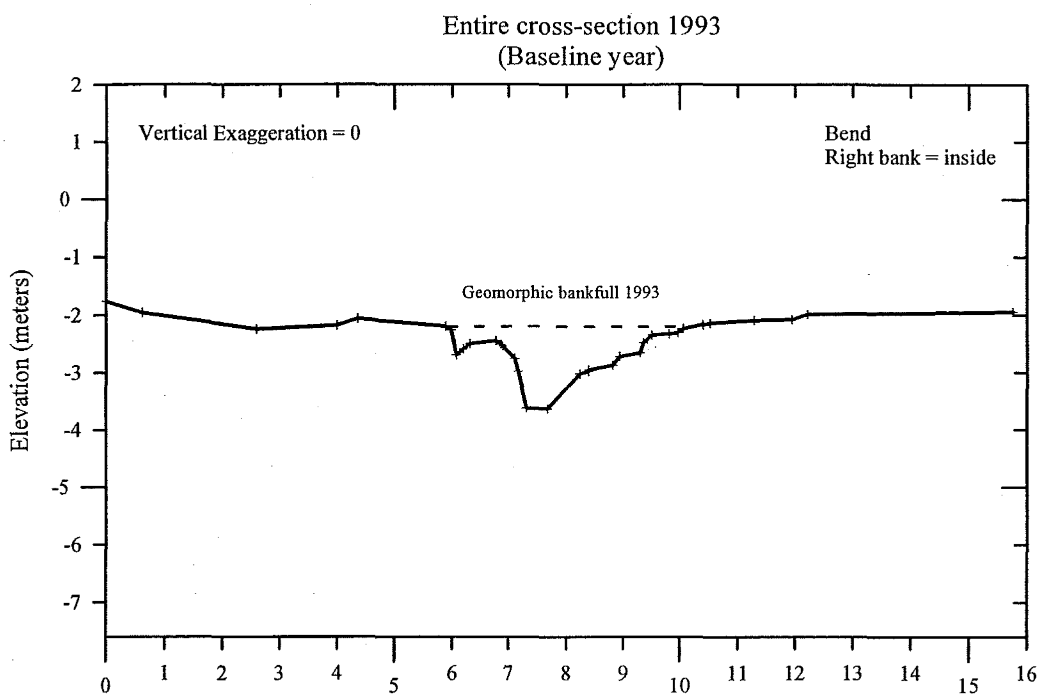
Entire cross-section 1993
(Baseline year)

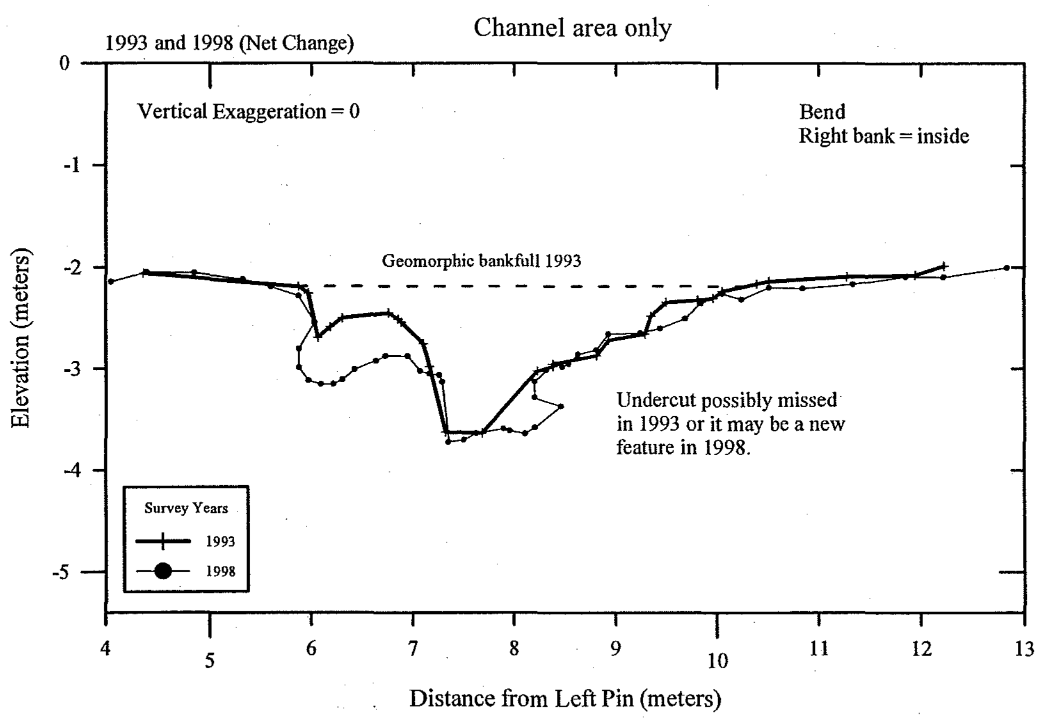


Channel area only

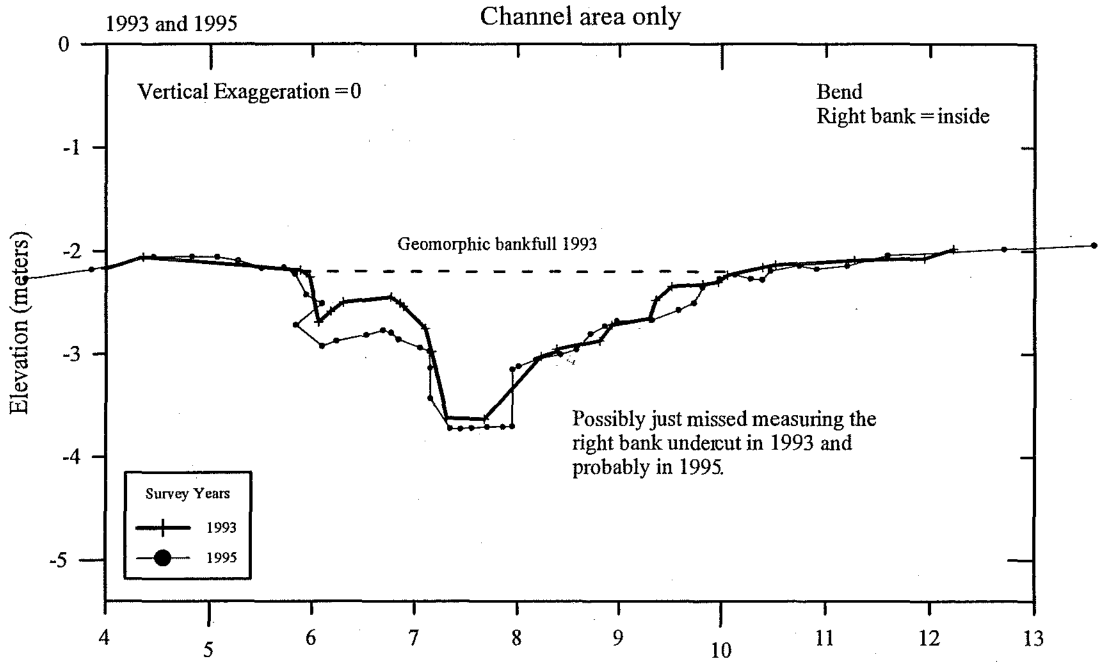


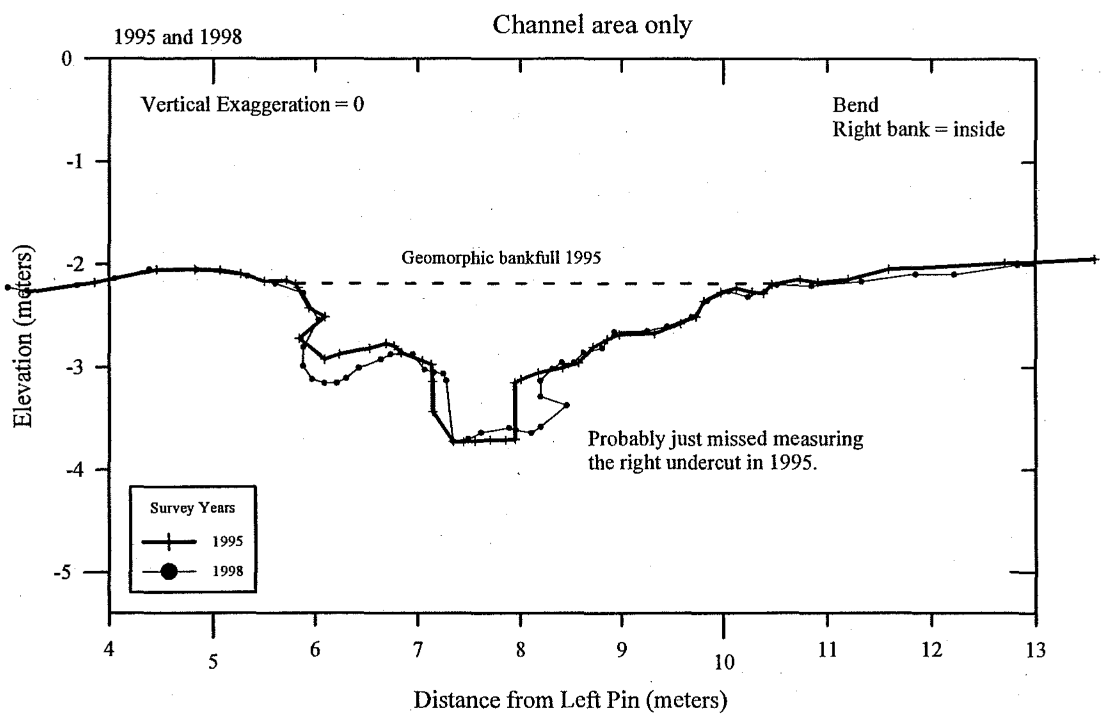
Muddy Creek cross-section 12
Old Cattle Exclosure
1993, 1995, and 1998





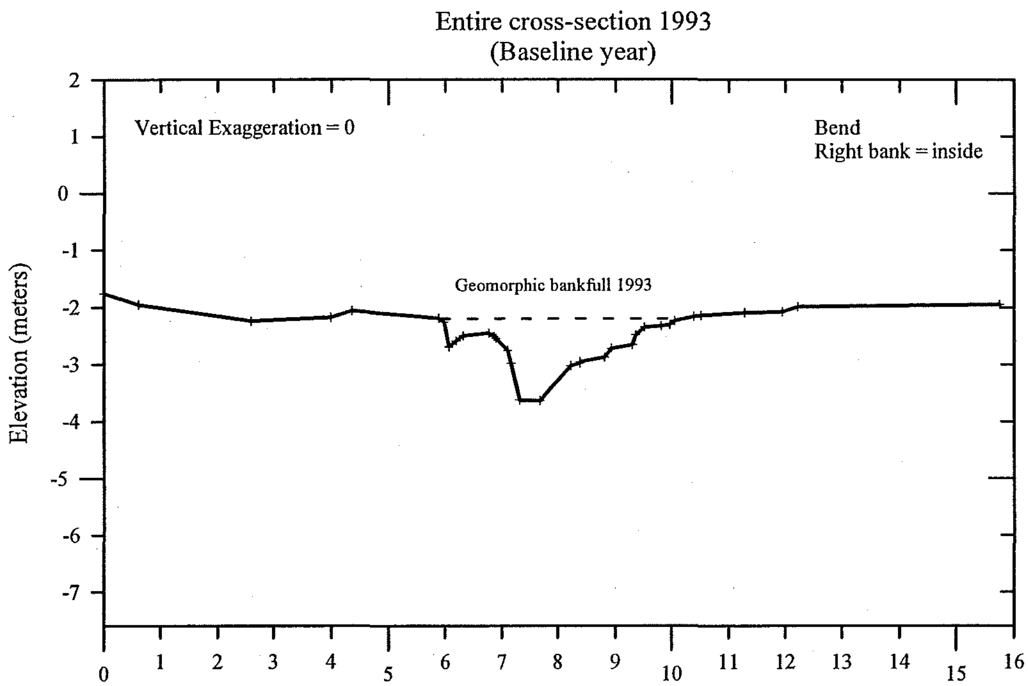
Muddy Creek cross-section 12 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

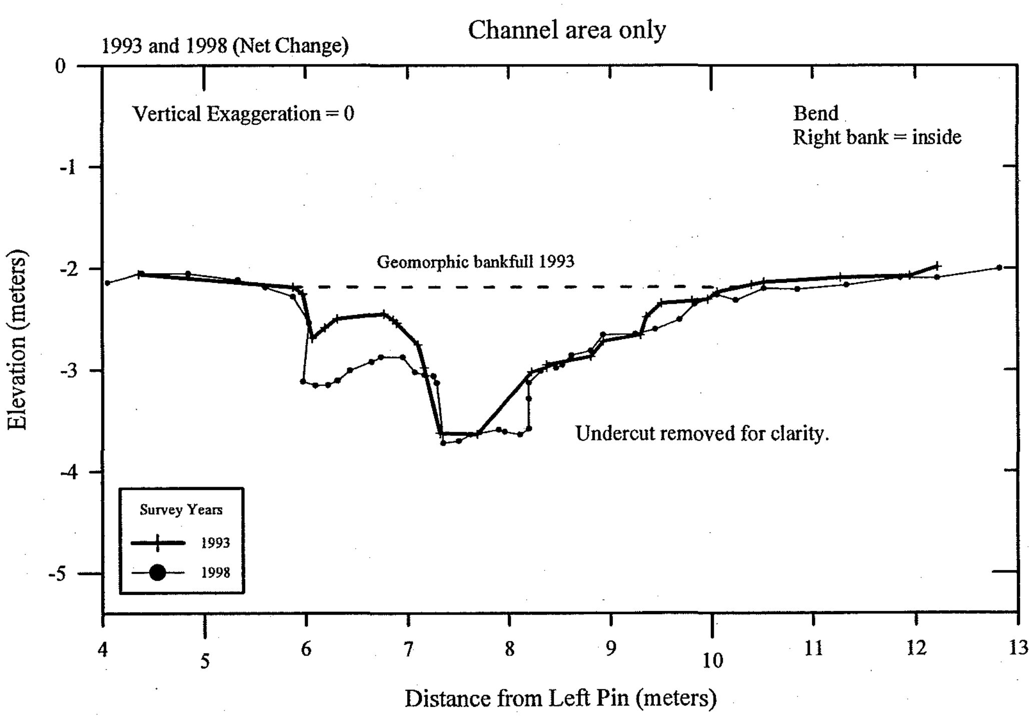




Muddy Creek cross-section 12 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

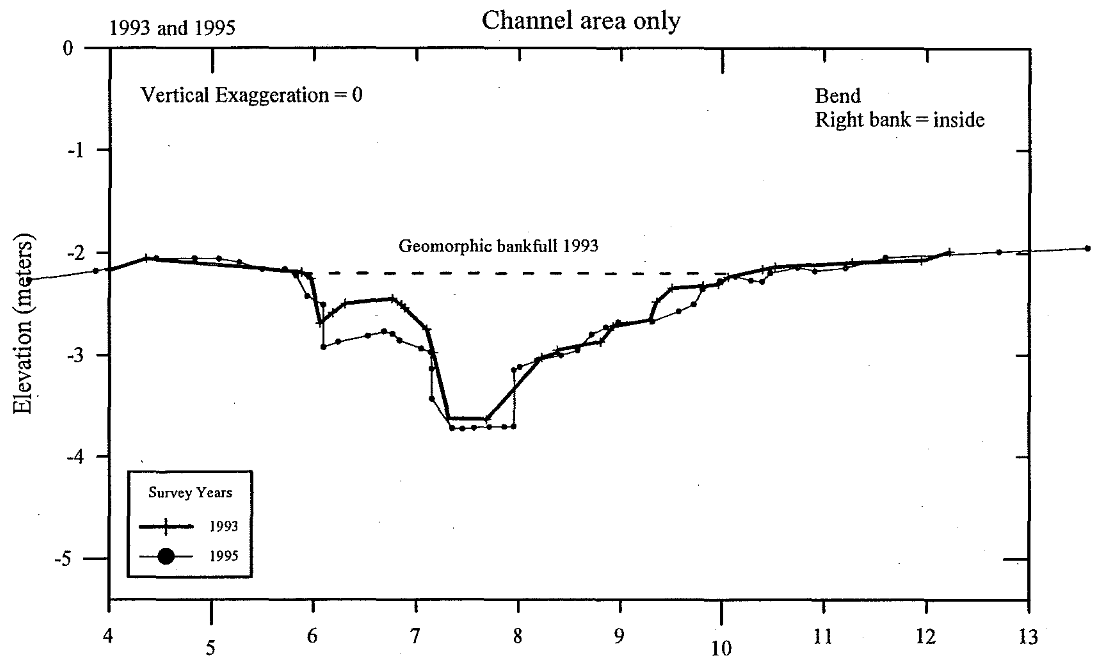
Undercut removed for clarity.

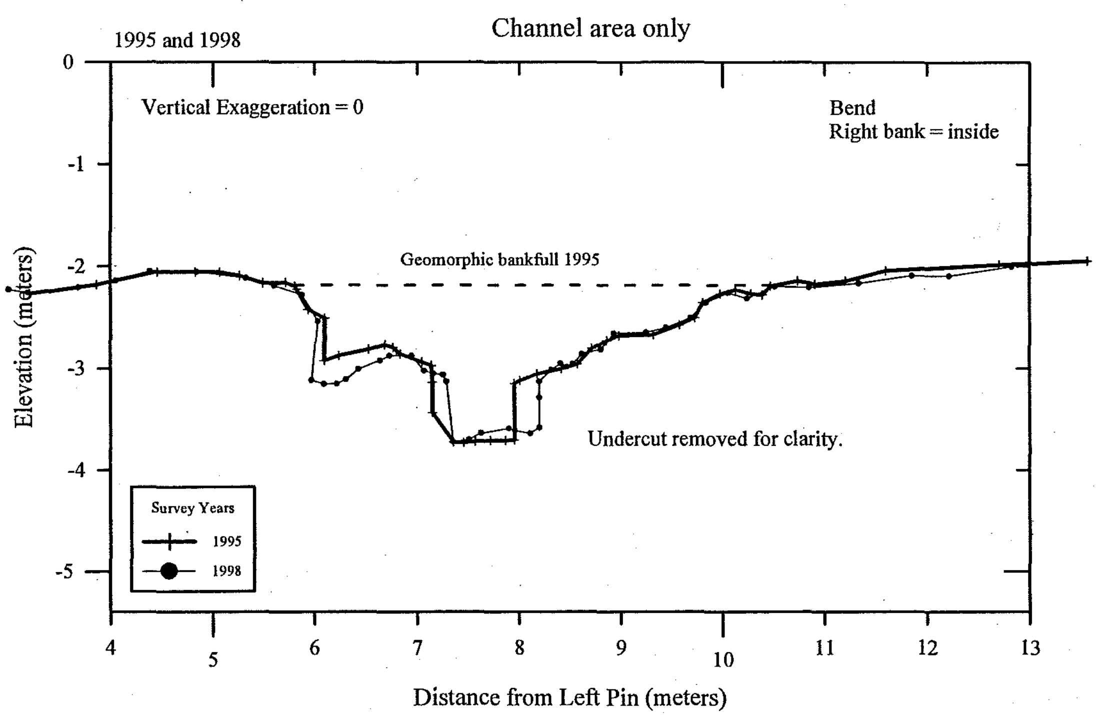




Muddy Creek cross-section 12 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

Undercut removed for clarity.

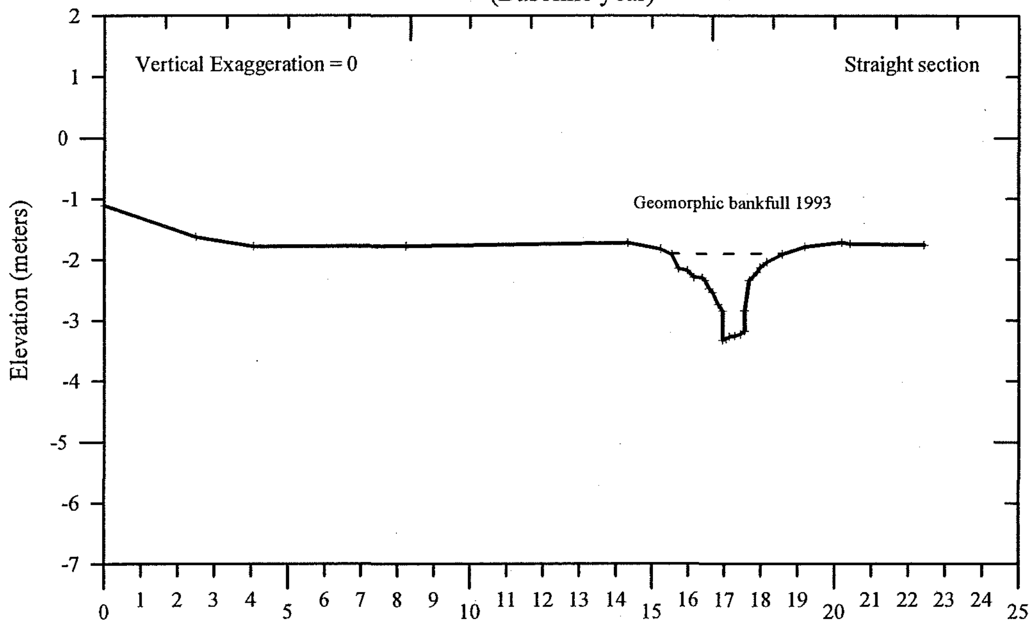




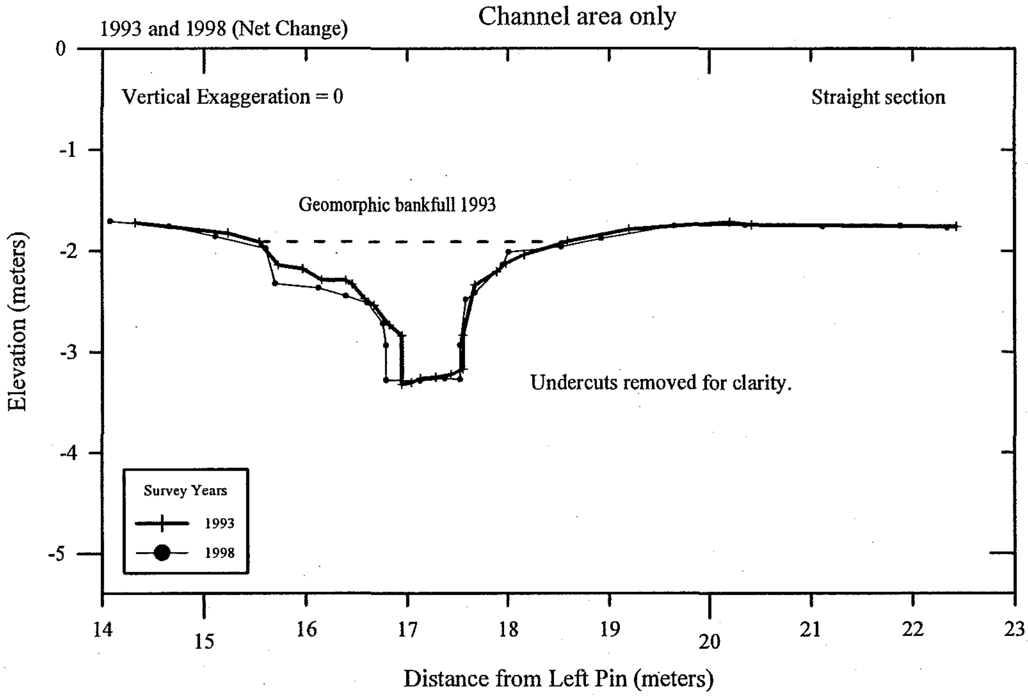
Muddy Creek cross-section 13 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

Undercuts removed for clarity

Entire cross-section 1993
(Baseline year)

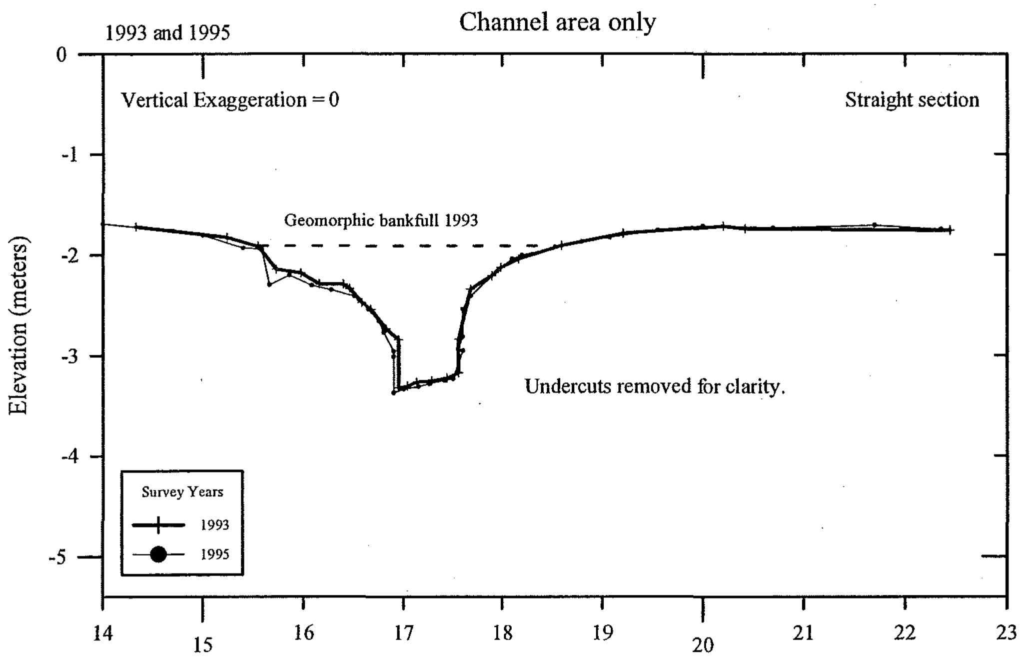


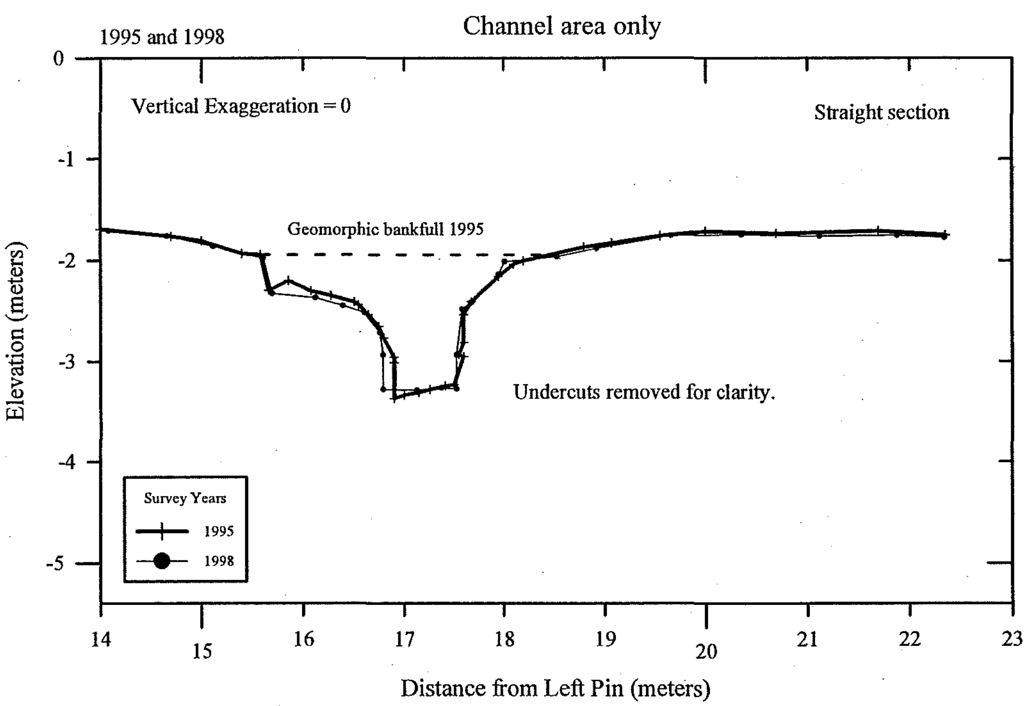
Channel area only



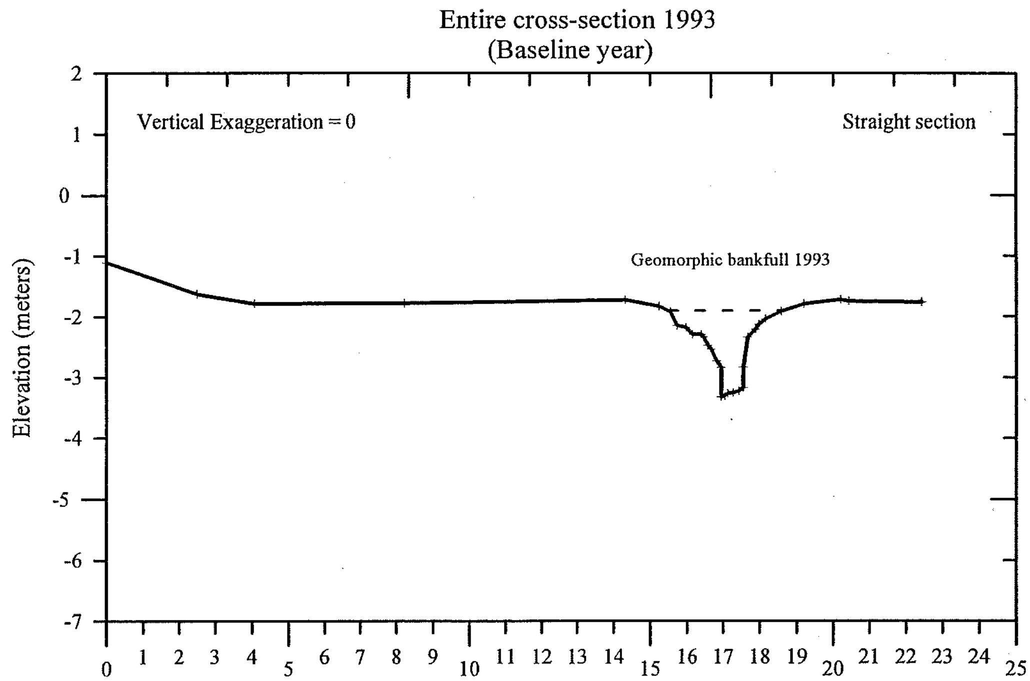
Muddy Creek cross-section 13 (continued)
Old Cattle Exclosure
1993, 1995, and 1998

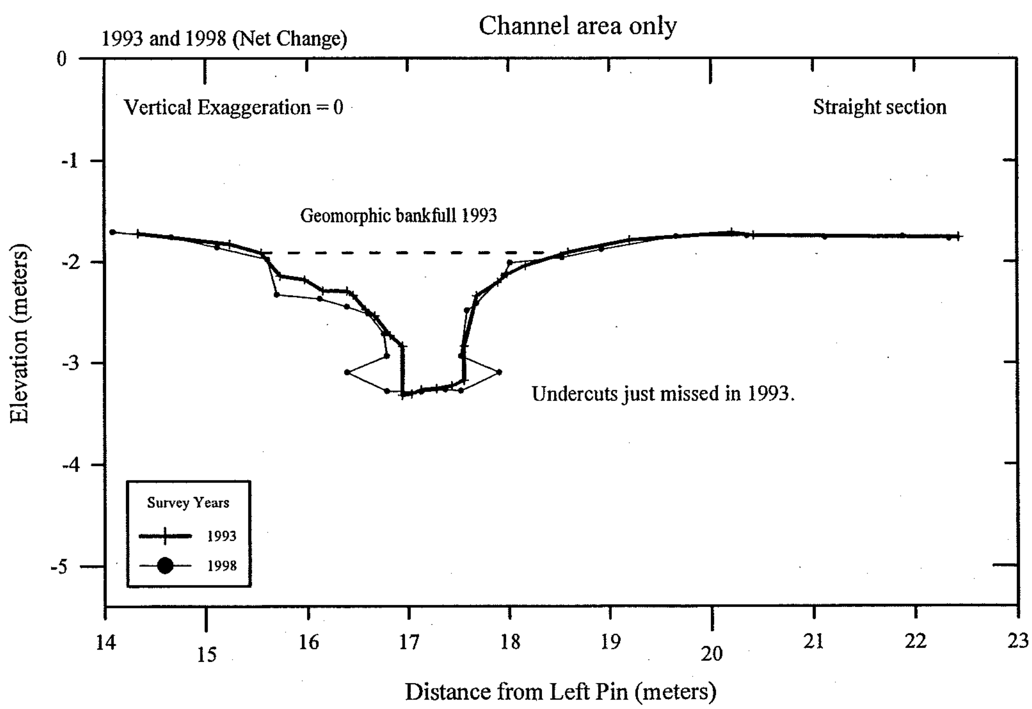
Undercuts removed for clarity.



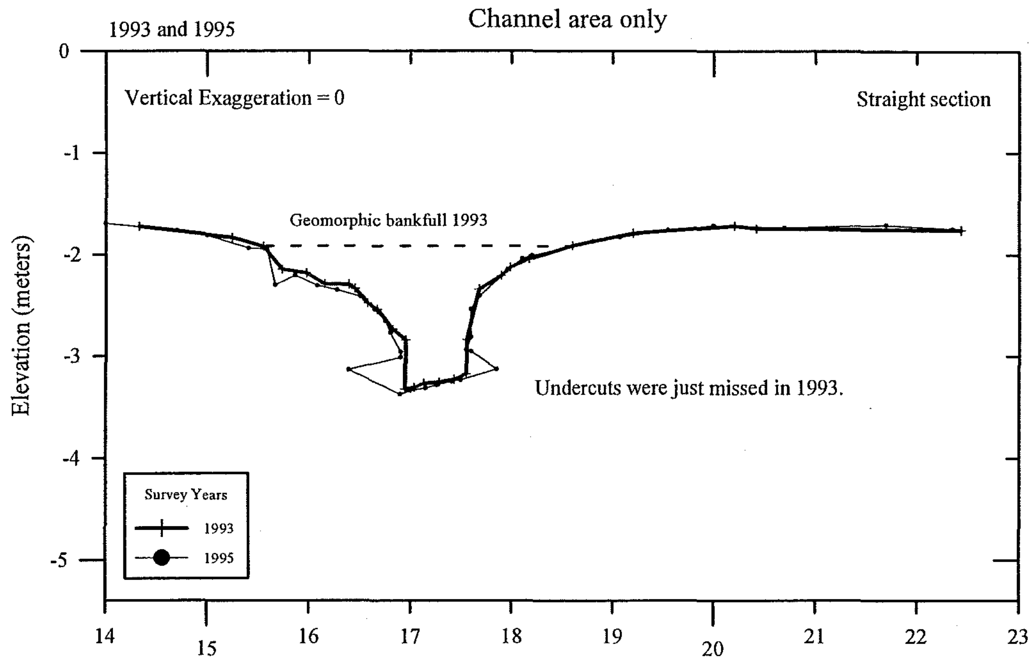


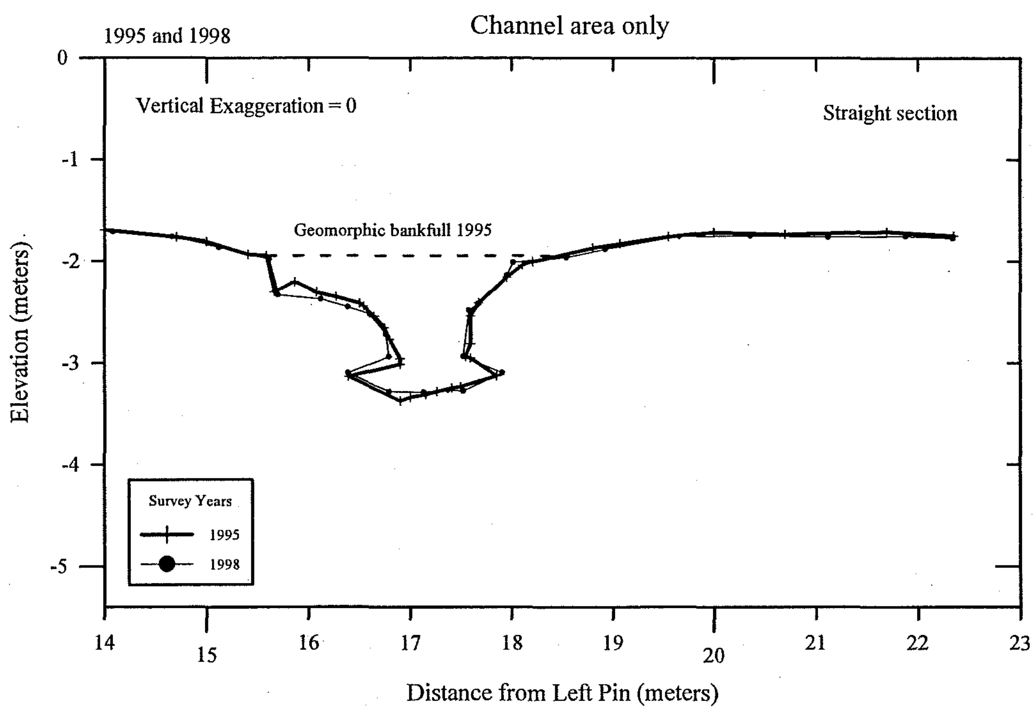
Muddy Creek cross-section 13
Old Cattle Exclosure
1993, 1995, and 1998





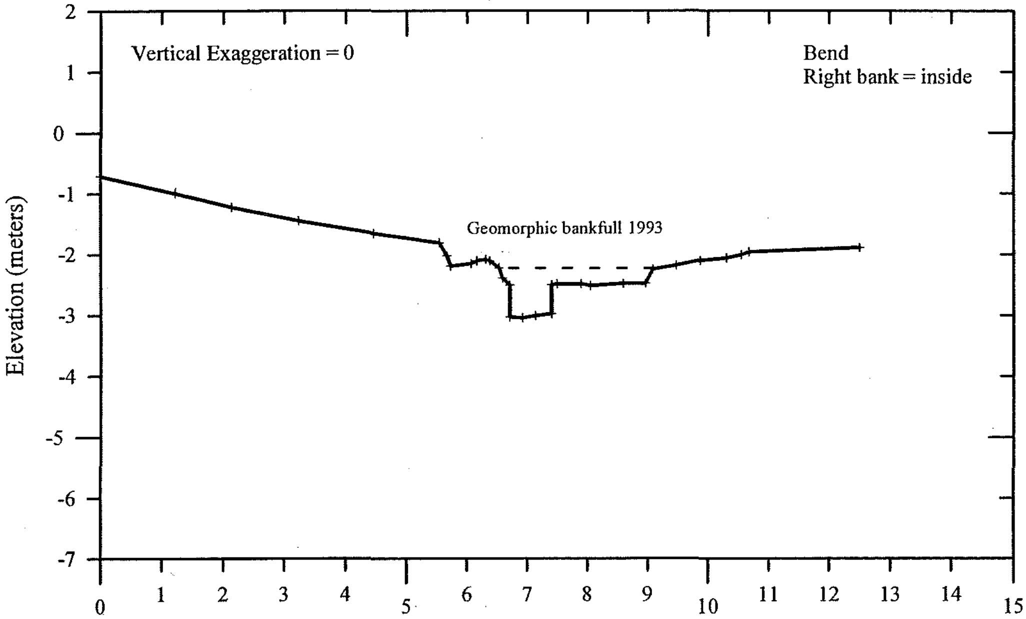
Muddy Creek cross-section 13 (continued)
Old Cattle Exclosure
1993, 1995, and 1998



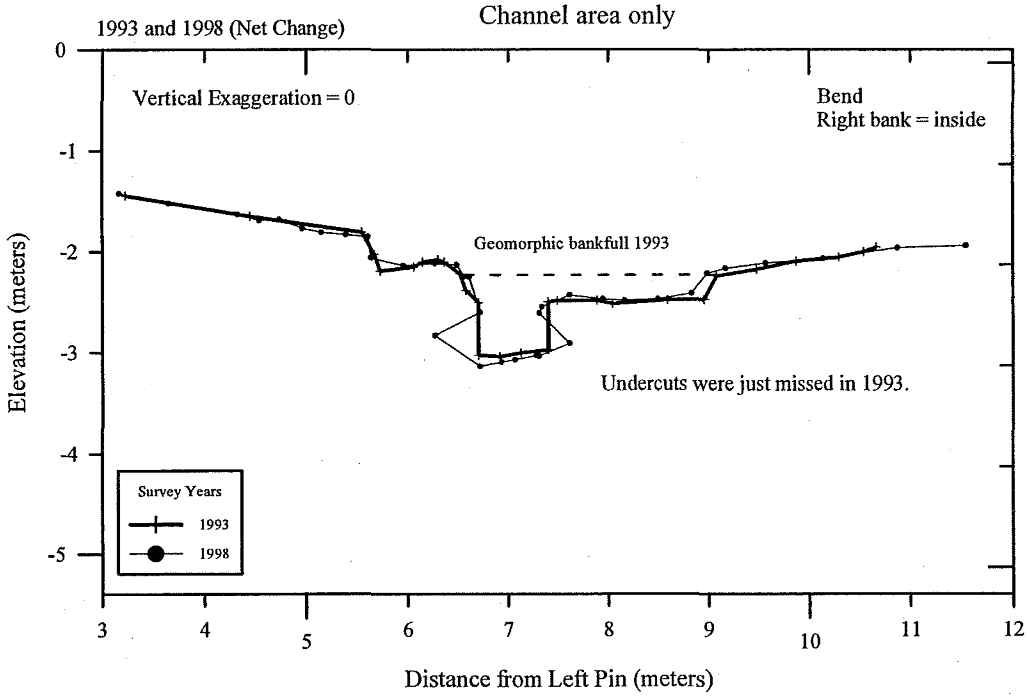


Muddy Creek cross-section 14
Riparian Guidelines
1993, 1995, and 1998

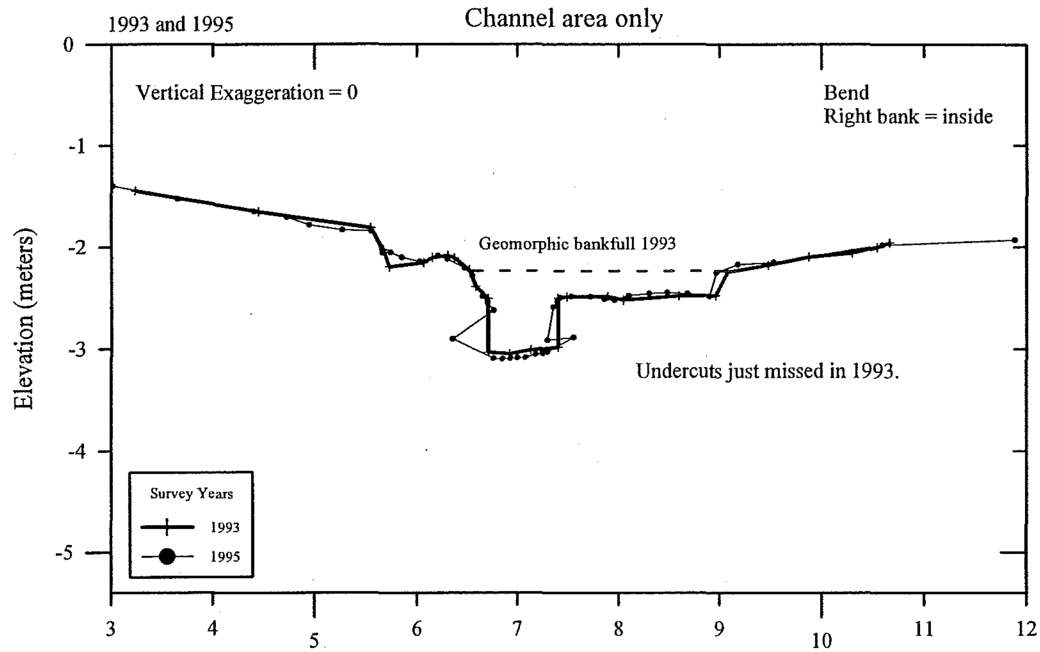
Entire cross-section 1993
(Baseline year)

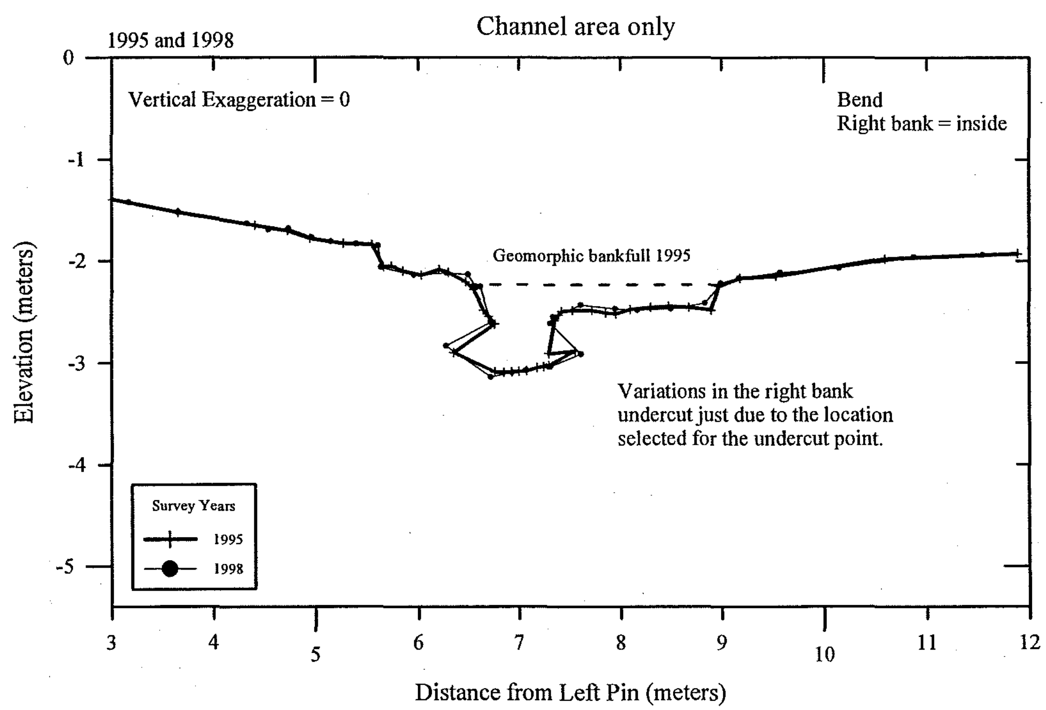


Channel area only



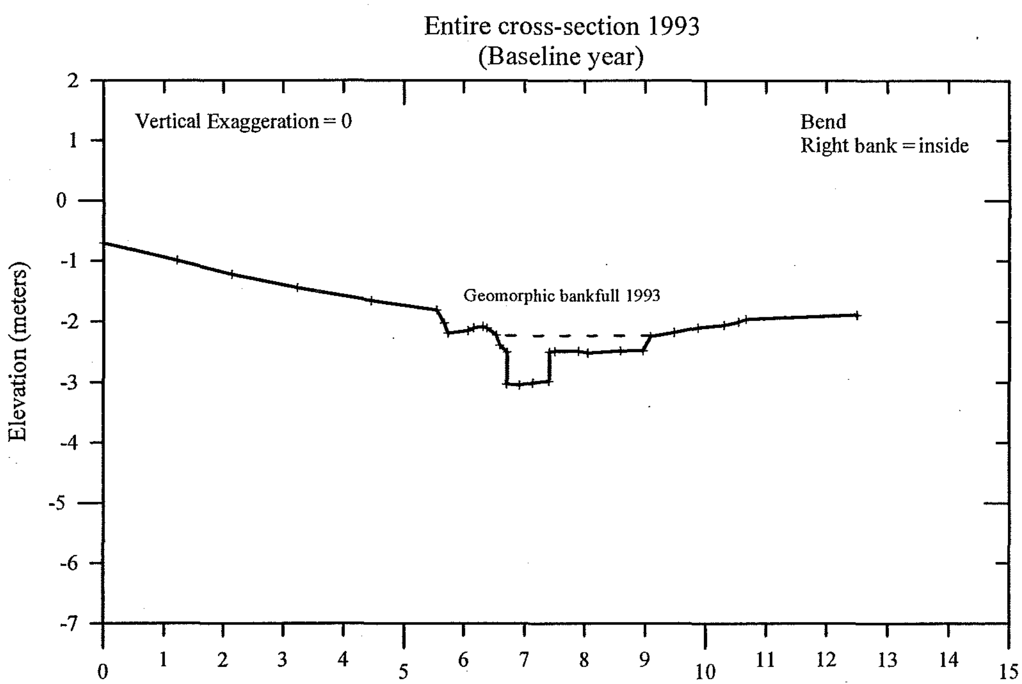
Muddy Creek cross-section 14 (continued)
Riparian Guidelines
1993, 1995, and 1998

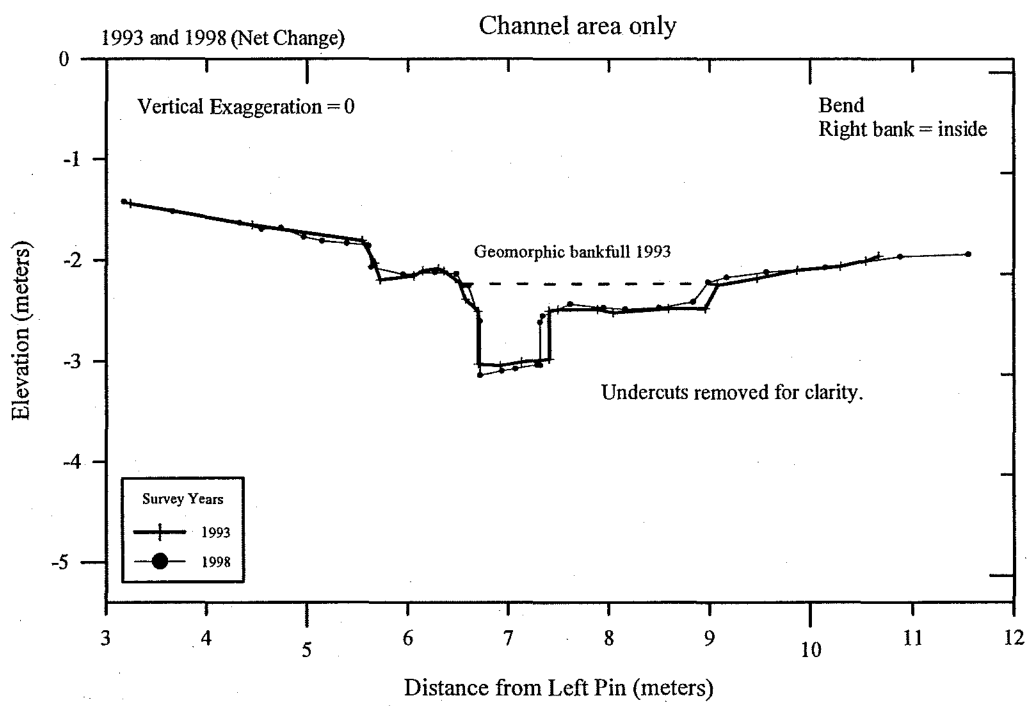




Muddy Creek cross-section 14 (continued)
1993, 1995, and 1998

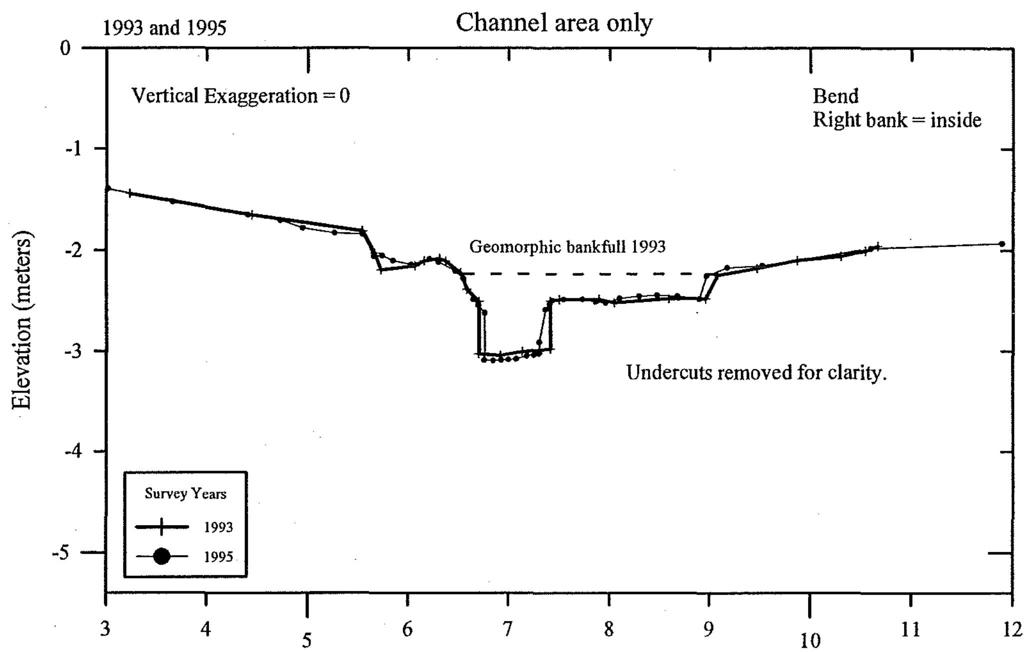
Undercuts removed for clarity.

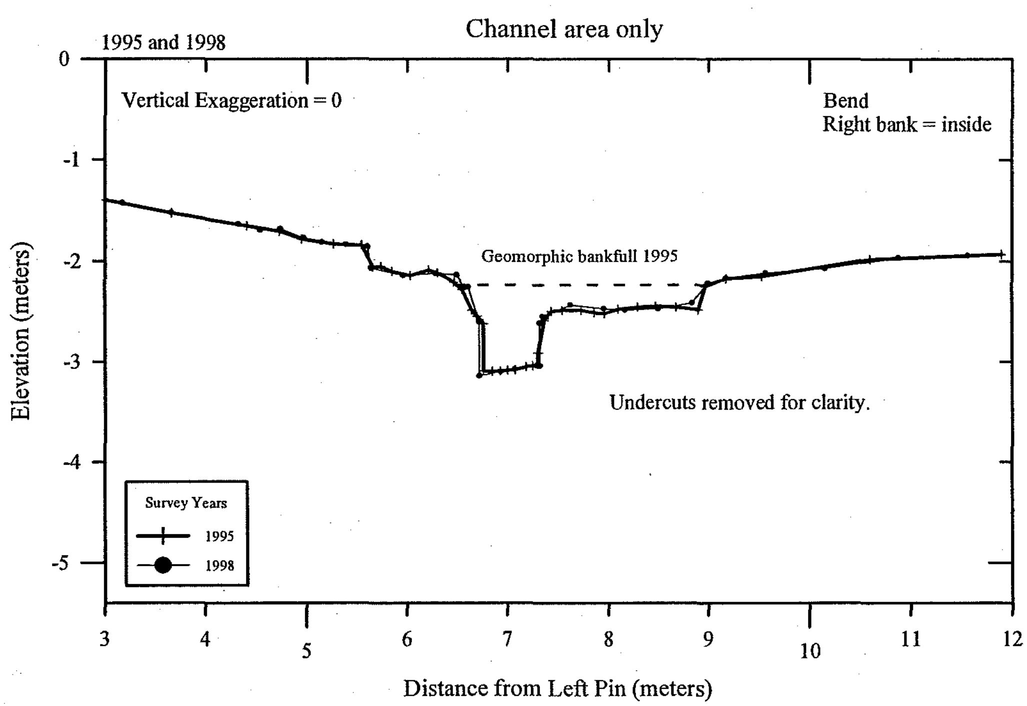




Muddy Creek cross-section 14 (continued)
Riparian Guidelines
1993, 1995, and 1998

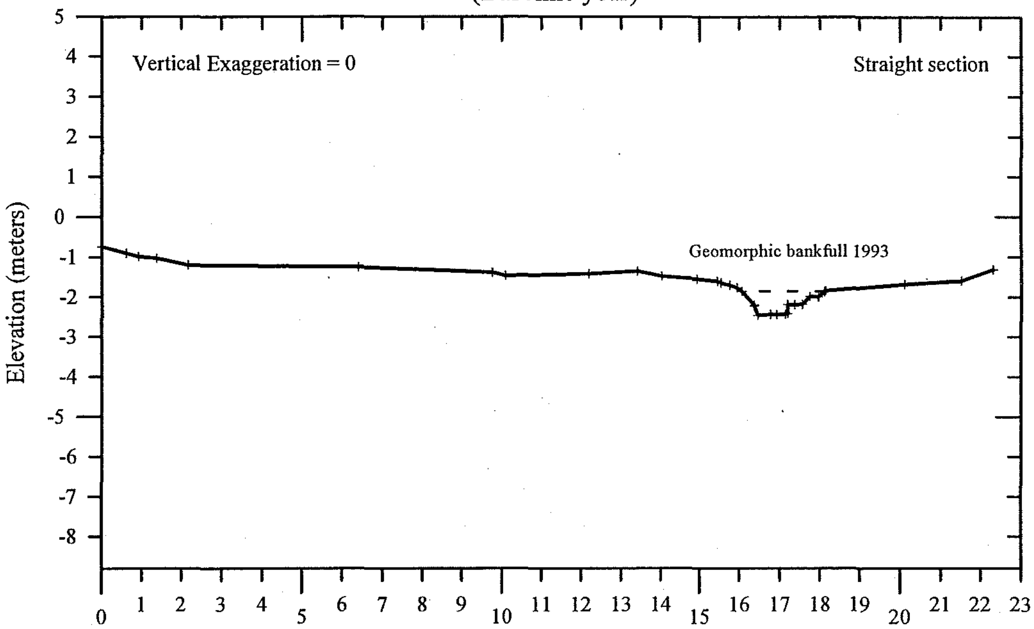
Undercuts removed for clarity.





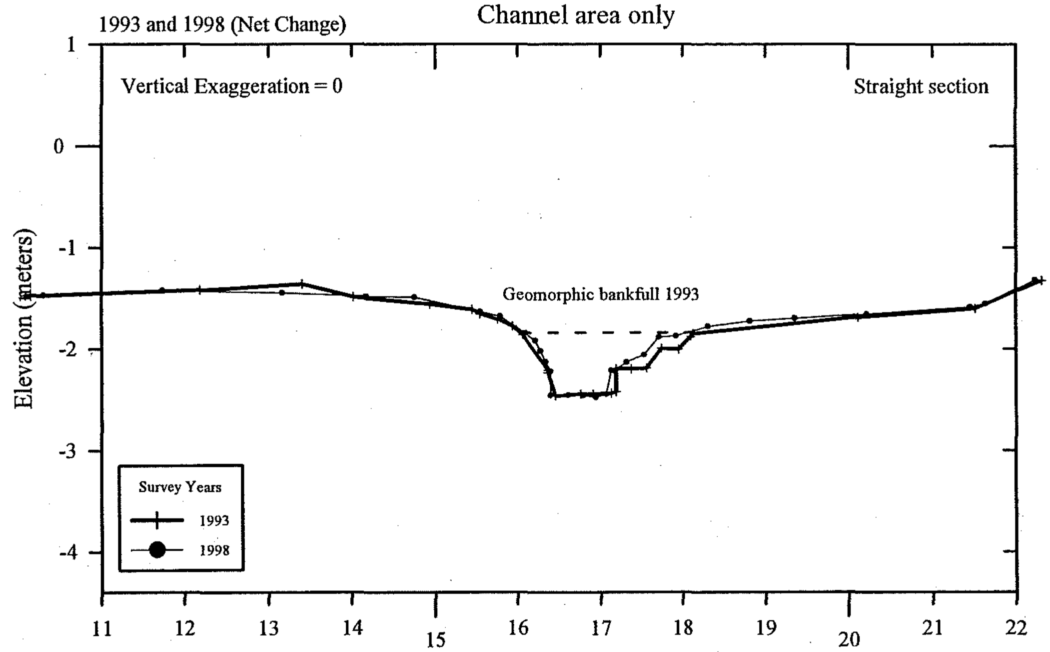
Muddy Creek cross-section 15
Riparian Guidelines
1993, 1995, and 1998

Entire cross-section 1993
(Baseline year)



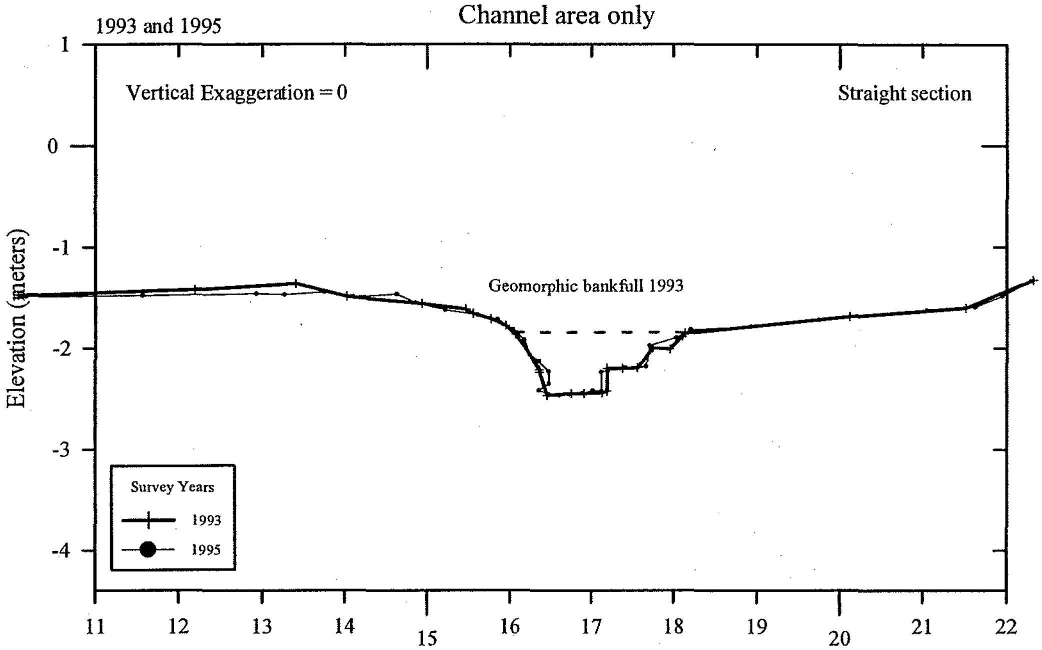
1993 and 1998 (Net Change)

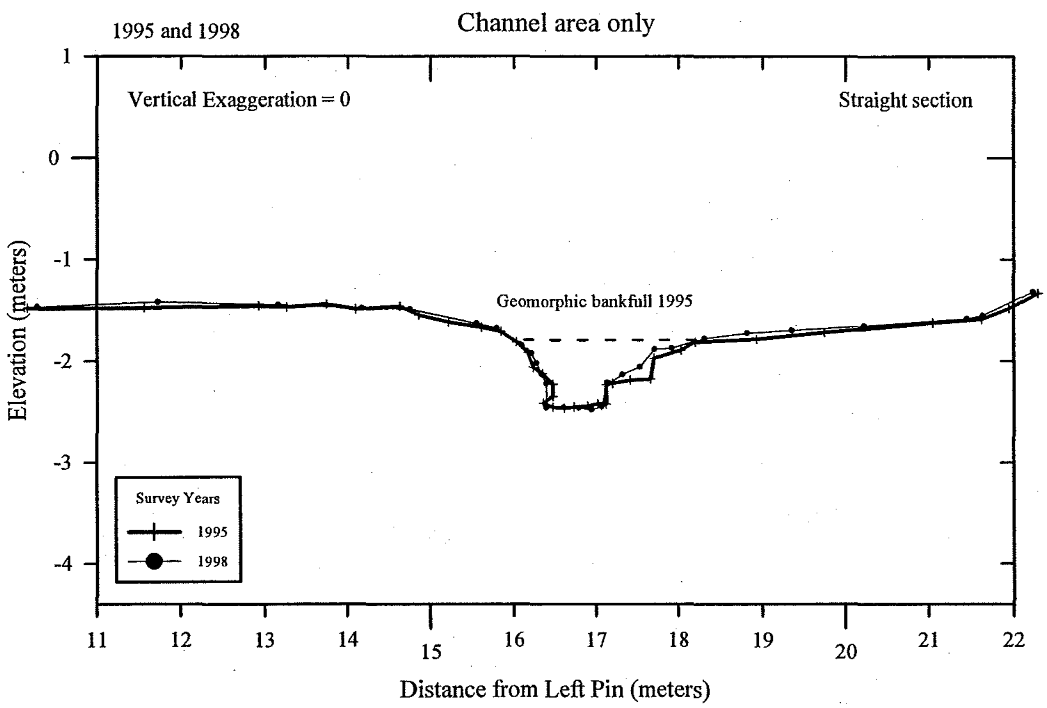
Channel area only



Distance from Left Pin (meters)

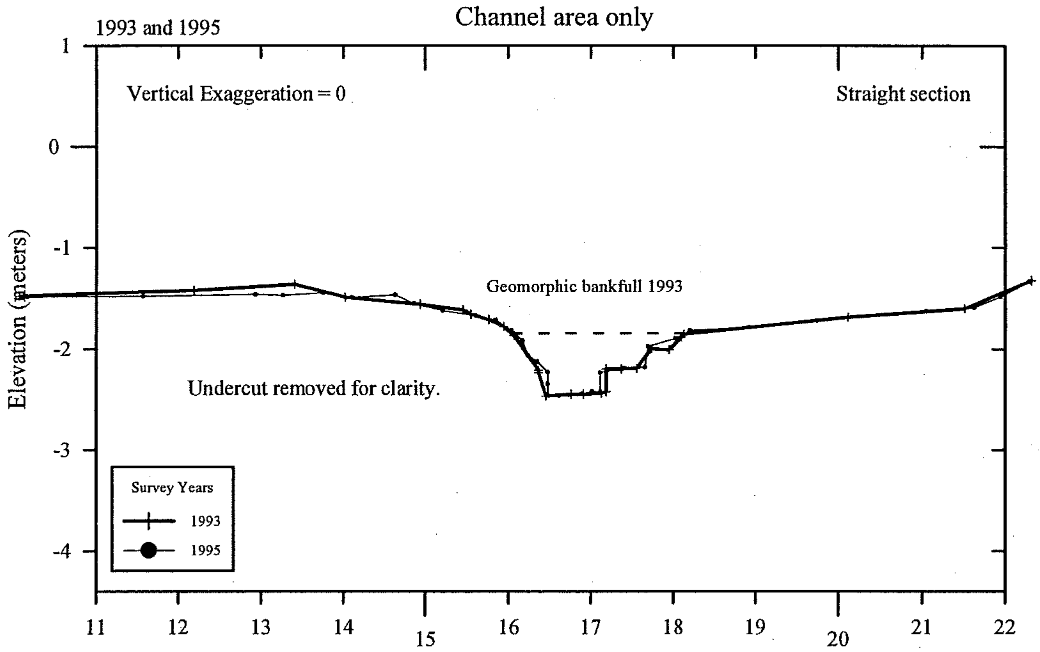
Muddy Creek cross-section 15 (continued)
Riparian Guidelines
1993, 1995, and 1998

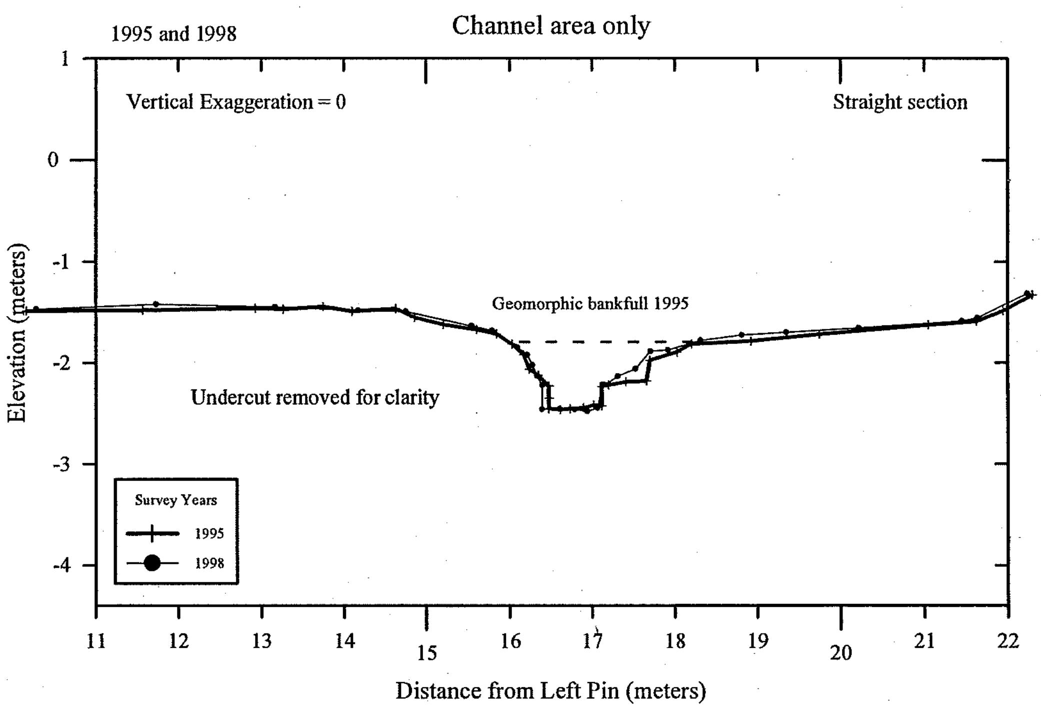




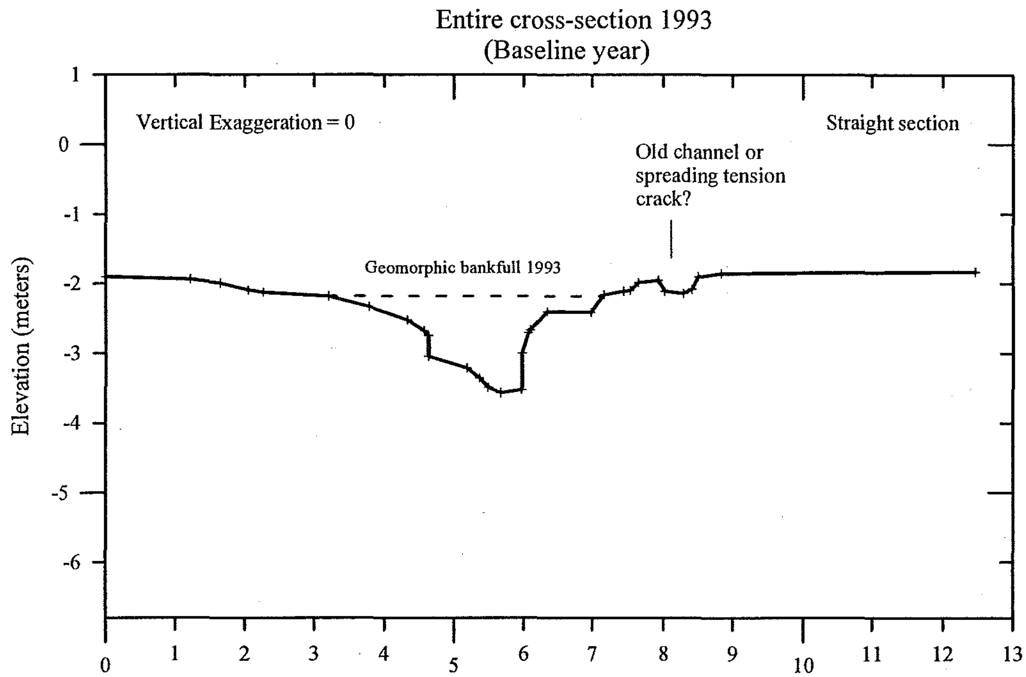
Muddy Creek cross-section 15 (continued)
Riparian Guidelines
1993, 1995, and 1998

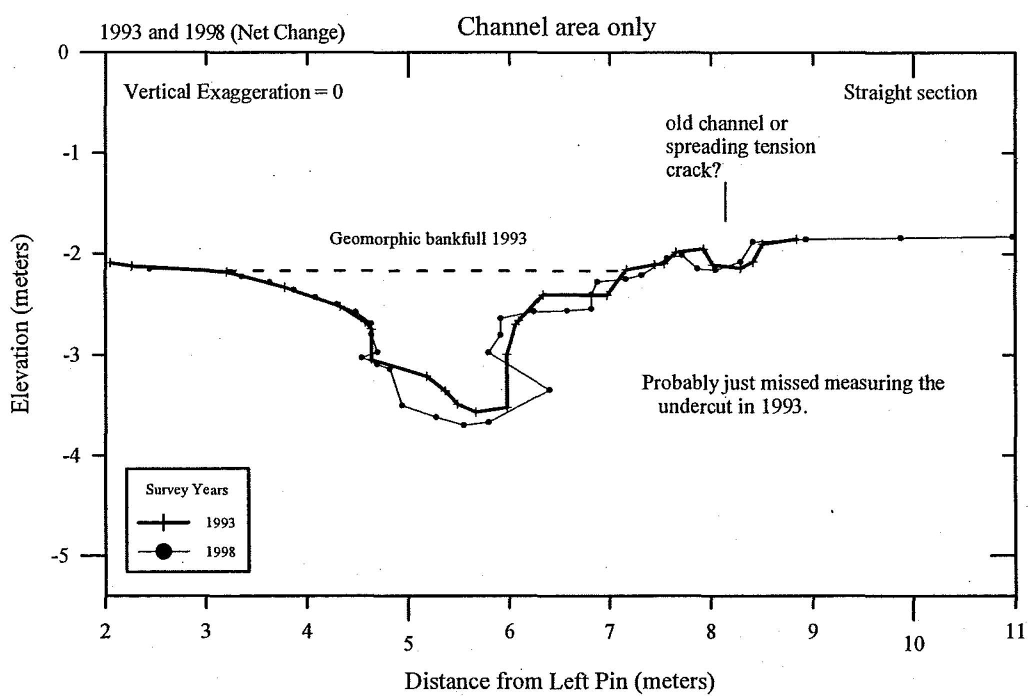
Undercut removed for clarity.



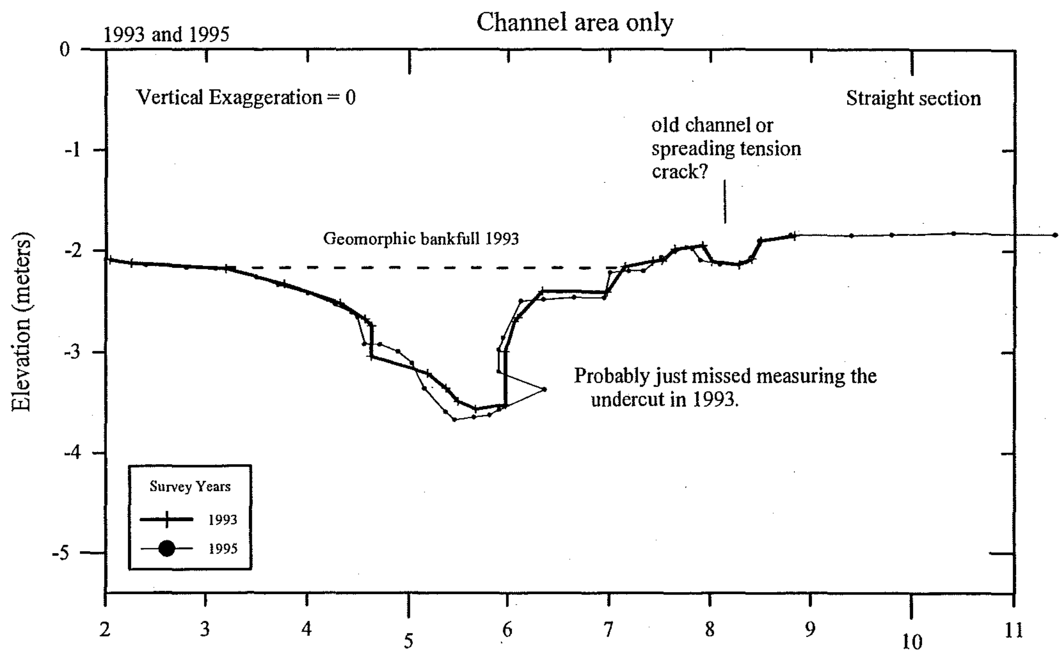


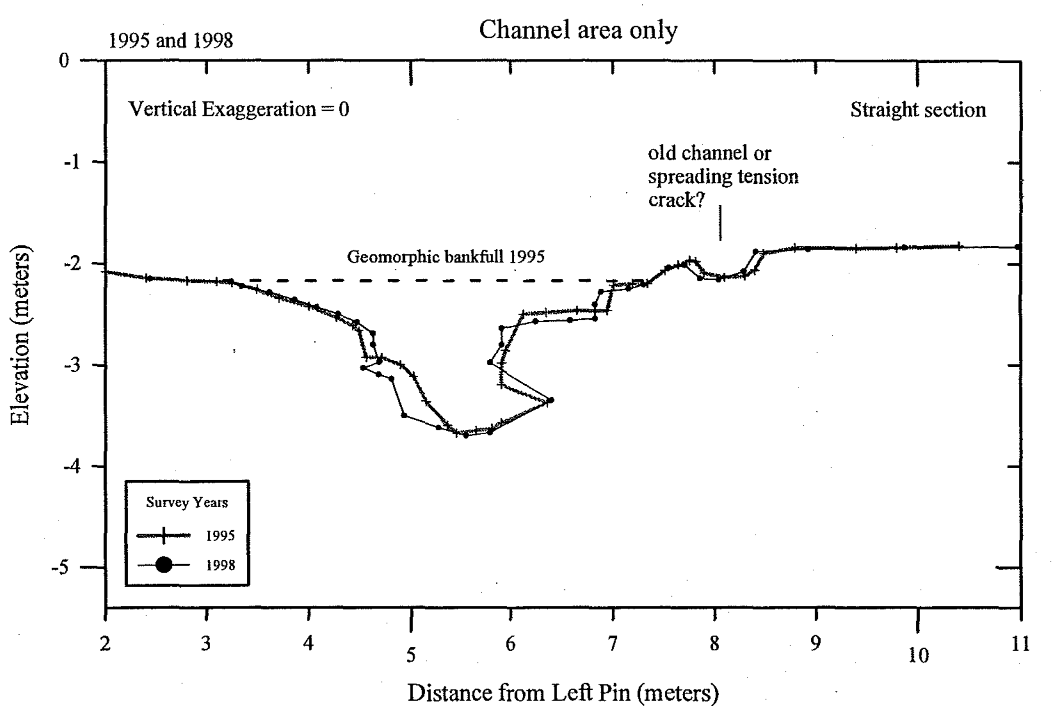
Muddy Creek cross-section 16
Riparian Guidelines
1993, 1995, and 1998





Muddy Creek cross-section 16 (continued)
Riparian Guidelines
1993, 1995, and 1998

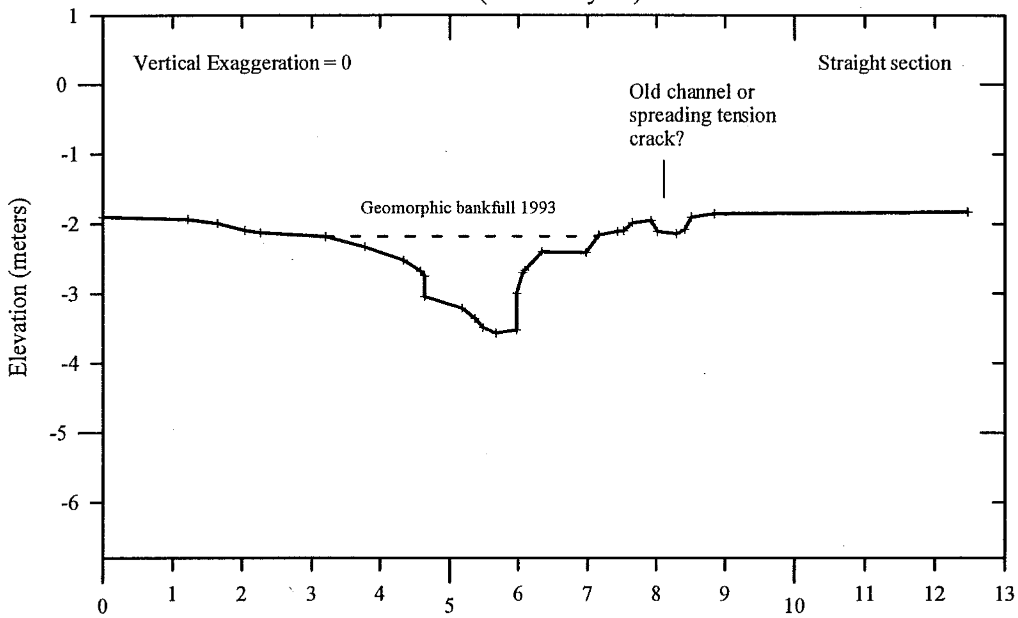




Muddy Creek cross-section 16 (continued)
Riparian Guidelines
1993, 1995, and 1998

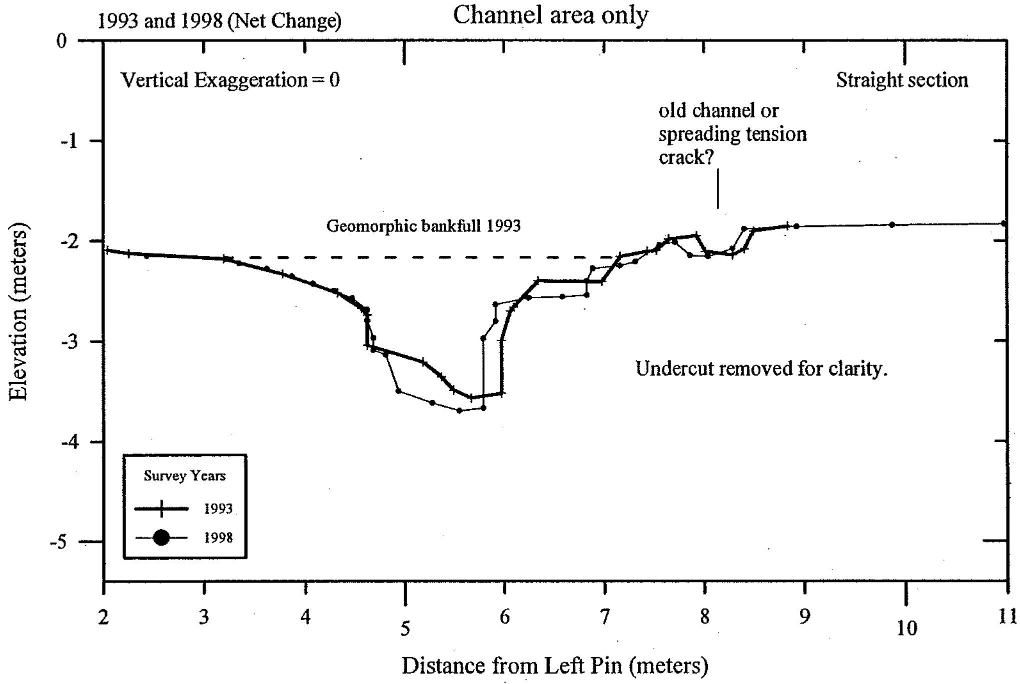
Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)



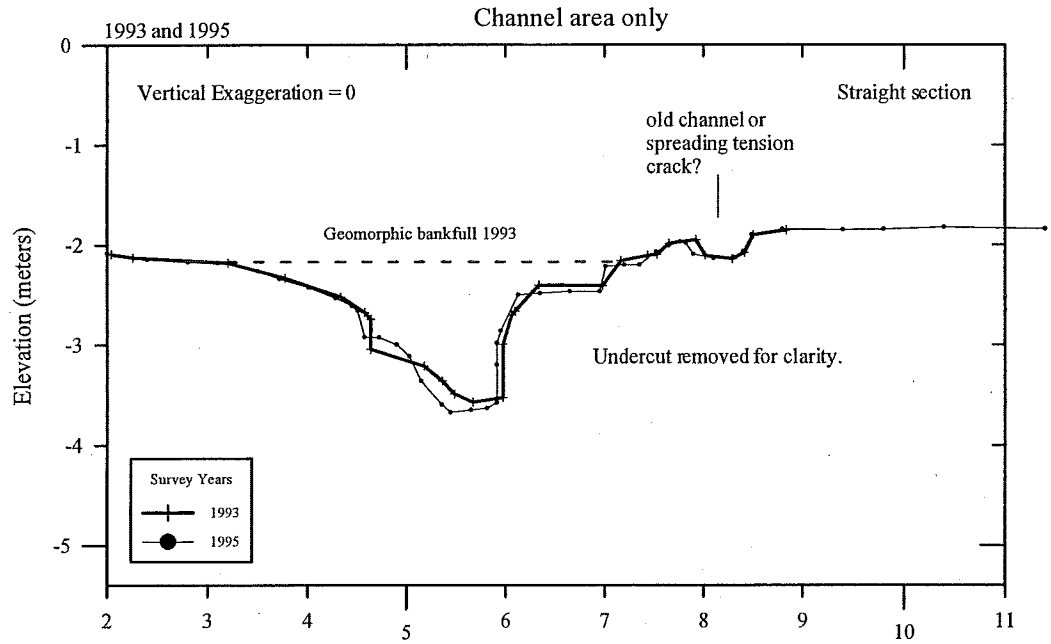
1993 and 1998 (Net Change)

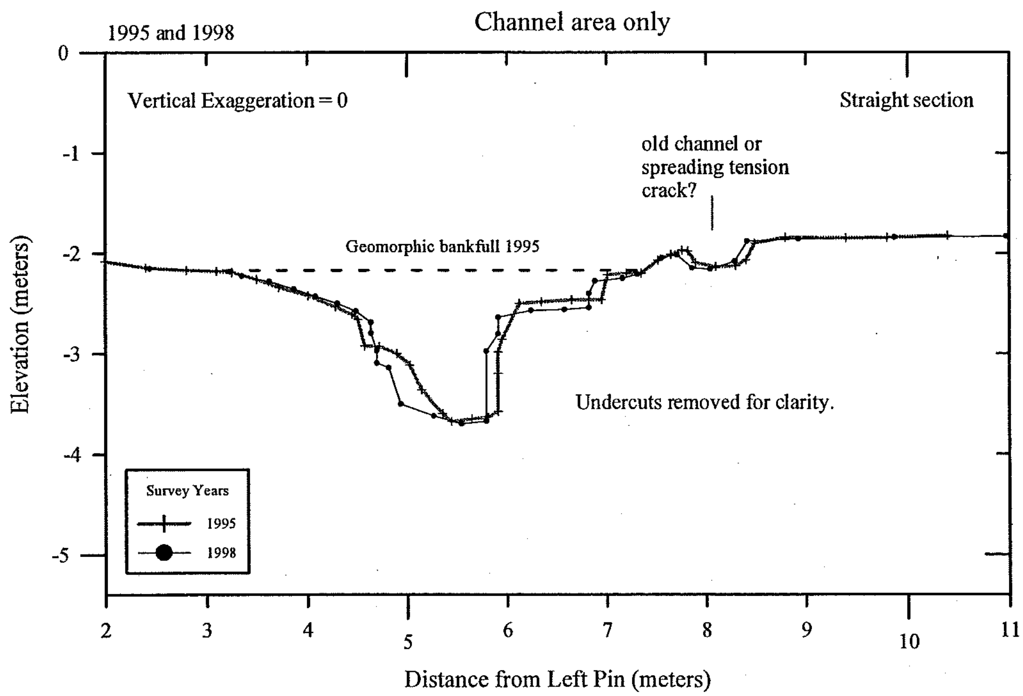
Channel area only



Muddy Creek cross-section 16 (continued)
Riparian Guidelines
1993, 1995, and 1998

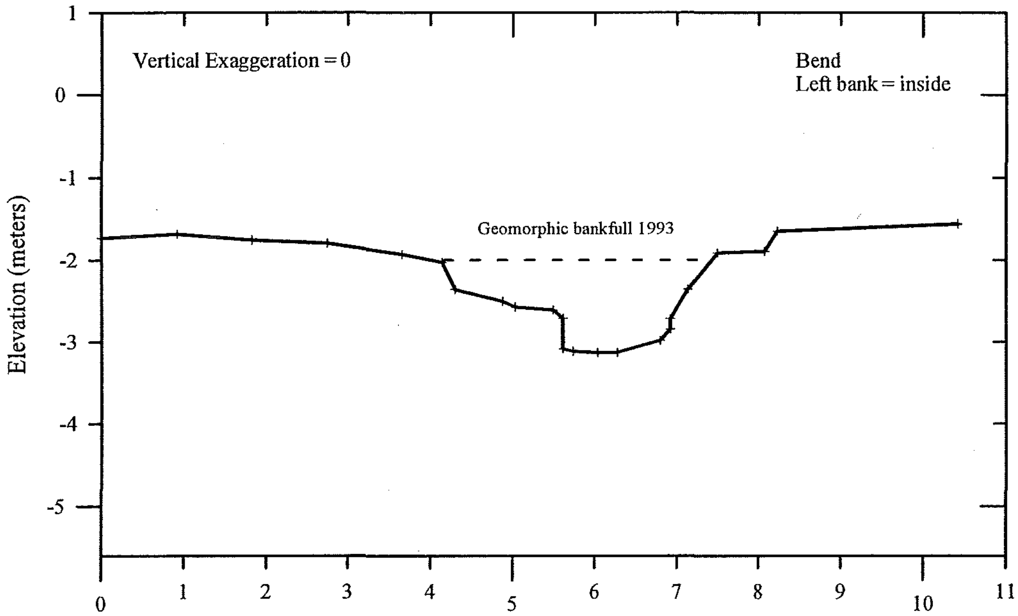
Undercuts removed for clarity.



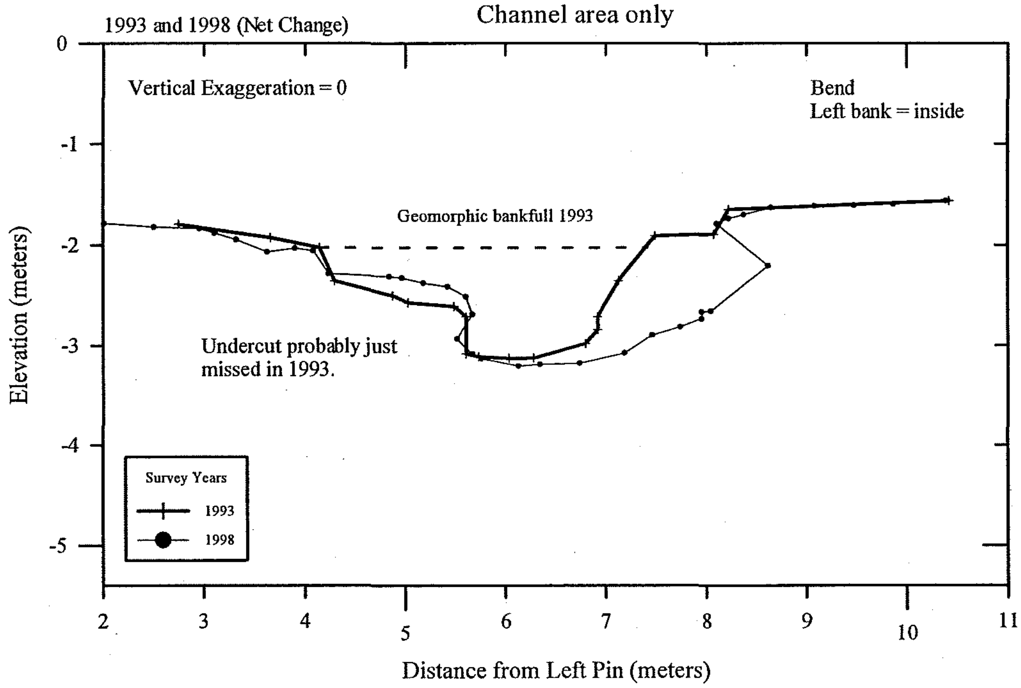


Muddy Creek cross-section 17
Riparian Guidelines
1993, 1995, and 1998

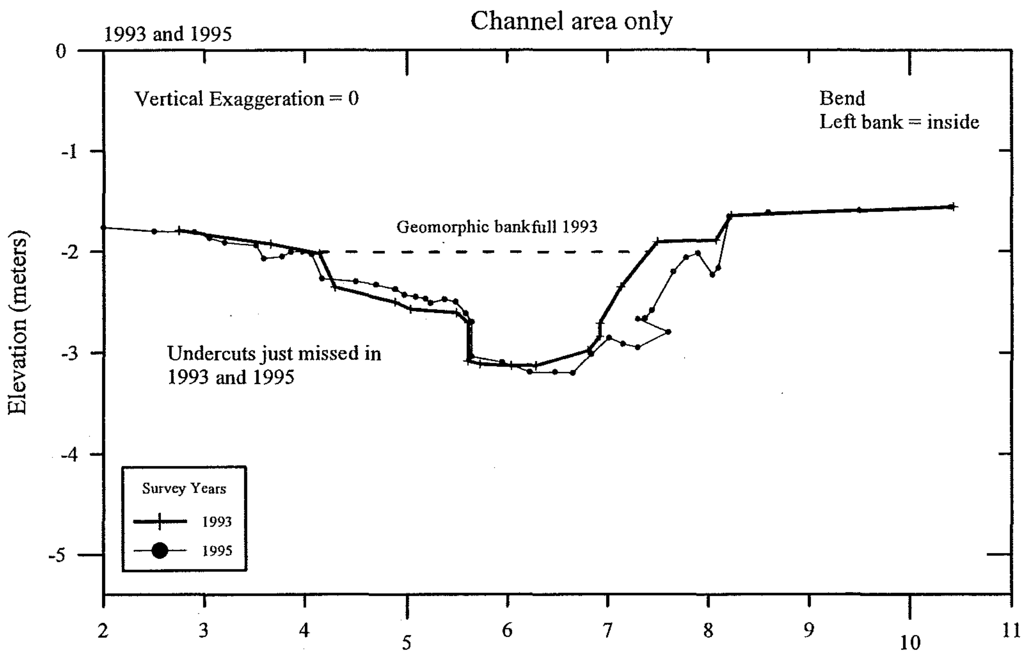
Entire cross-section 1993
(Baseline year)

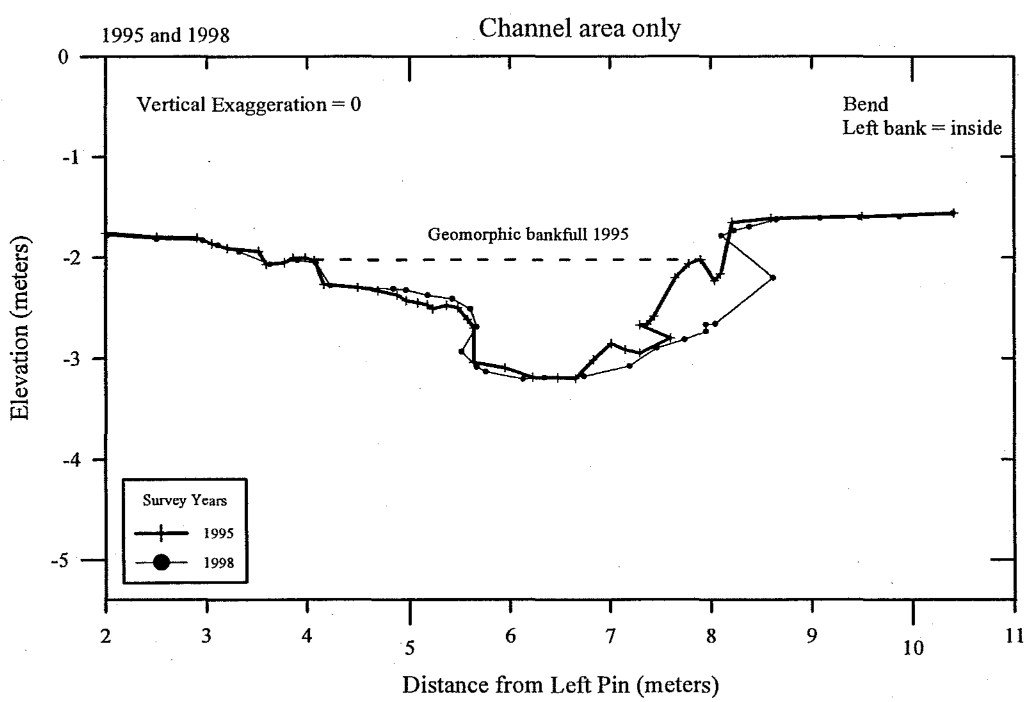


Channel area only



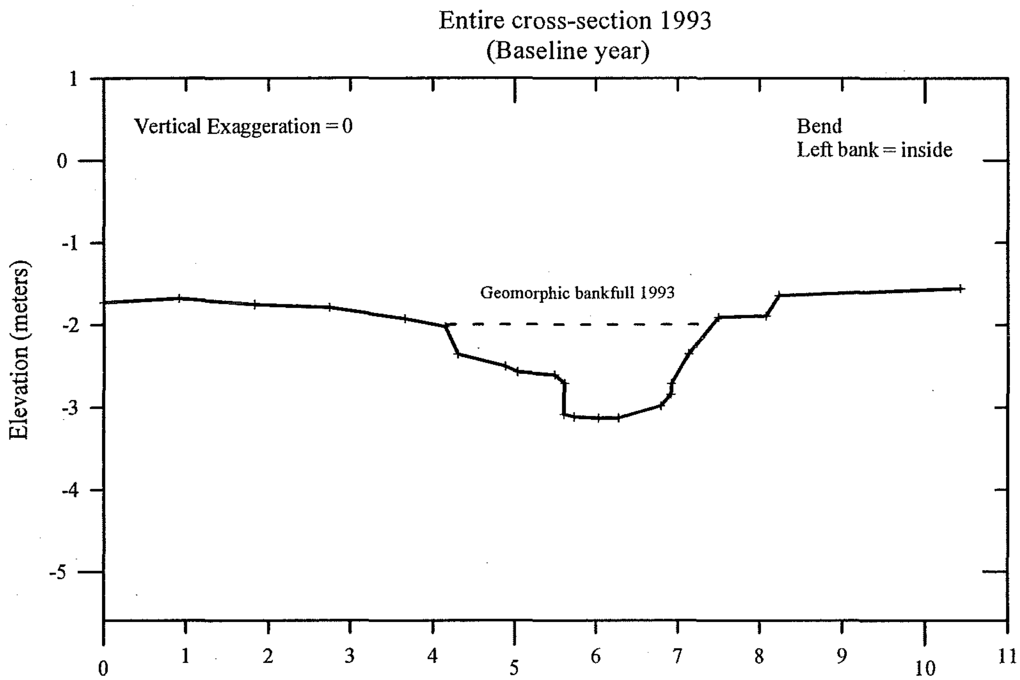
Muddy Creek cross-section 17 (continued)
Riparian Guidelines
1993, 1995, and 1998

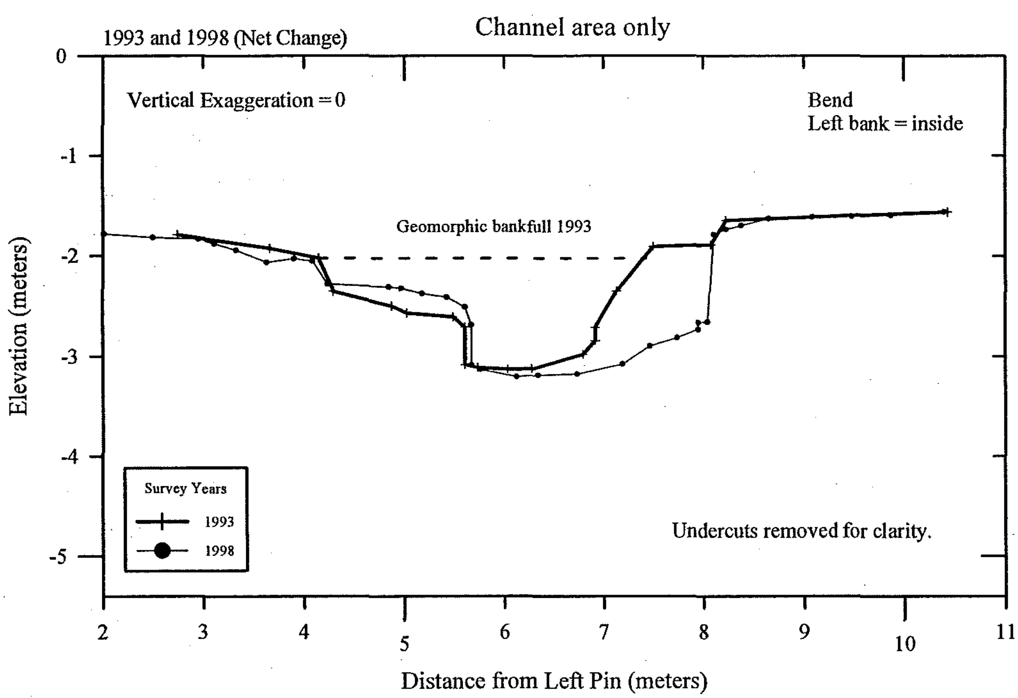




Muddy Creek cross-section 17 (continued)
Riparian Guidelines
1993, 1995, and 1998

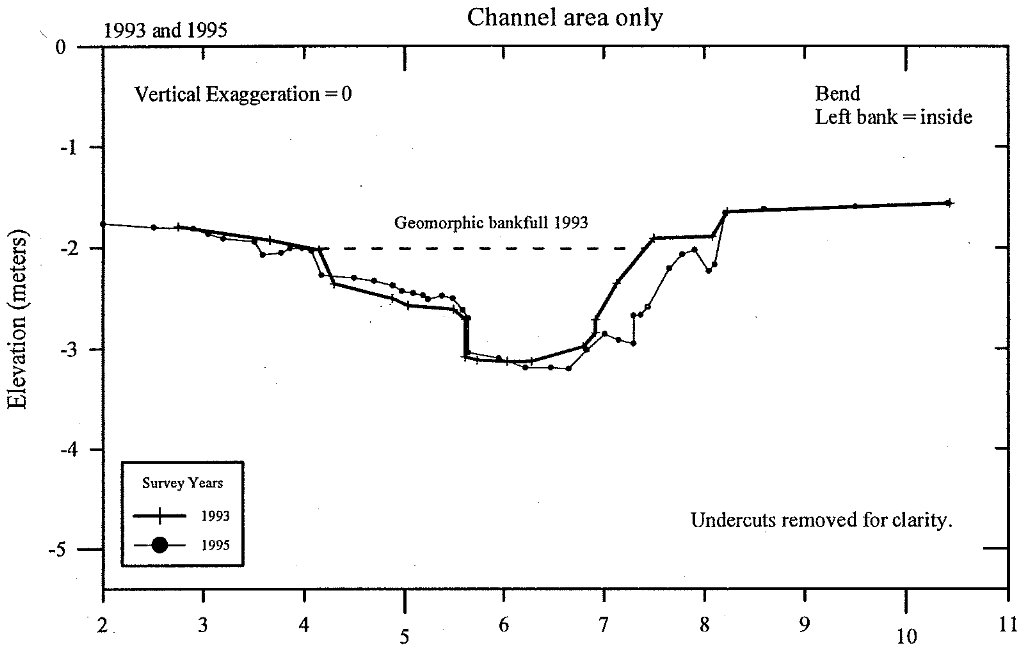
Undercuts removed for clarity.

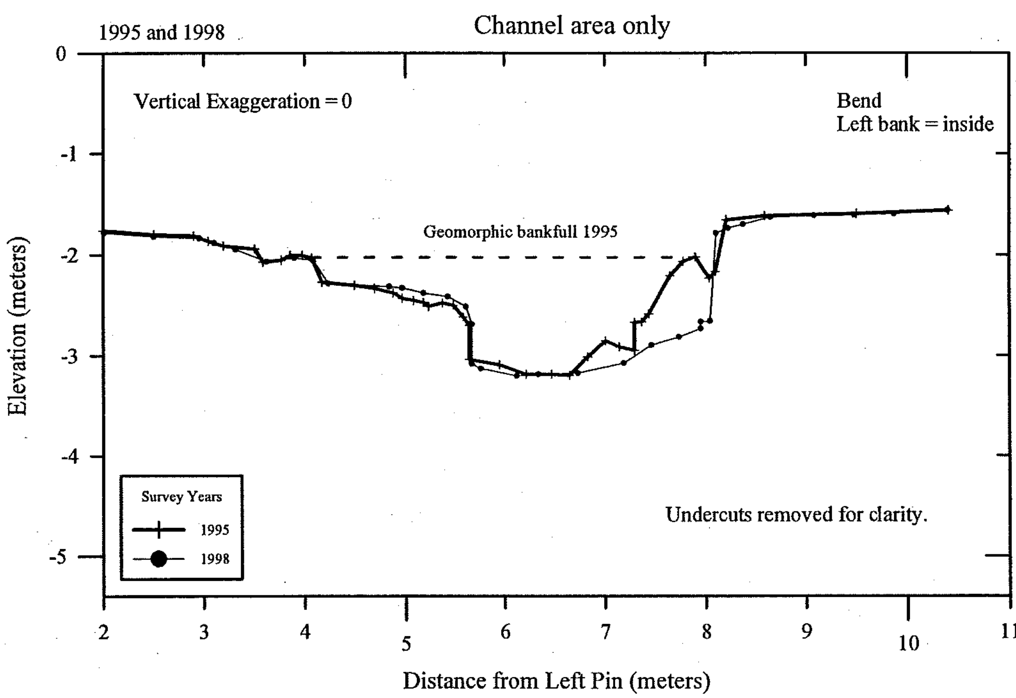




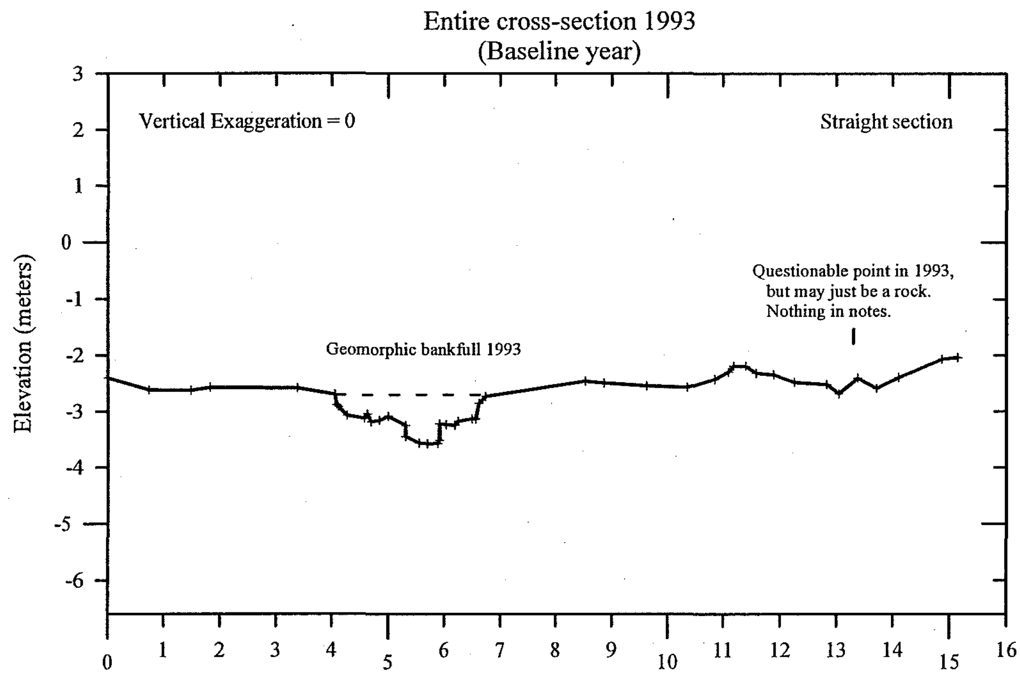
Muddy Creek cross-section 17 (continued)
Riparian Guidelines
1993, 1995, and 1998

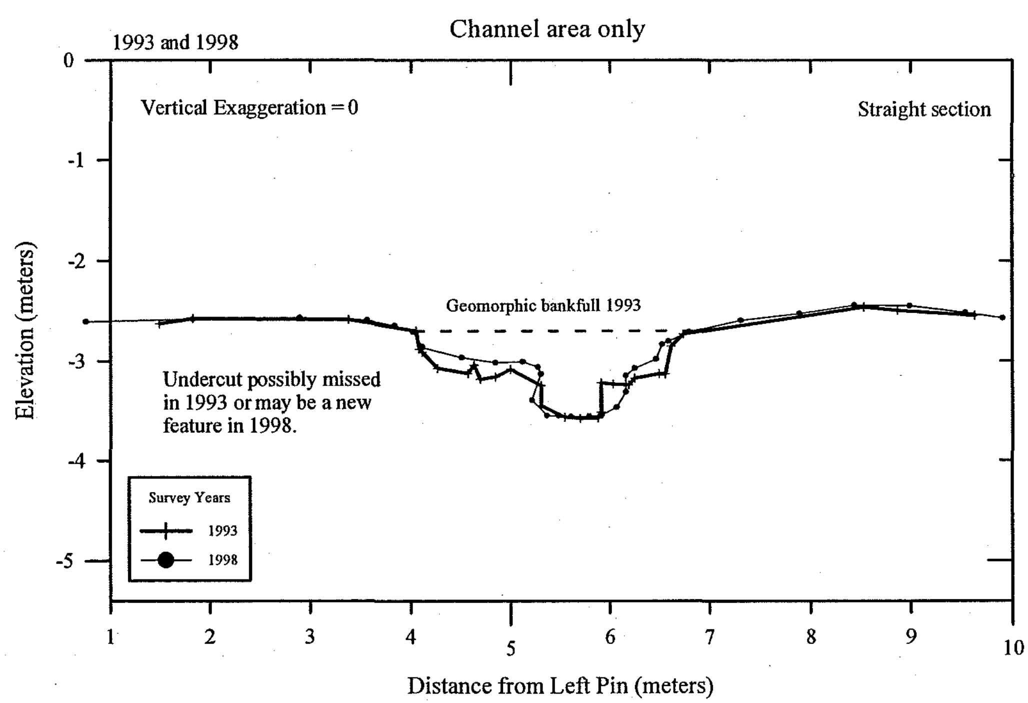
Undercuts removed for clarity.





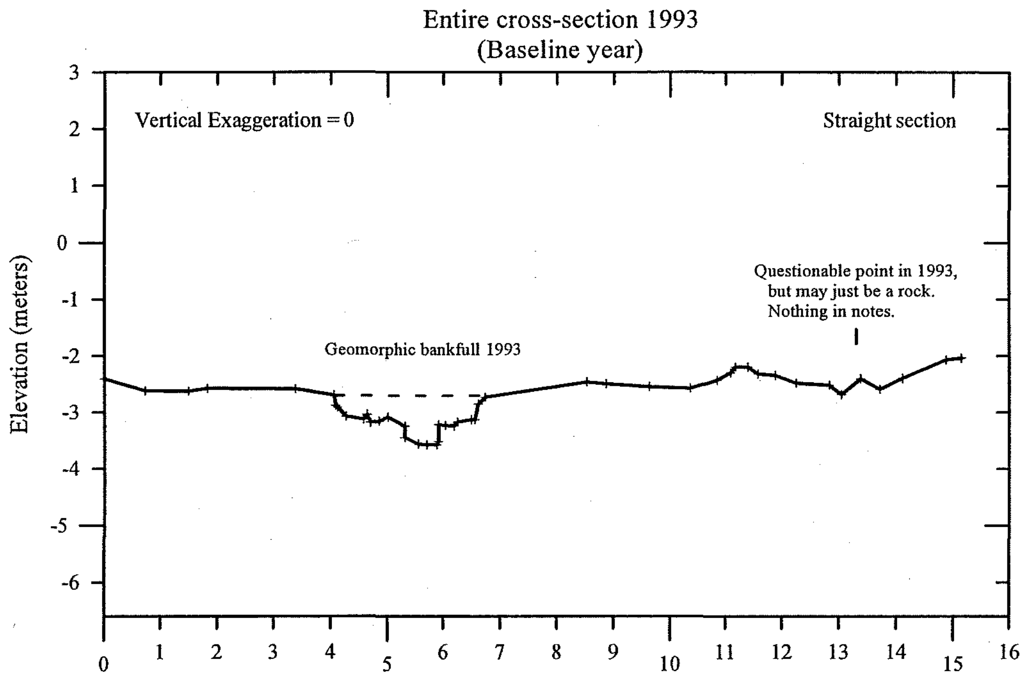
Muddy Creek cross-section 18
Riparian Guidelines
1993 and 1998

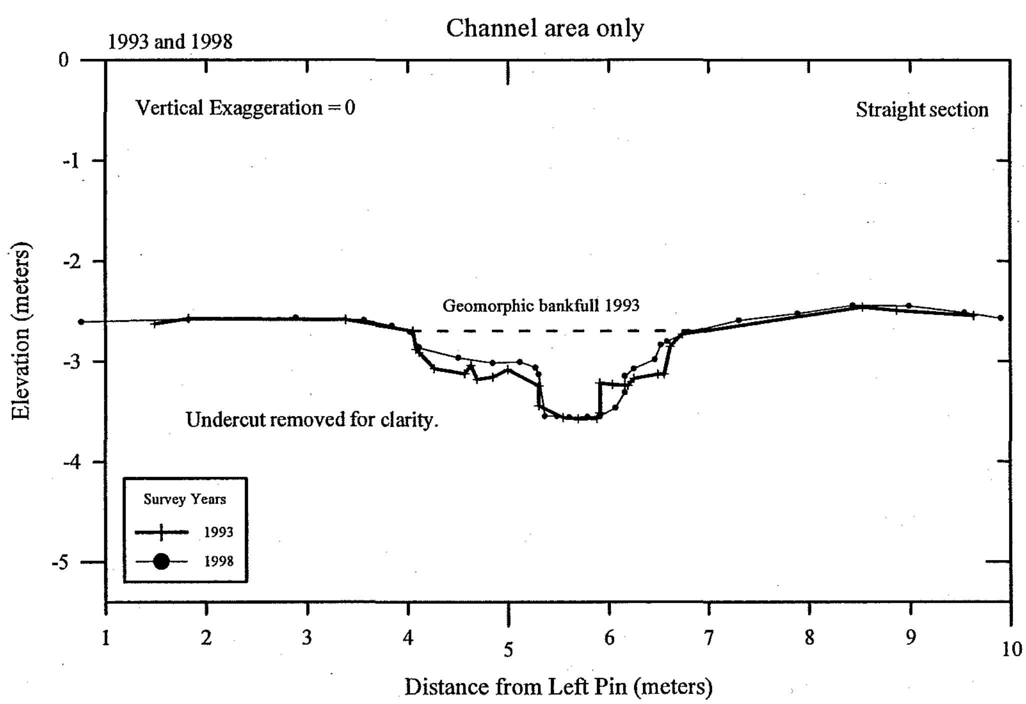




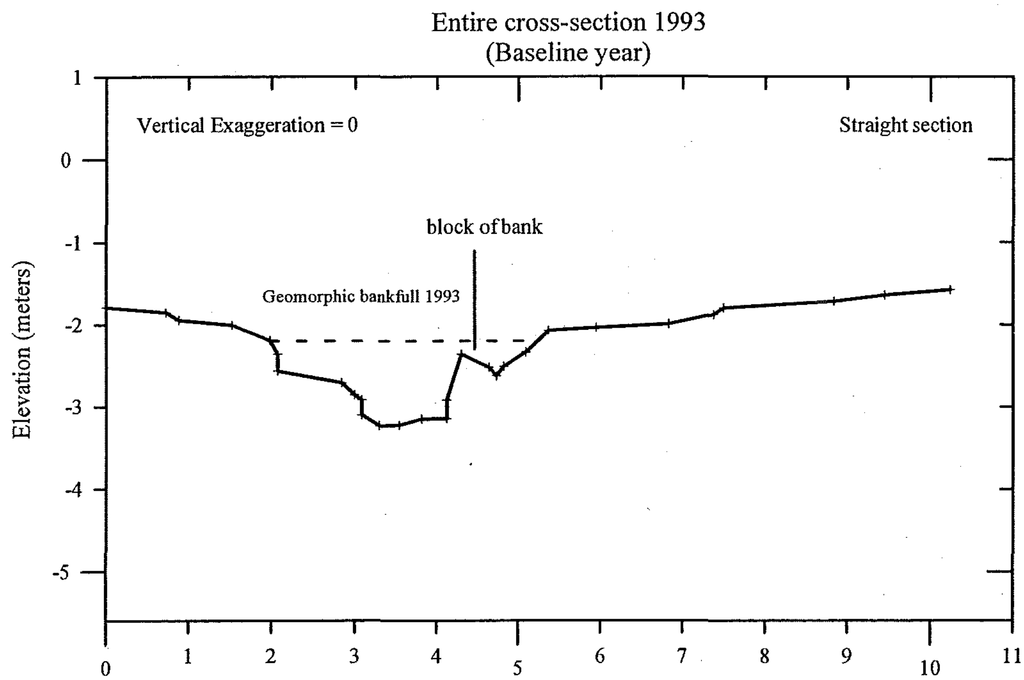
Muddy Creek cross-section 18 (continued)
Riparian Guidelines
1993 and 1998

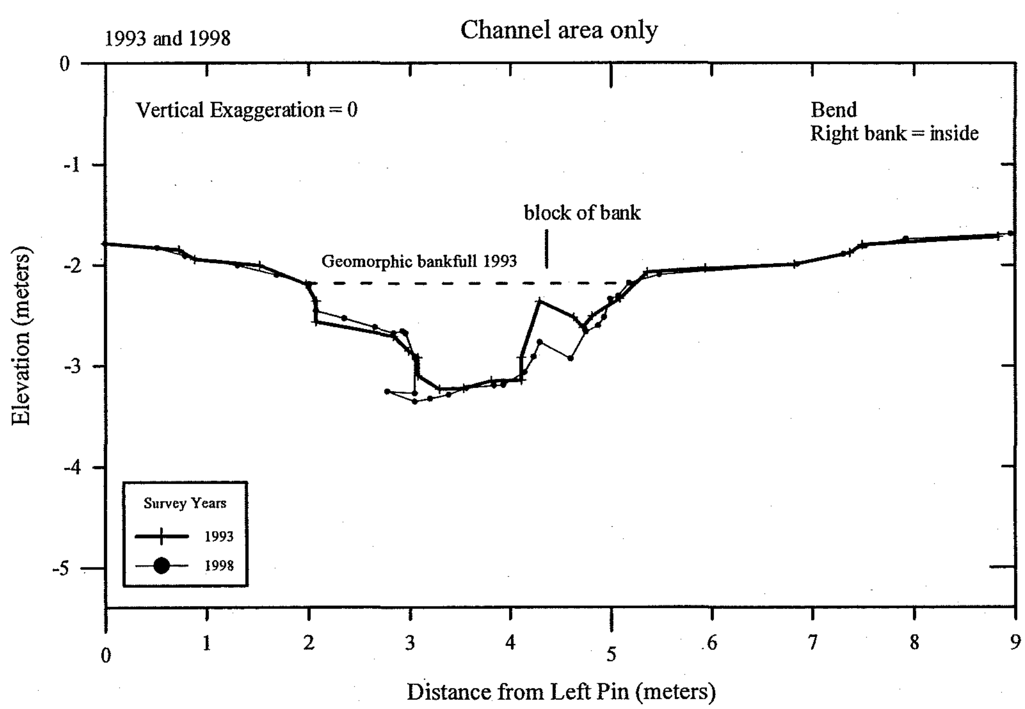
Undercut removed for clarity.





Muddy Creek cross-section 19
Riparian Guidelines
1993 and 1998

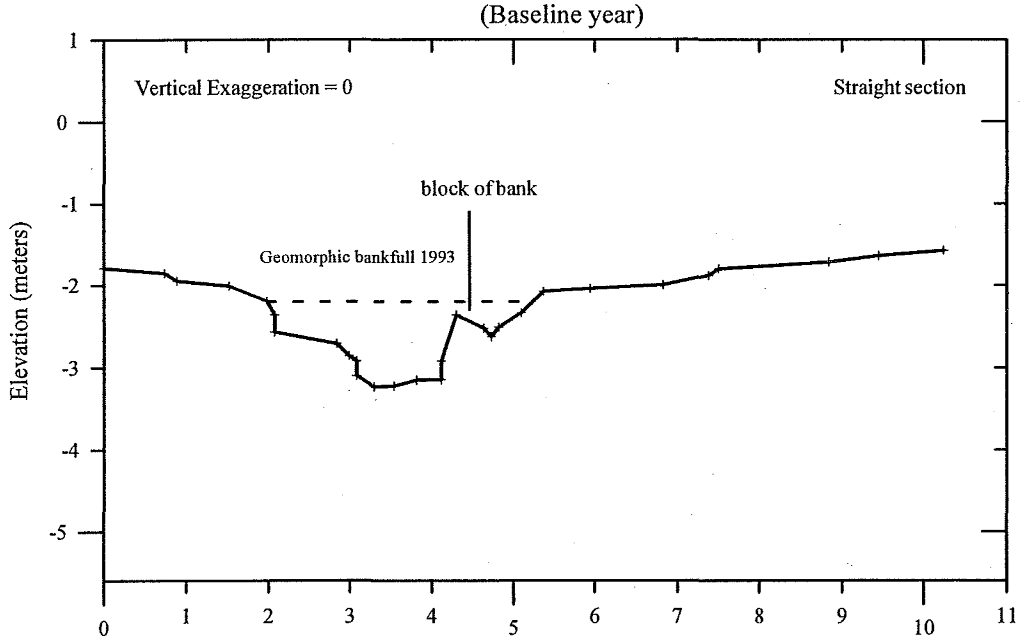




Muddy Creek cross-section 19 (continued)
Riparian Guidelines
1993 and 1998

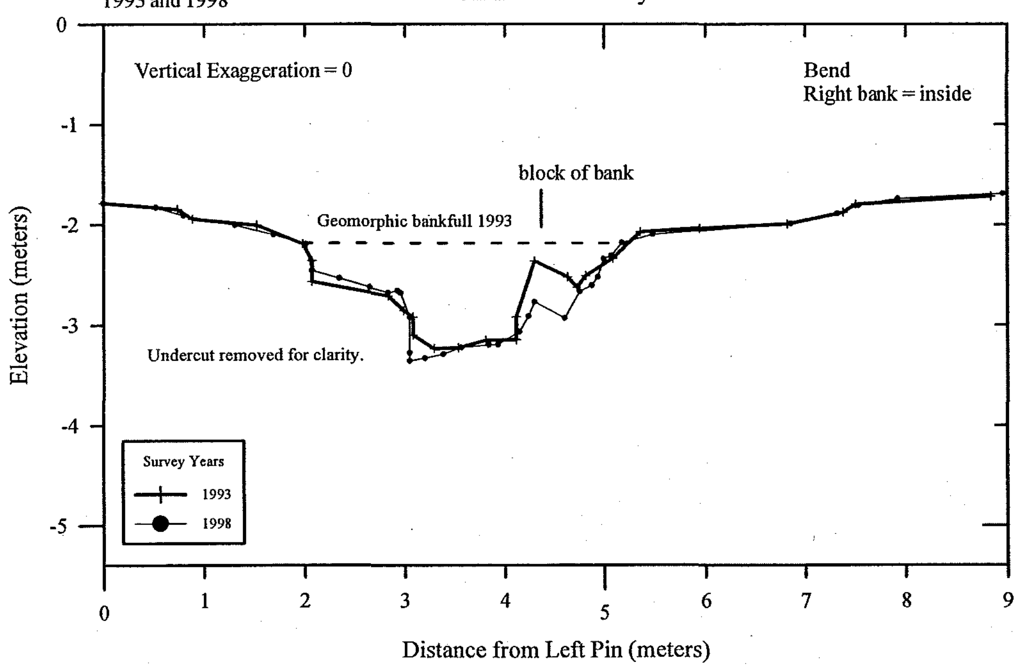
Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)



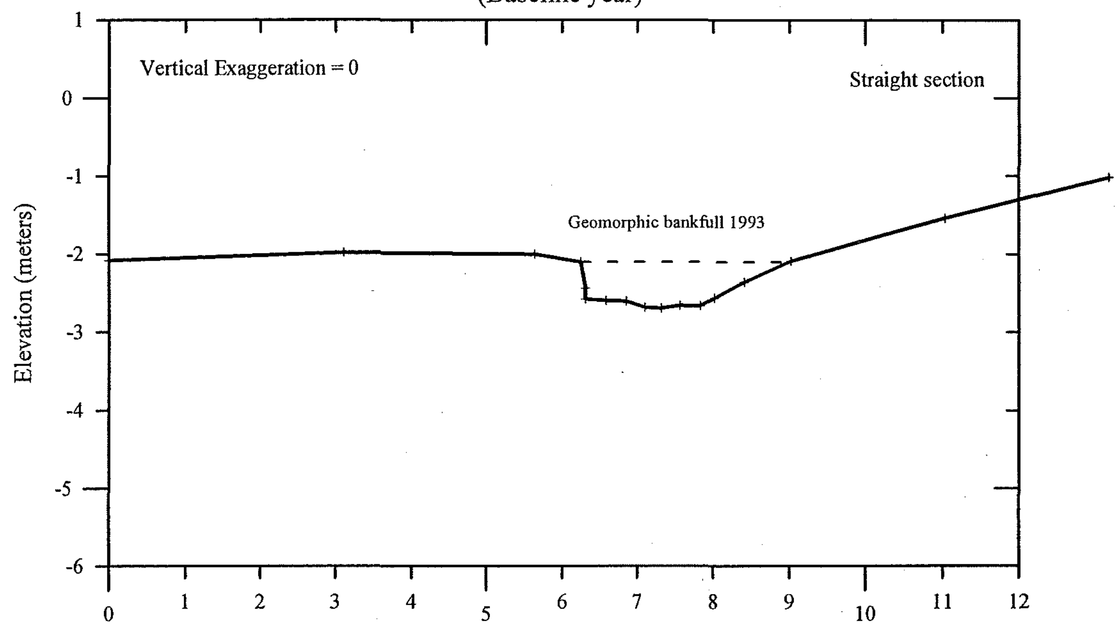
1993 and 1998

Channel area only



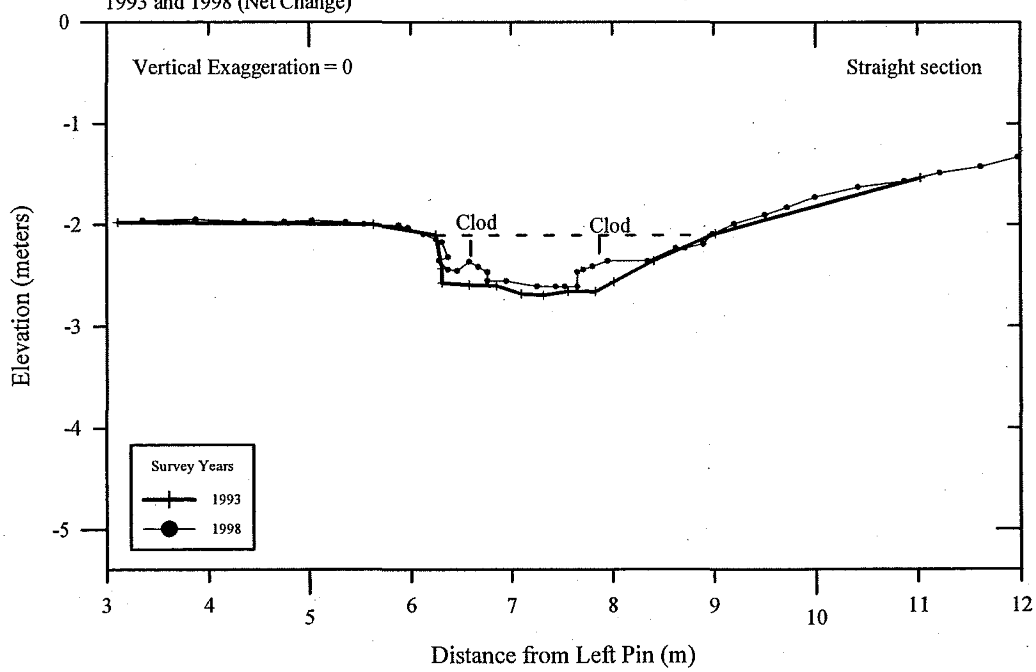
Muddy Creek cross-section 22
New Cattle Exclosure
1993, 1995, and 1998

Entire cross-section 1993
(Baseline year)

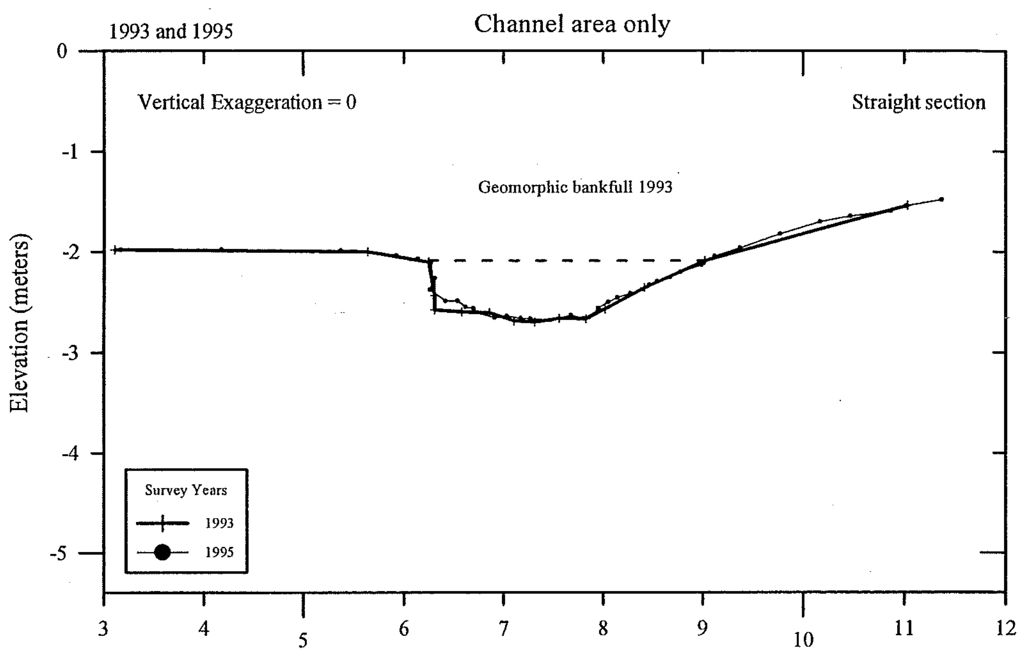


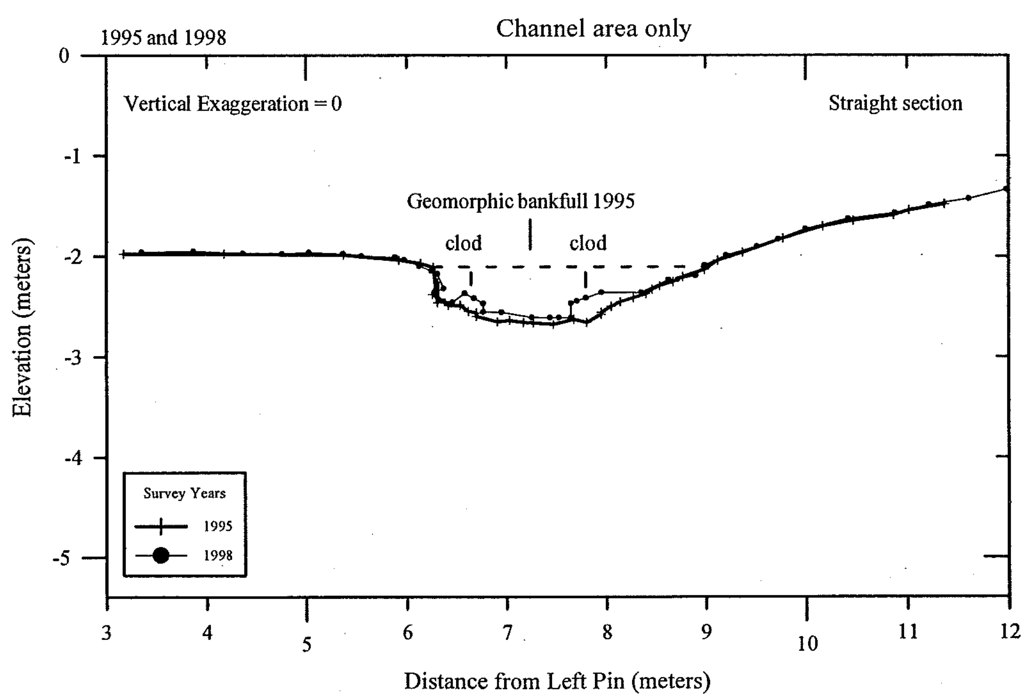
Channel area only

1993 and 1998 (Net Change)



Muddy Creek cross-section 22 (continued)
New Cattle Exclosure
1993, 1995, and 1998

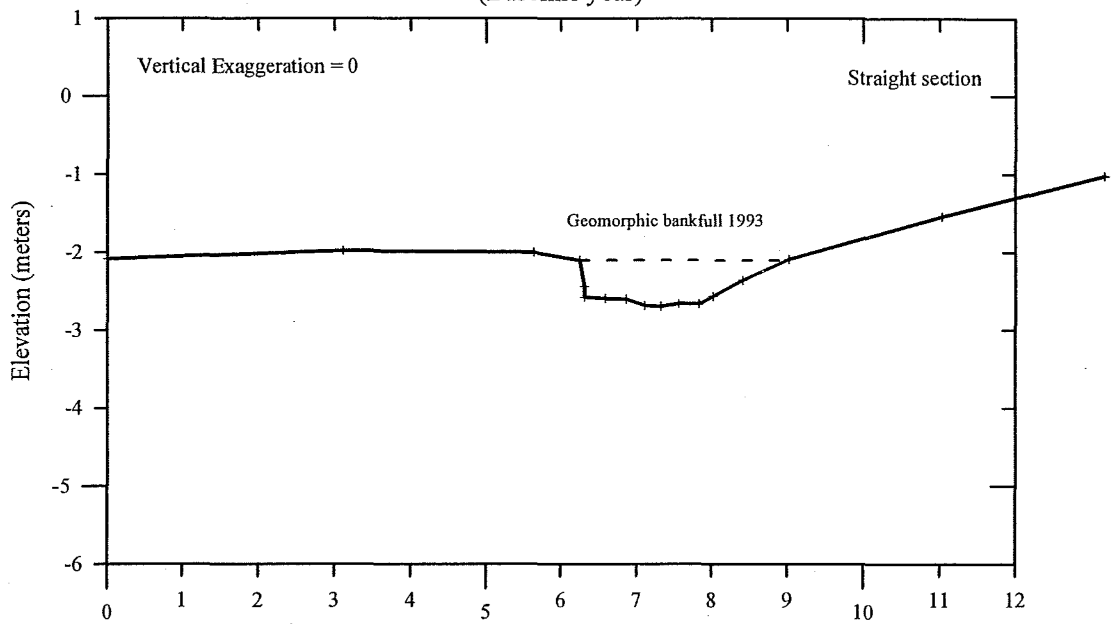




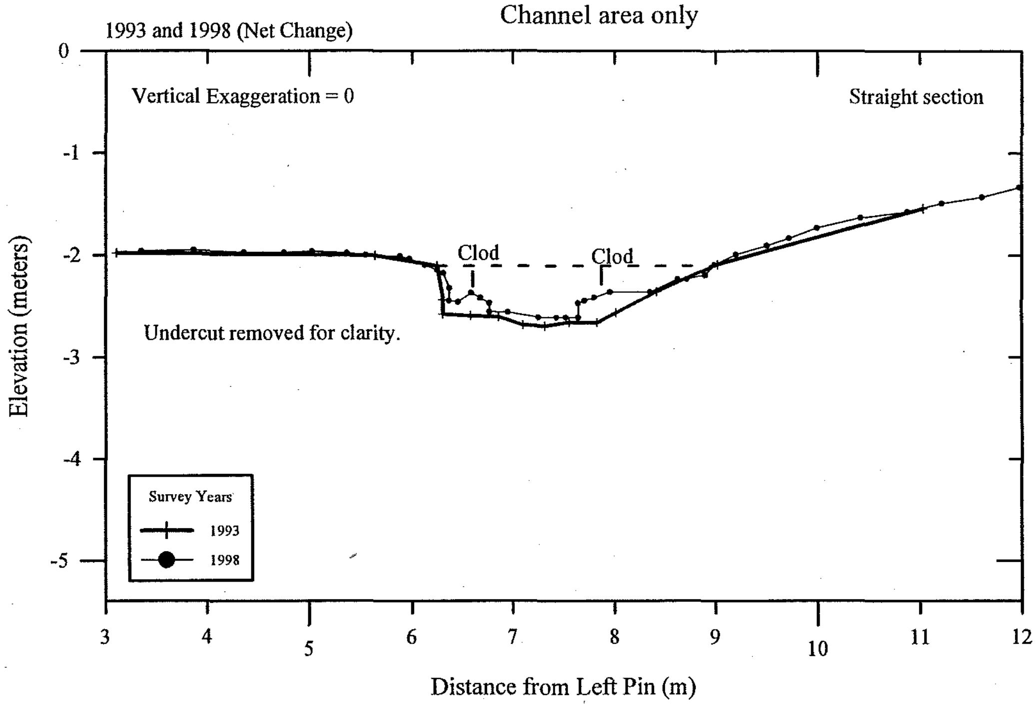
Muddy Creek cross-section 22 (continued)
New Cattle Exclosure
1993, 1995, and 1998

Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)

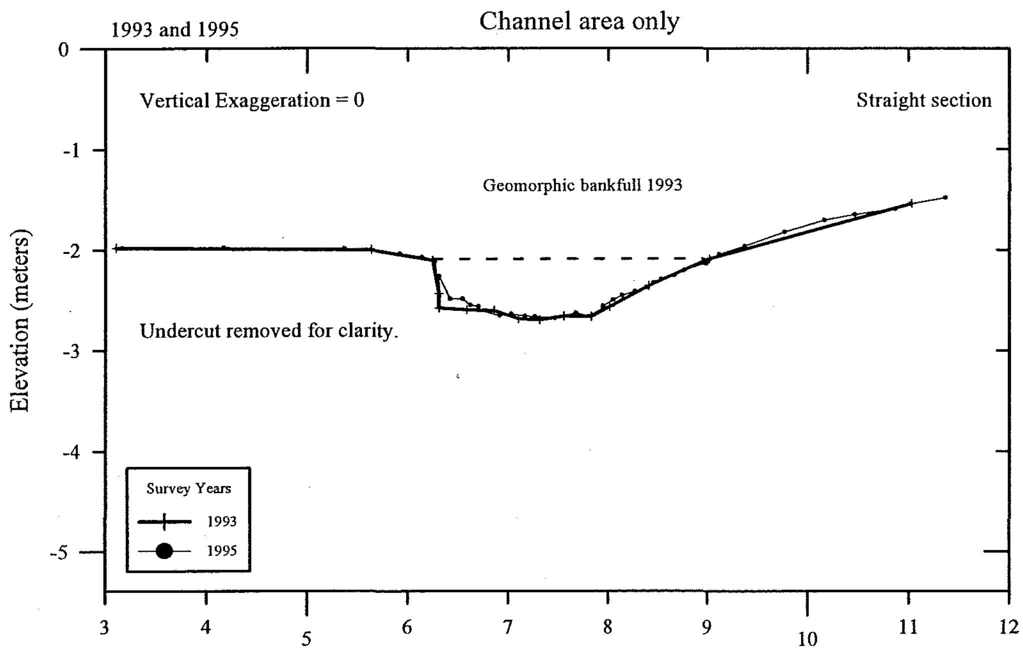


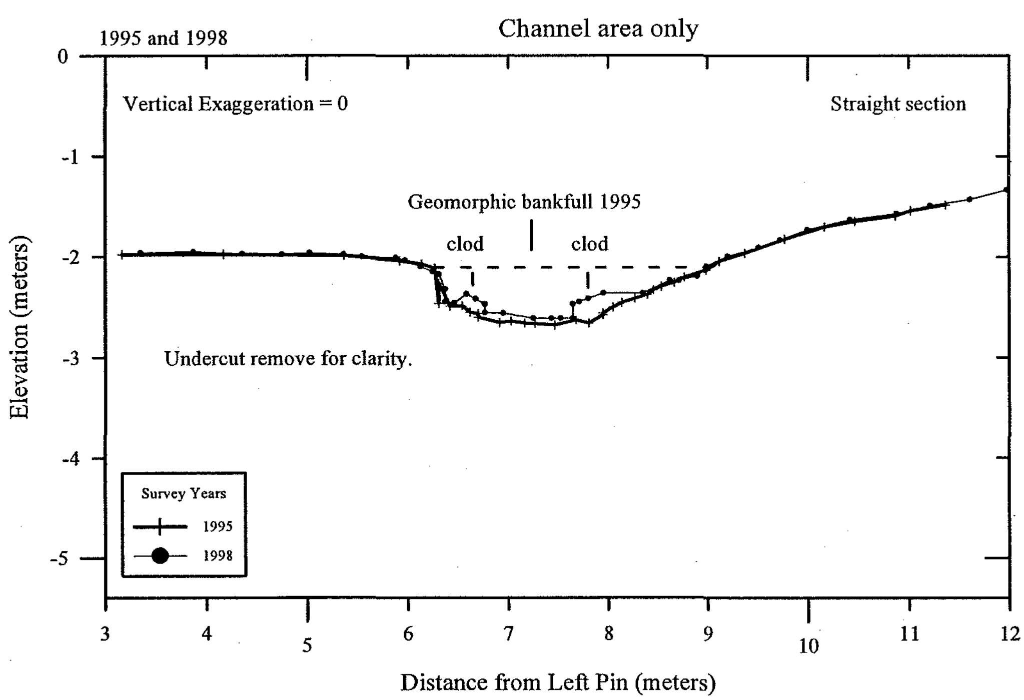
Channel area only



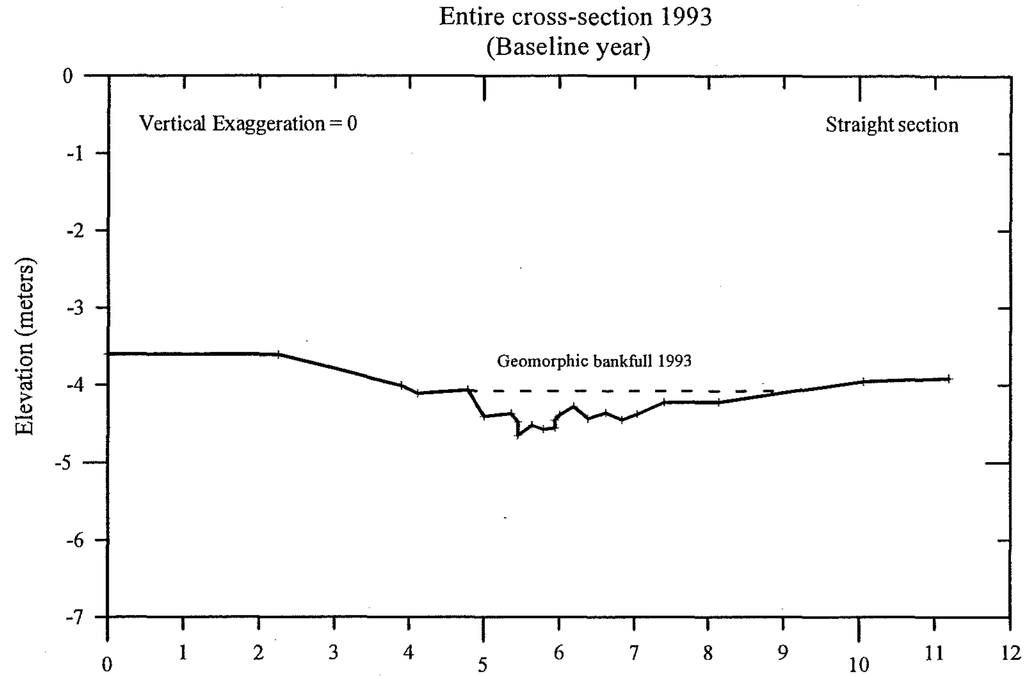
Muddy Creek cross-section 22 (continued)
New Cattle Exclosure
1993, 1995, and 1998

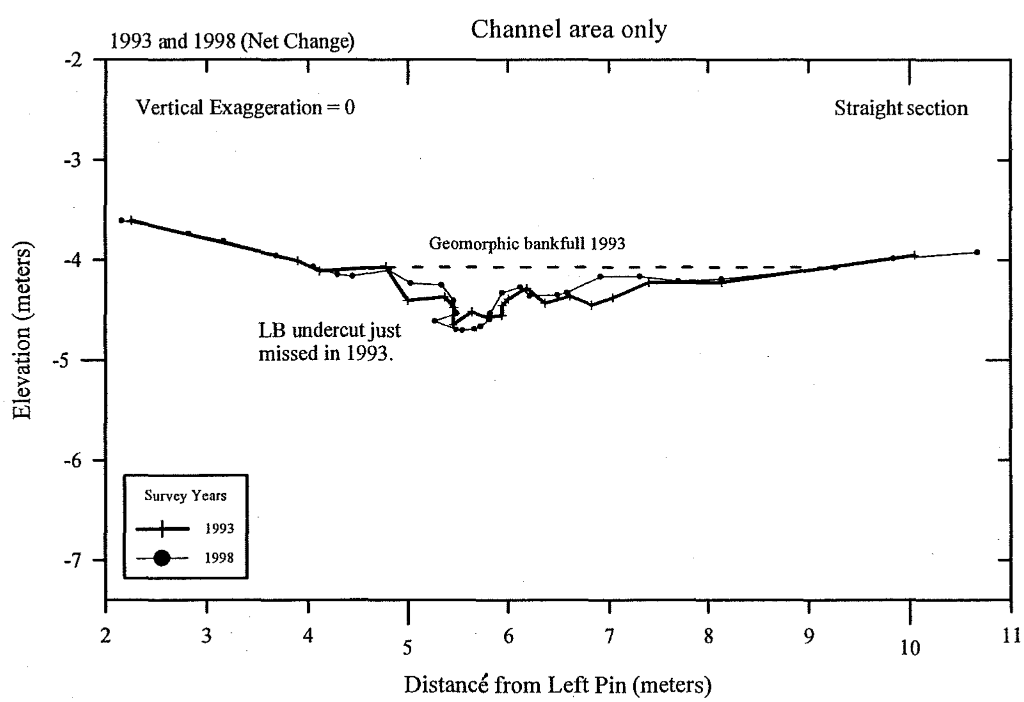
Undercut removed for clarity,



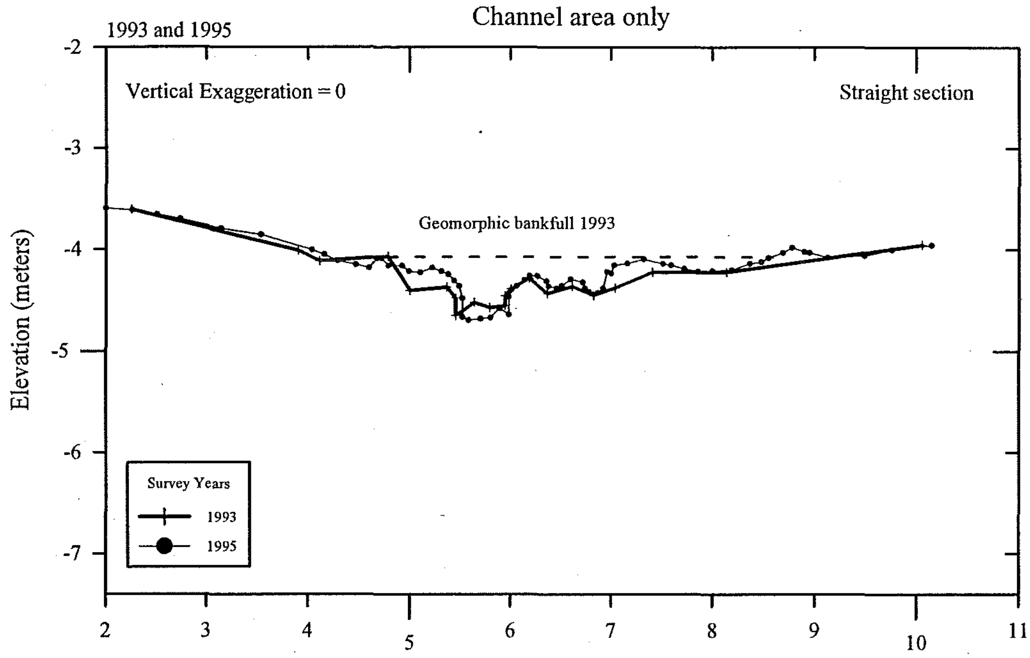


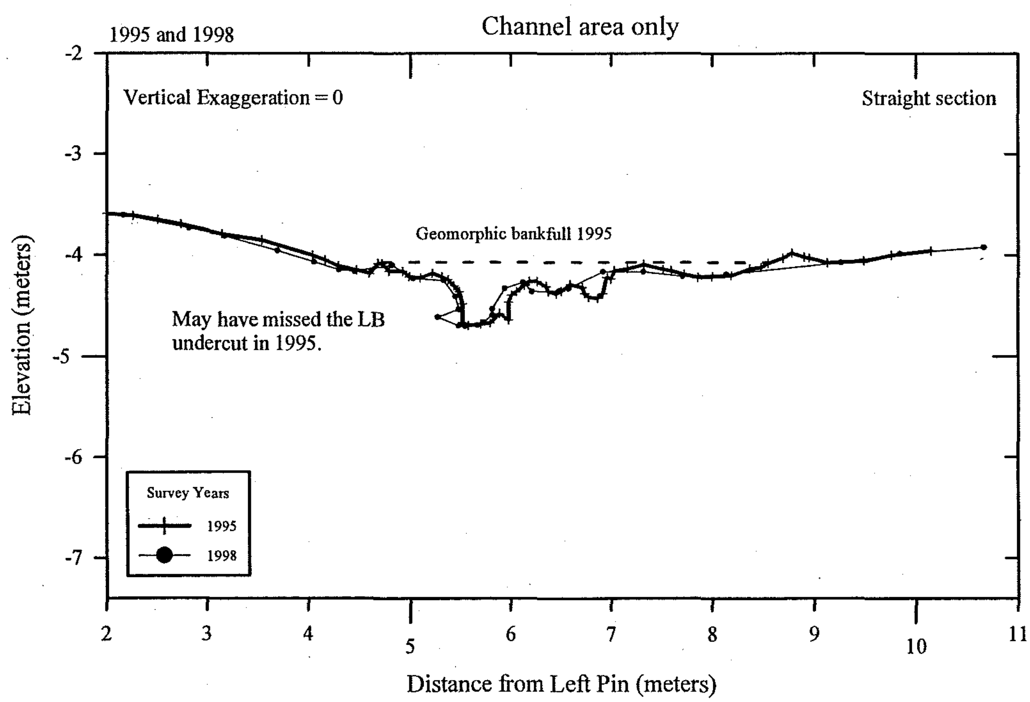
Muddy Creek cross-section 23
New Cattle Exclosure
1993, 1995, and 1998





Muddy Creek cross-section 23 (continued)
New Cattle Exclosure
1993, 1995, and 1998

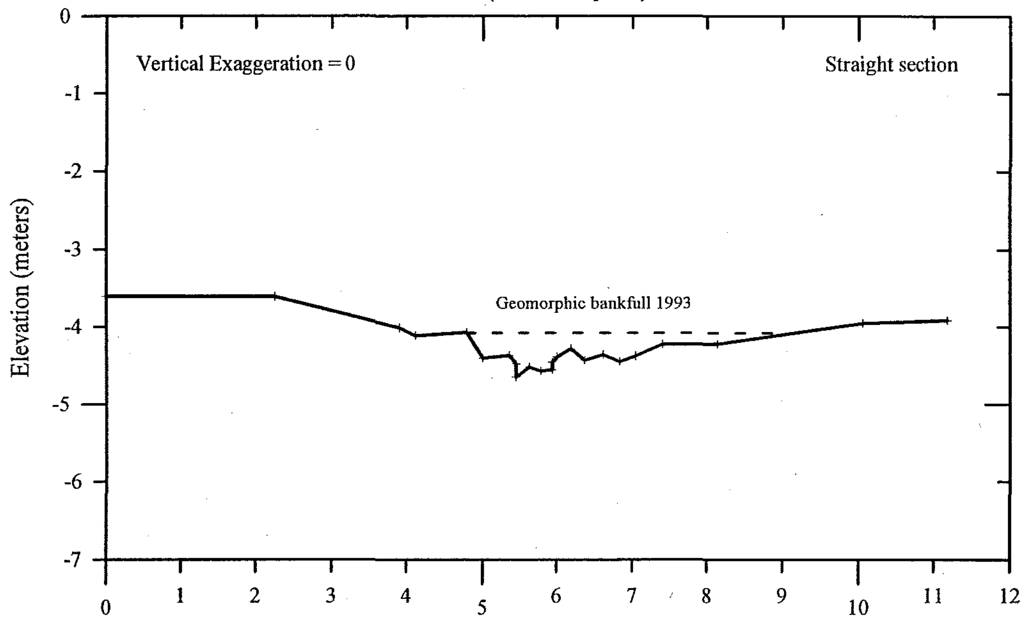




Muddy Creek cross-section 23 (continued)
New Cattle Exclosure
1993, 1995, and 1998

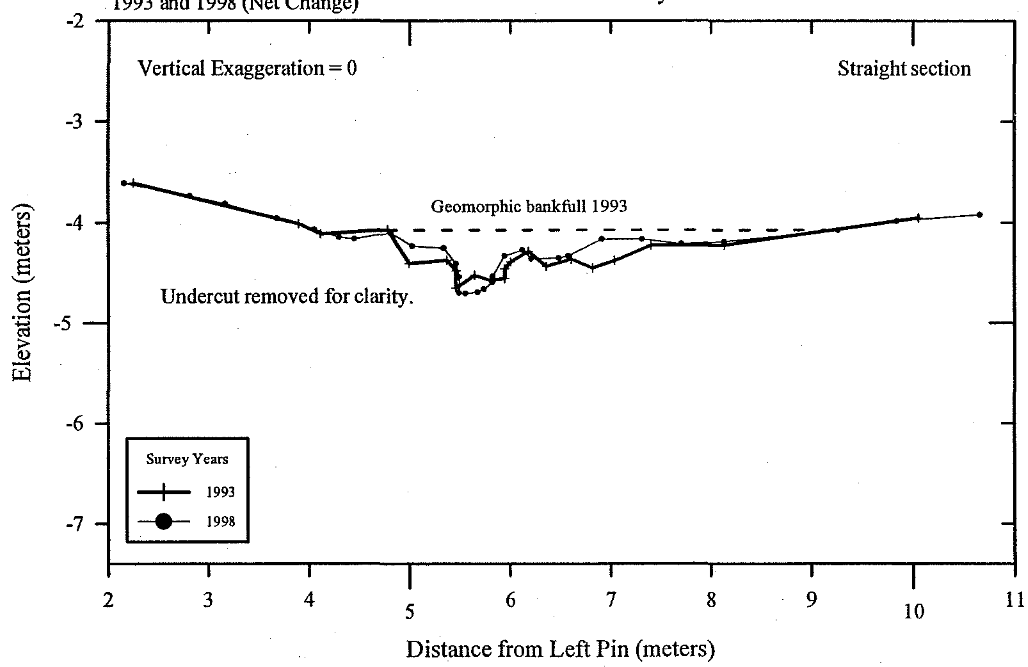
Undercut removed for clarity.

Entire cross-section 1993
(Baseline year)



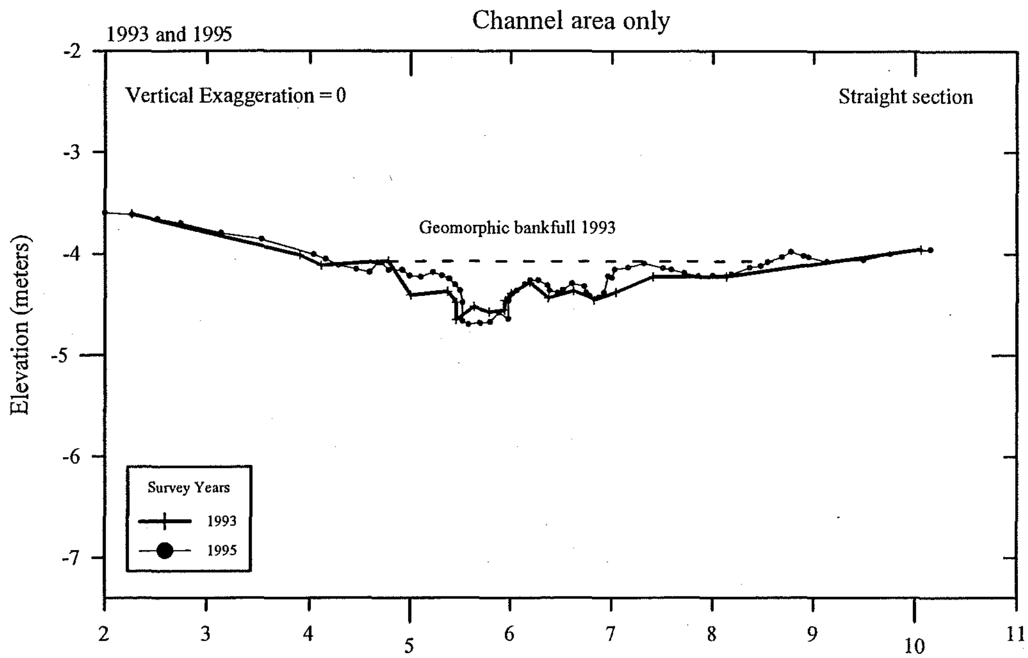
1993 and 1998 (Net Change)

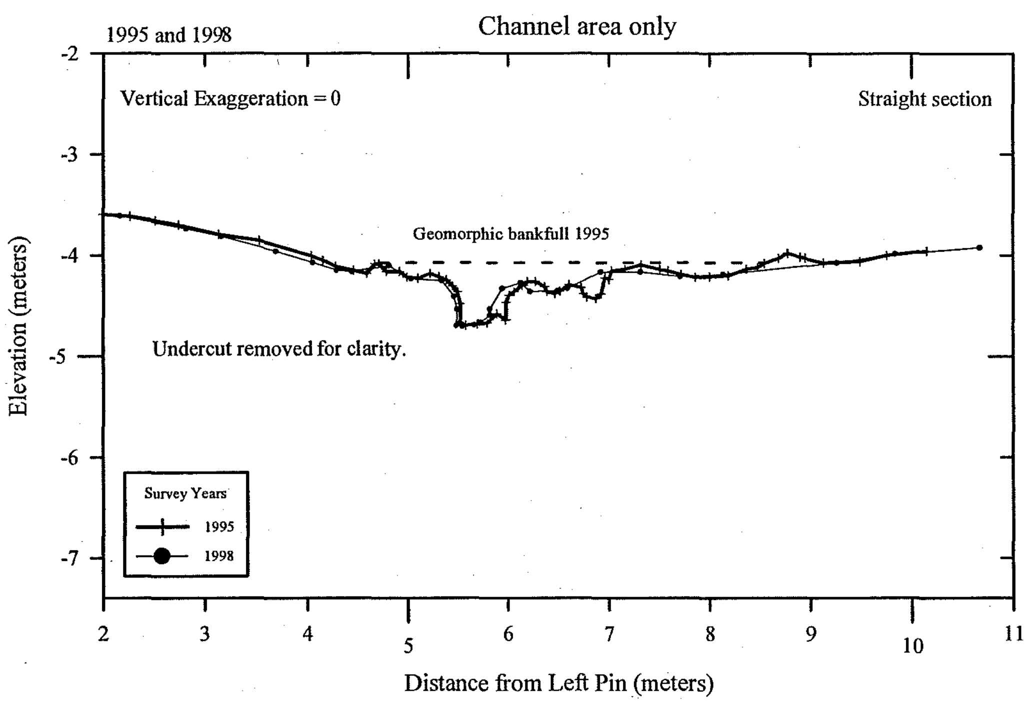
Channel area only



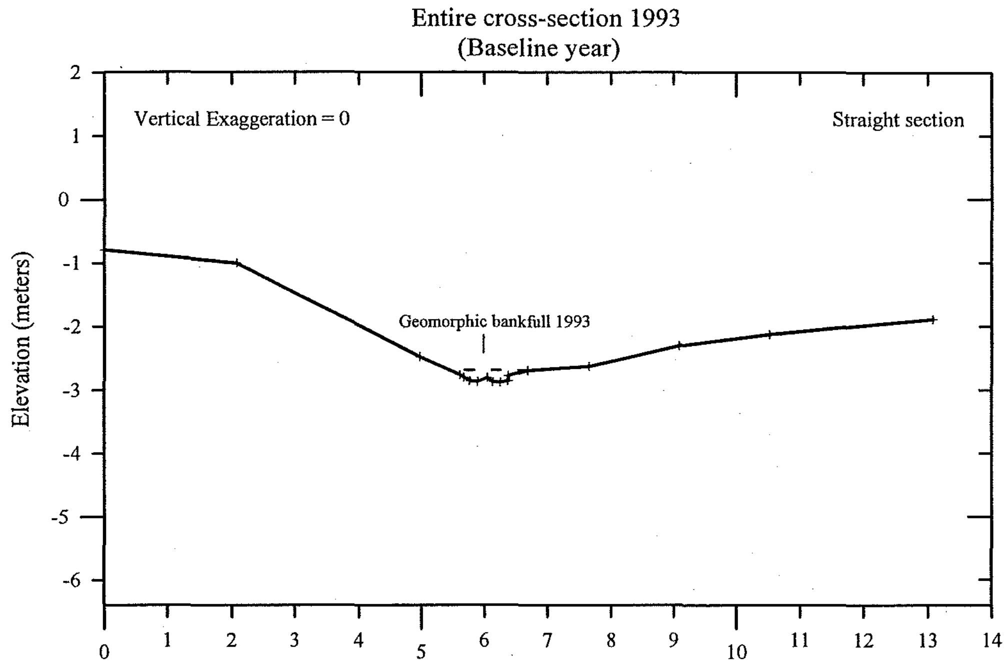
Muddy Creek cross-section 23 (continued)
New Cattle Exclosure
1993, 1995, and 1998

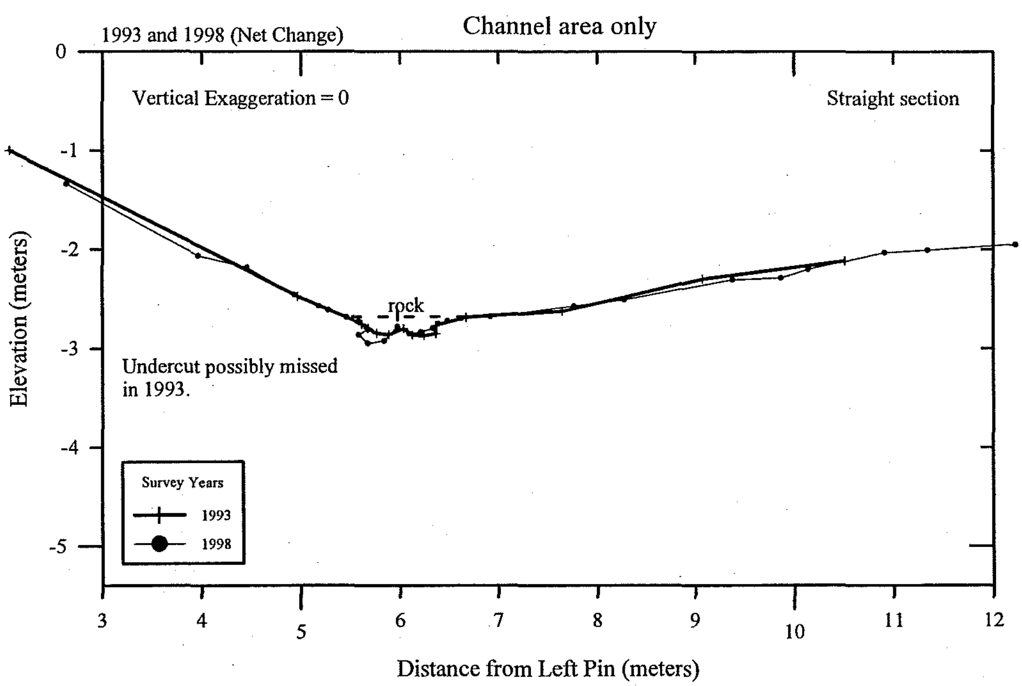
Undercut removed for clarity.



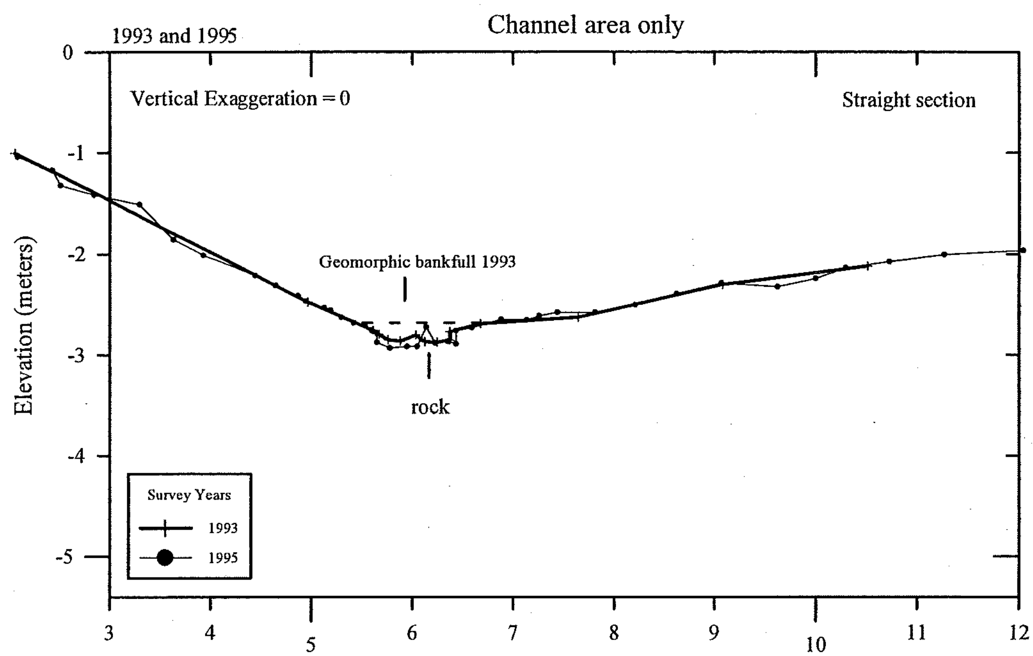


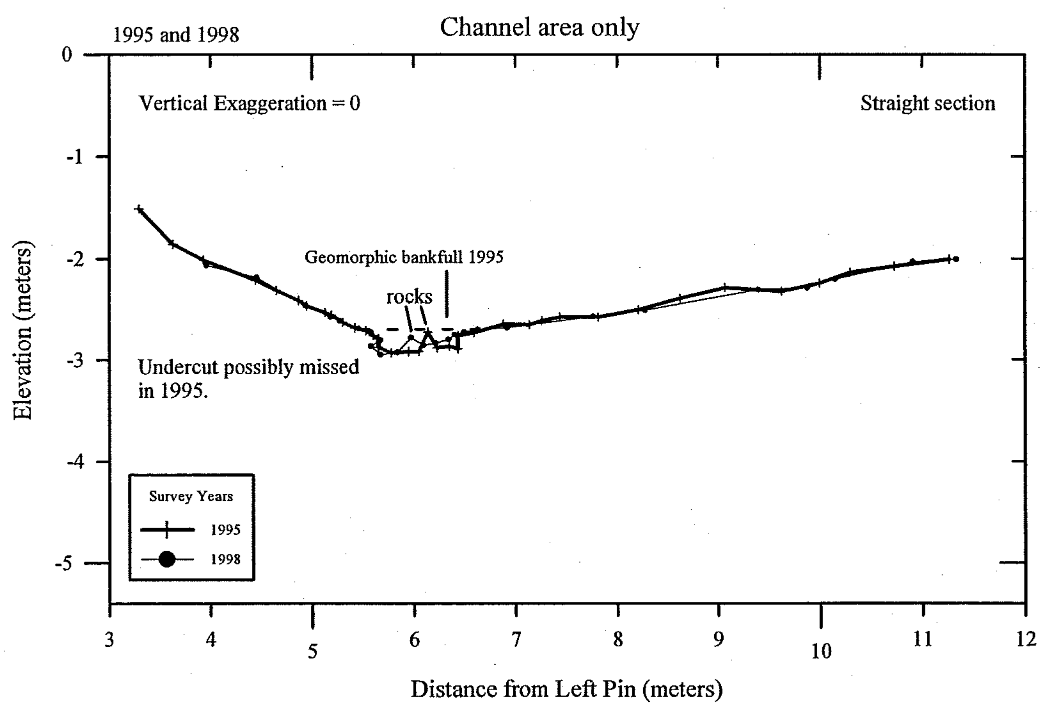
Muddy Creek cross-section 24
New Cattle Exclosure
1993, 1995, and 1998





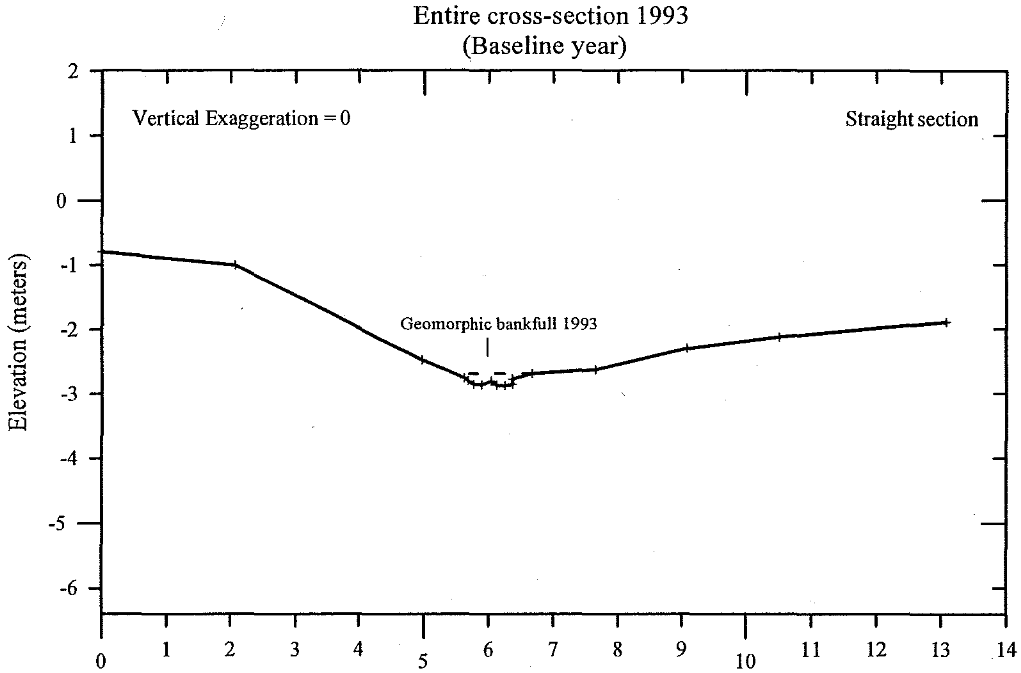
Muddy Creek cross-section 24 (continued)
New Cattle Exclosure
1993, 1995, and 1998

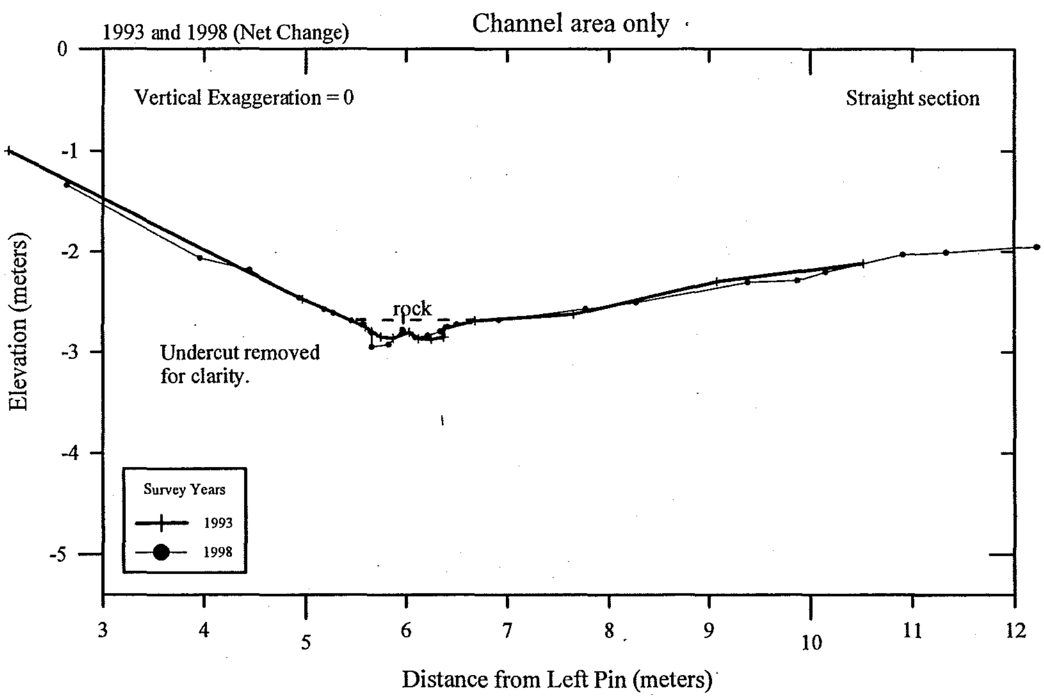




Muddy Creek cross-section 24 (continued)
New Cattle Exclosure
1993, 1995, and 1998

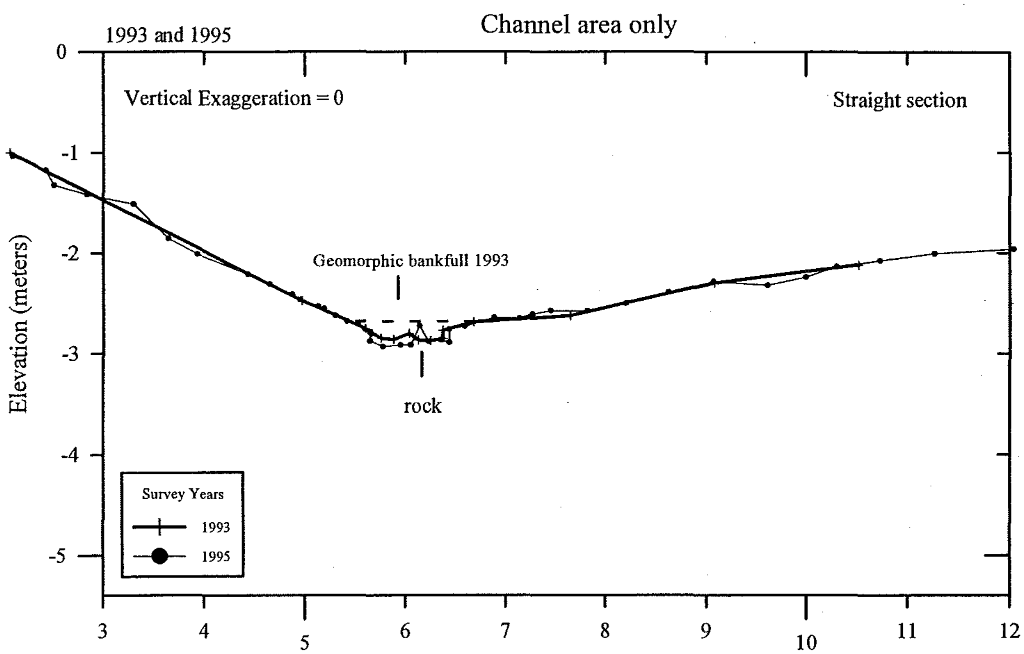
Undercut removed for clarity.

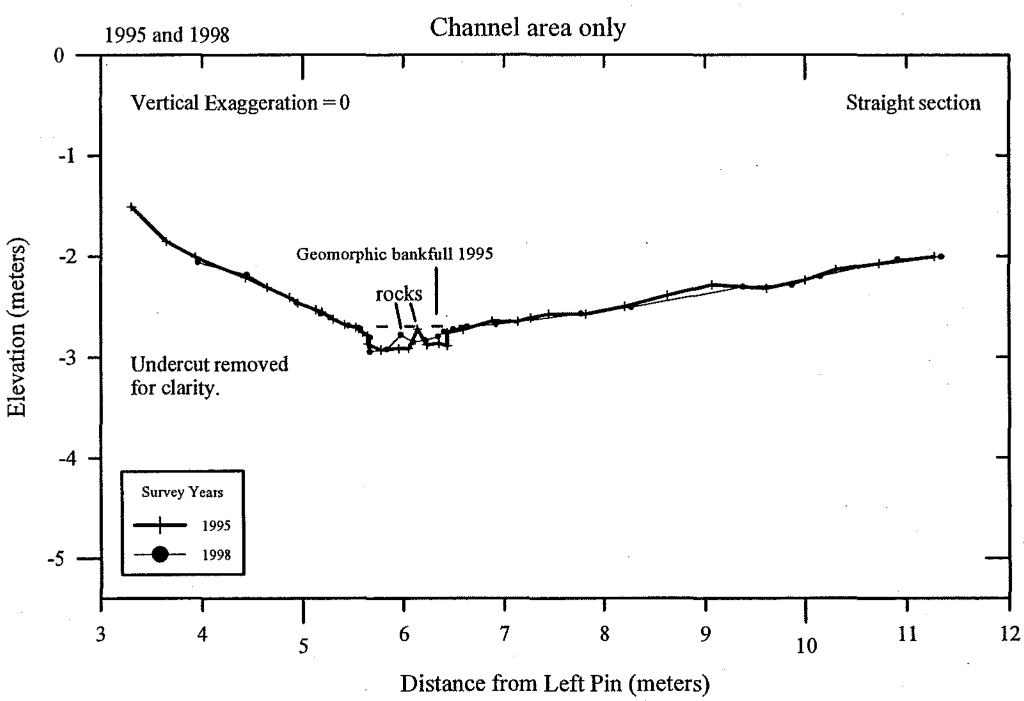




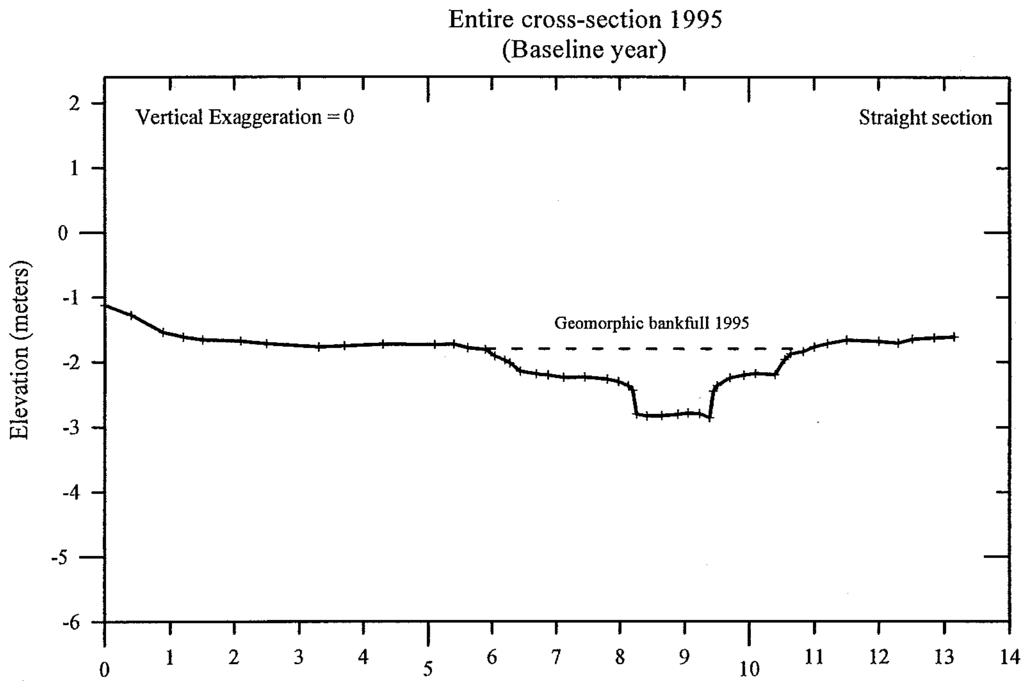
Muddy Creek cross-section 24 (continued)
New Cattle Exclosure
1993, 1995, and 1998

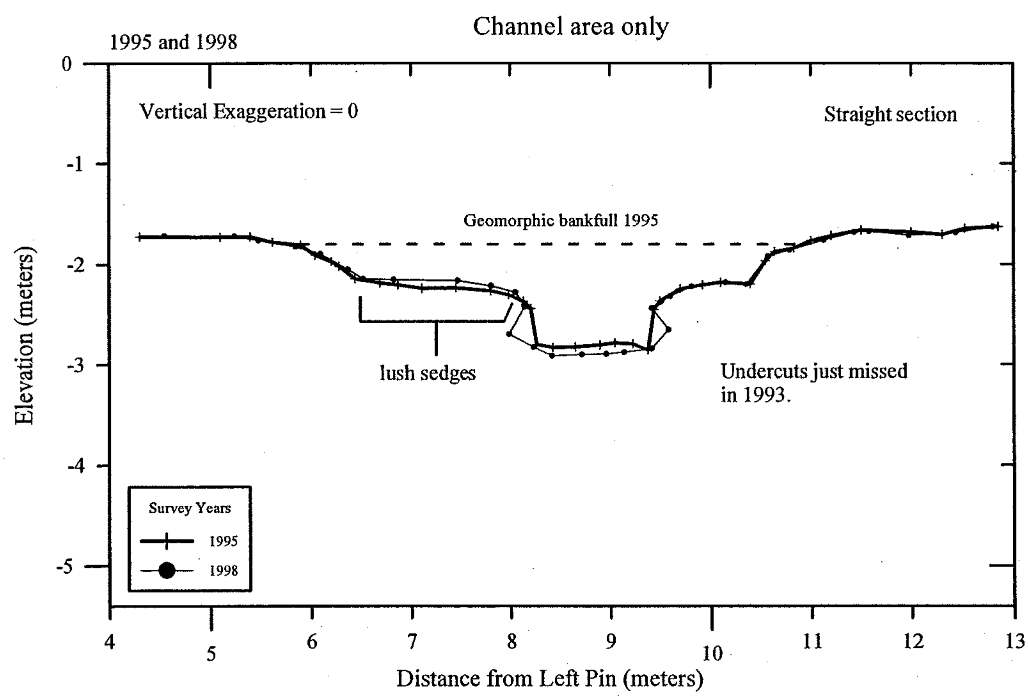
Undercut removed for clarity.





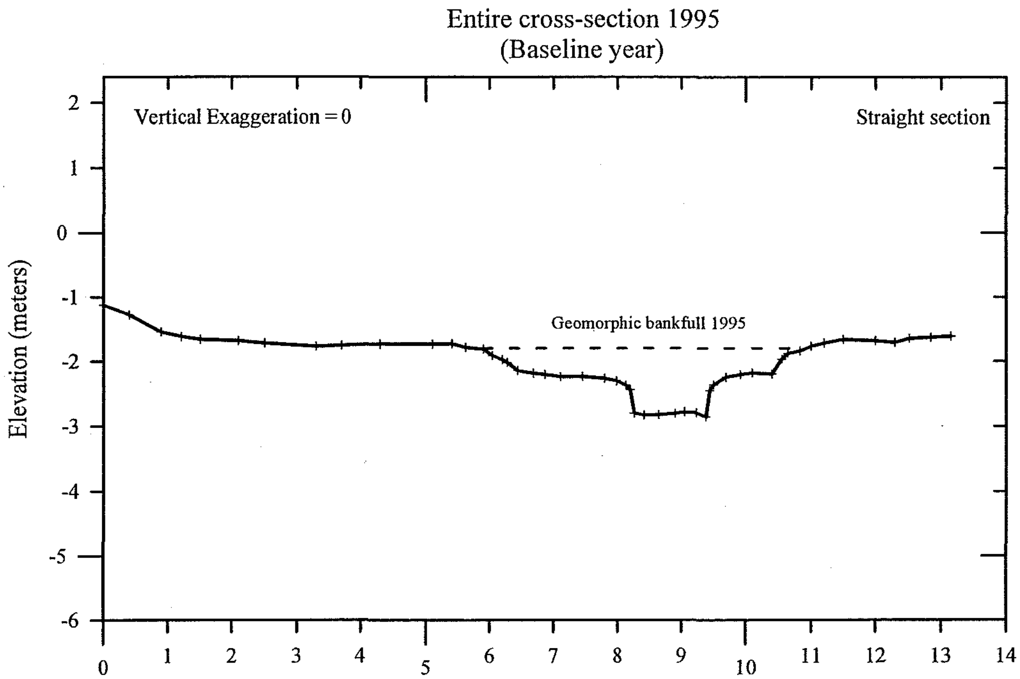
Muddy Creek cross-section 25
Old Cattle Exclosure
1995, and 1998

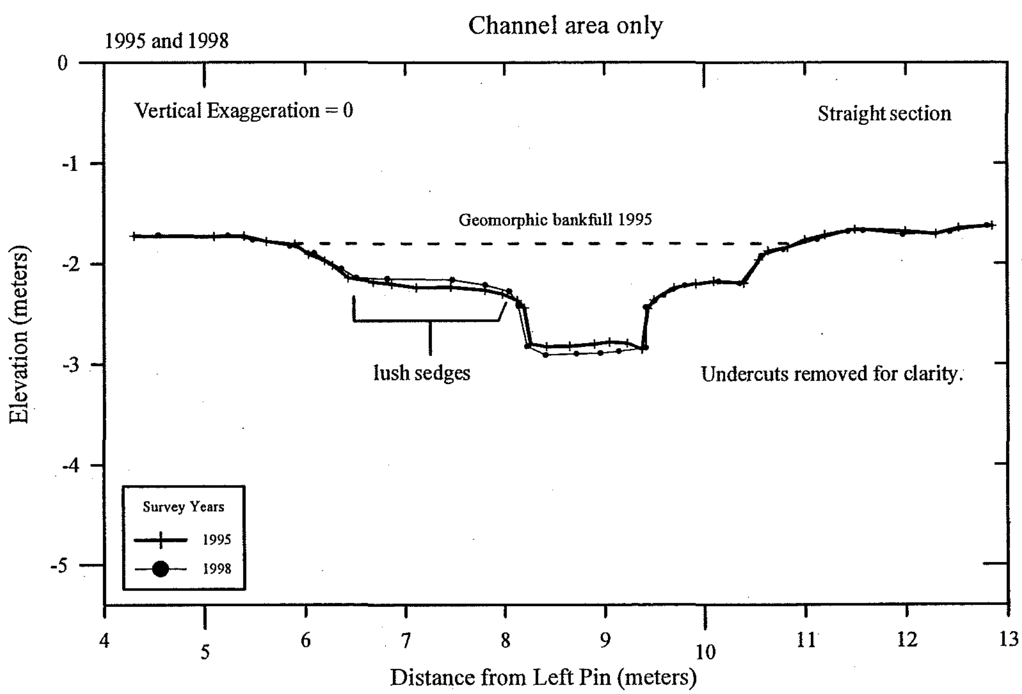




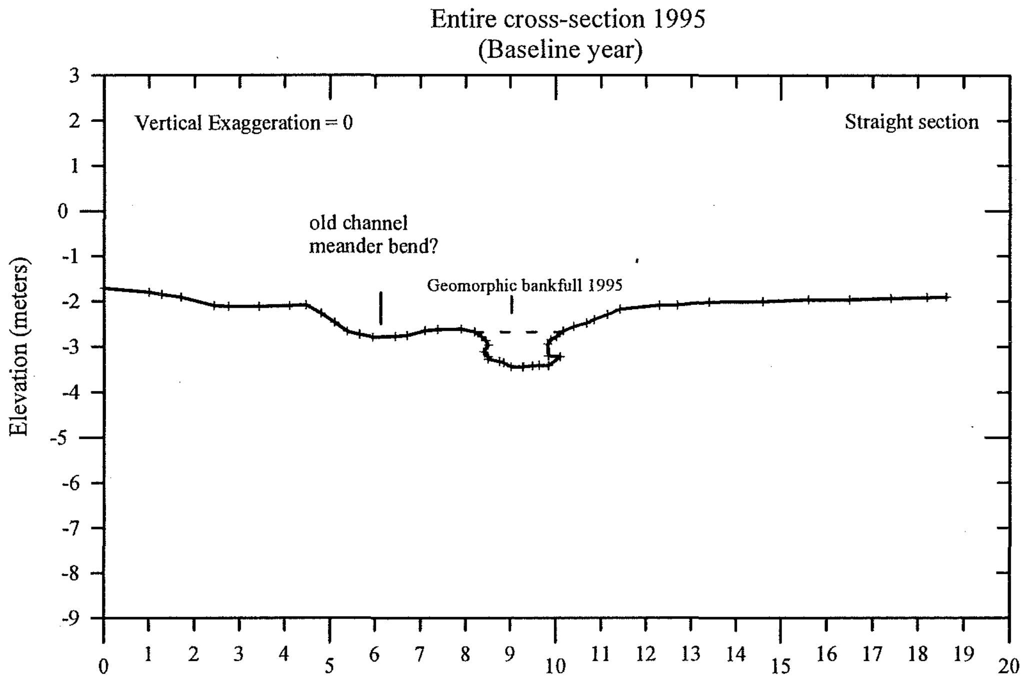
Muddy Creek cross-section 25 (continued)
Old Cattle Exclosure
1995, and 1998

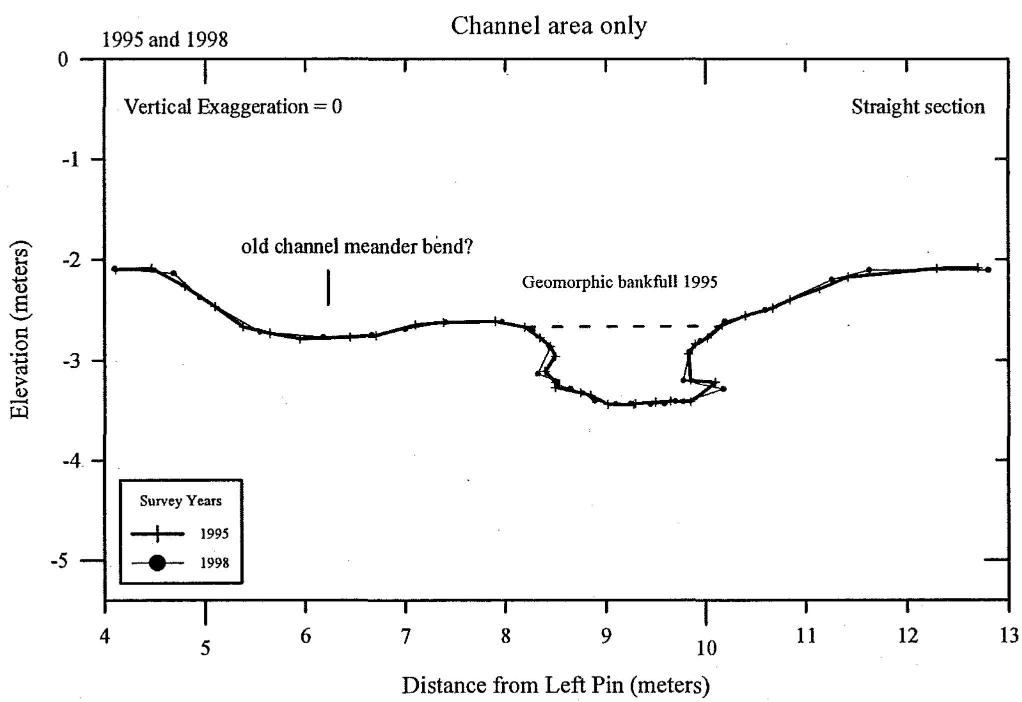
Undercuts removed for clarity.





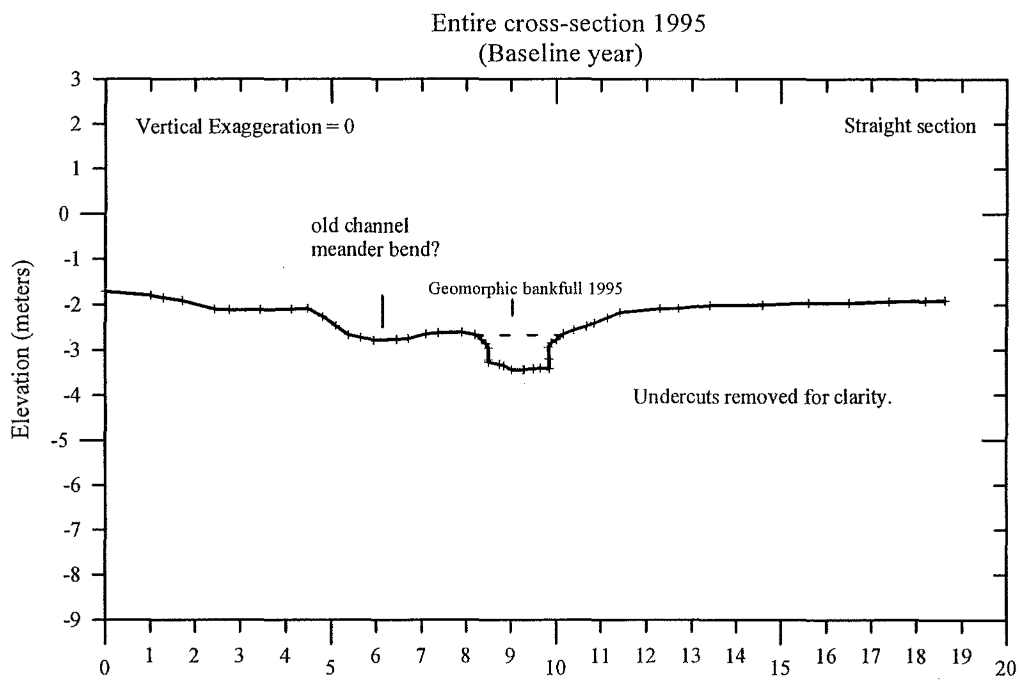
Muddy Creek cross-section 26
Old Cattle Exclosure
1995 and 1998

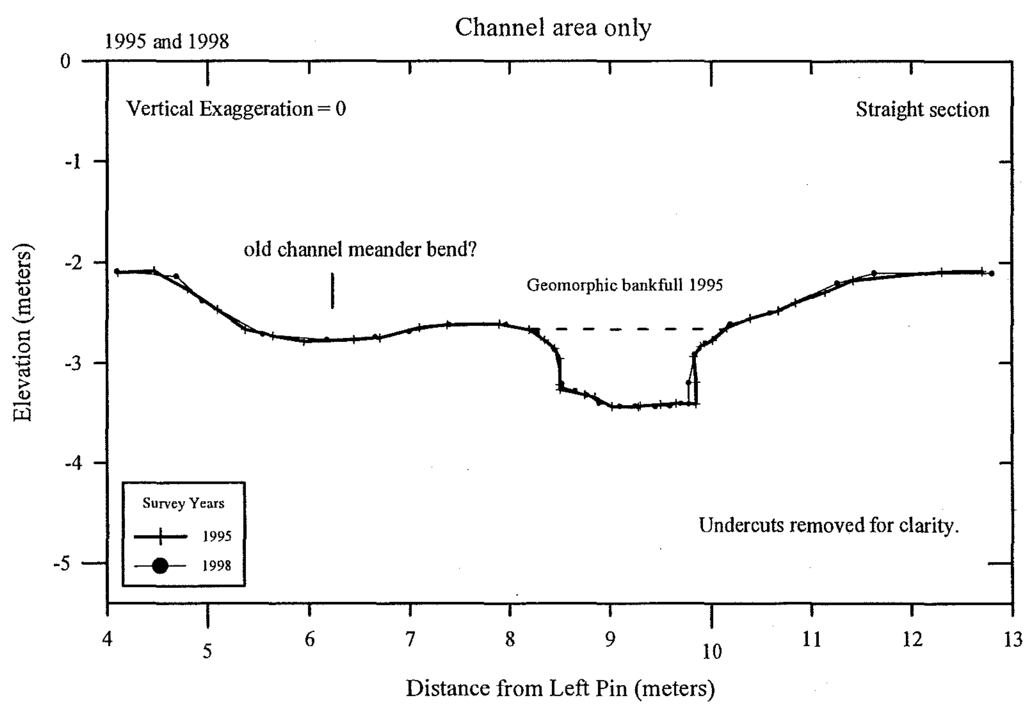




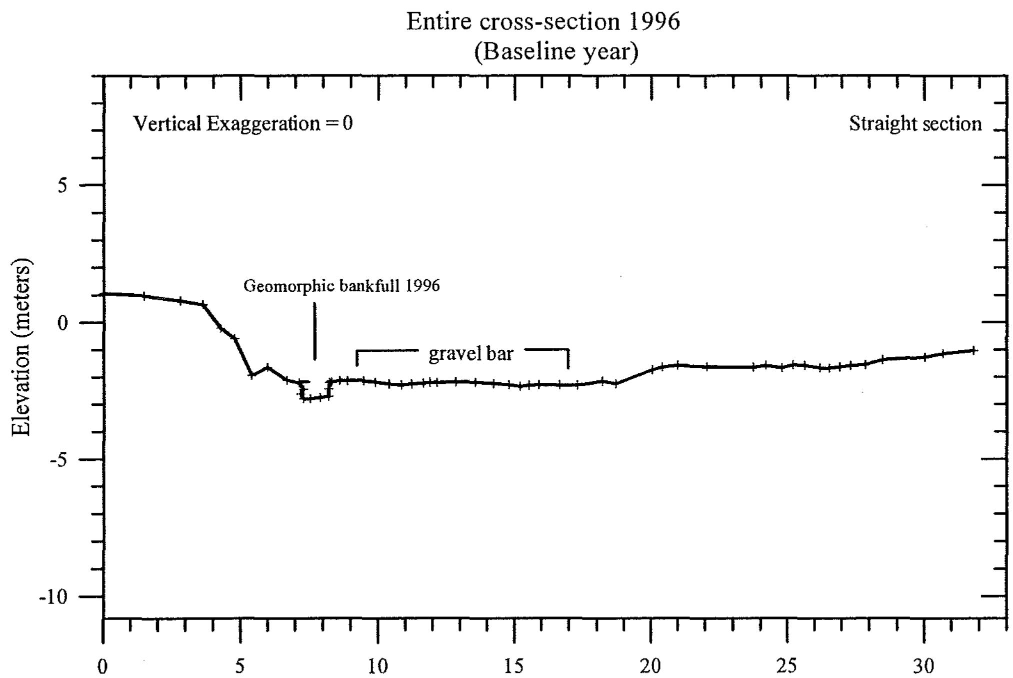
Muddy Creek cross-section 26 (continued)
Old Cattle Exclosure
1995 and 1998

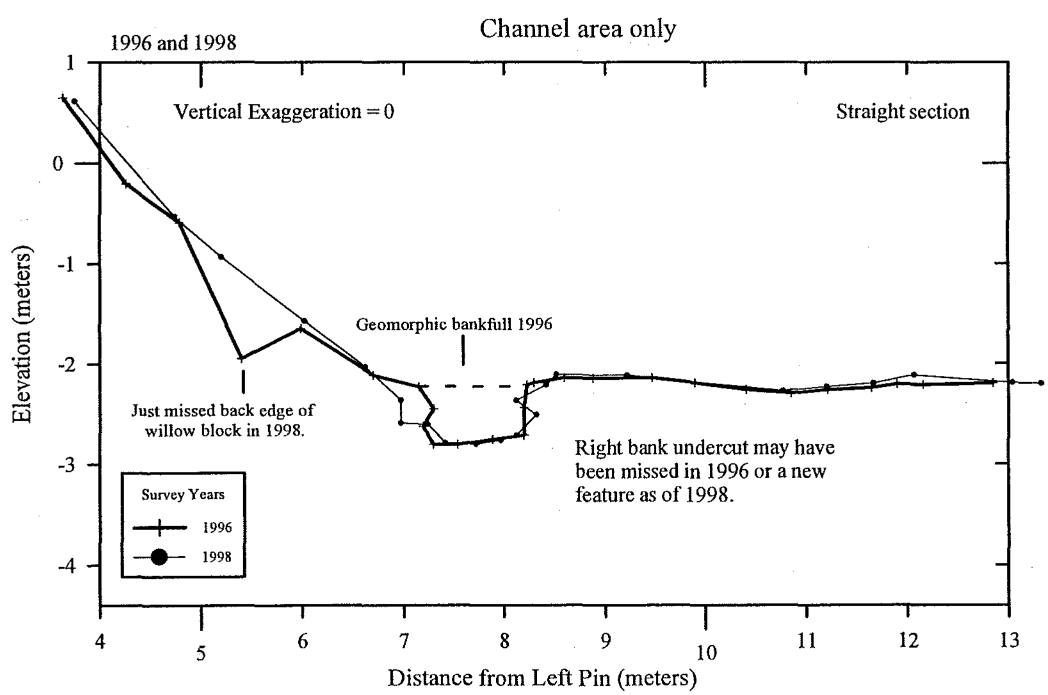
Undercuts removed for clarity.





Muddy Creek cross-section 30
Old Cattle Exclosure
1996 and 1998

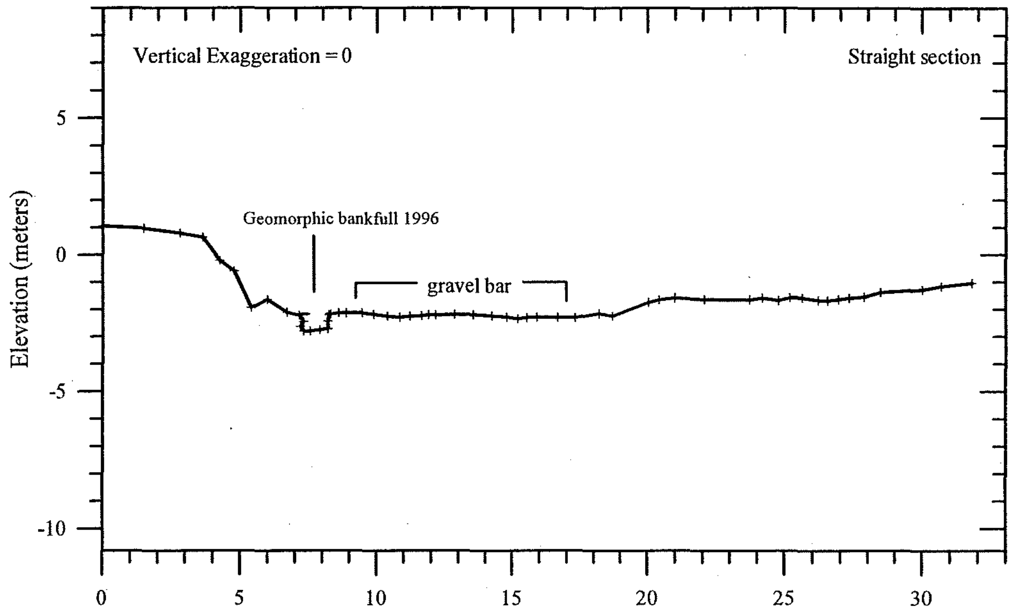




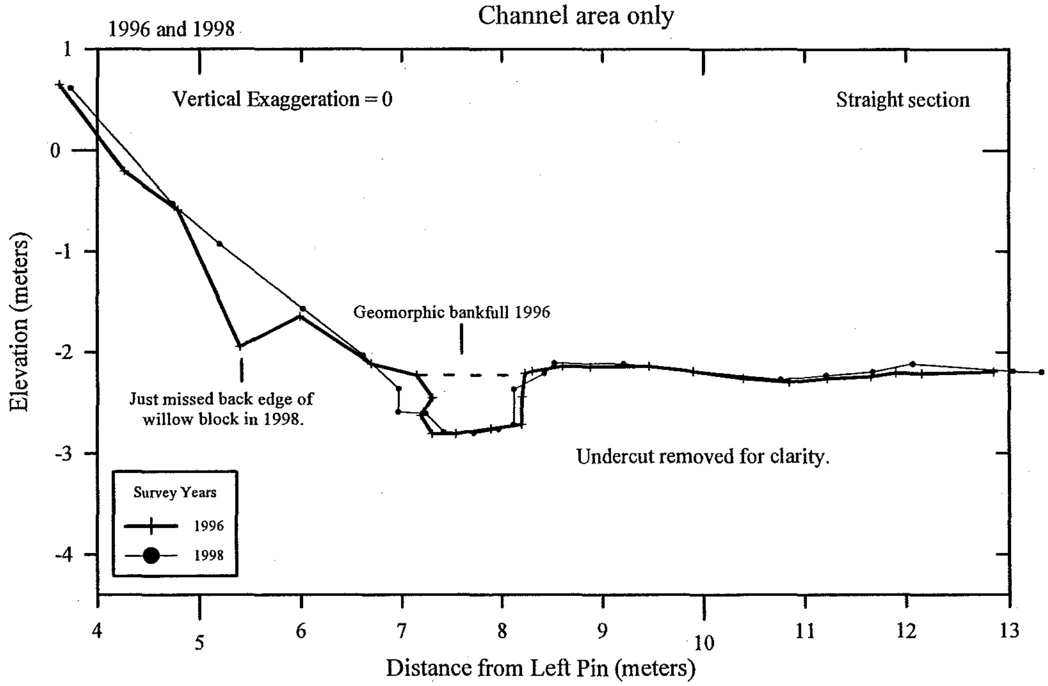
Muddy Creek cross-section 30 (continued)
Old Cattle Exclosure
1996 and 1998

Undercut removed for clarity.

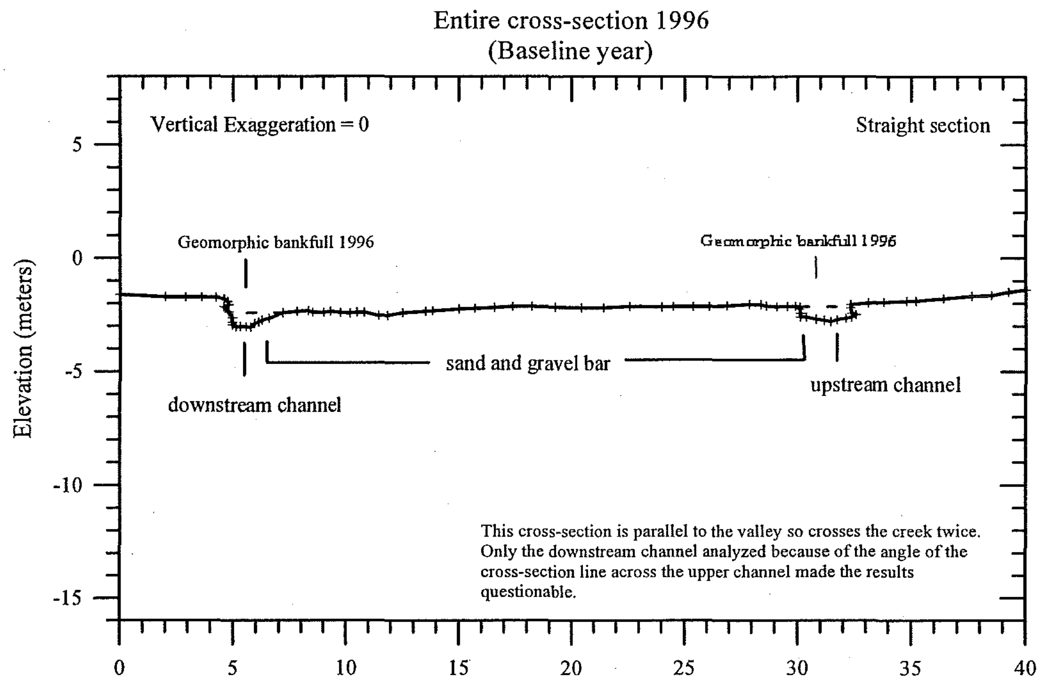
Entire cross-section 1996
(Baseline year)

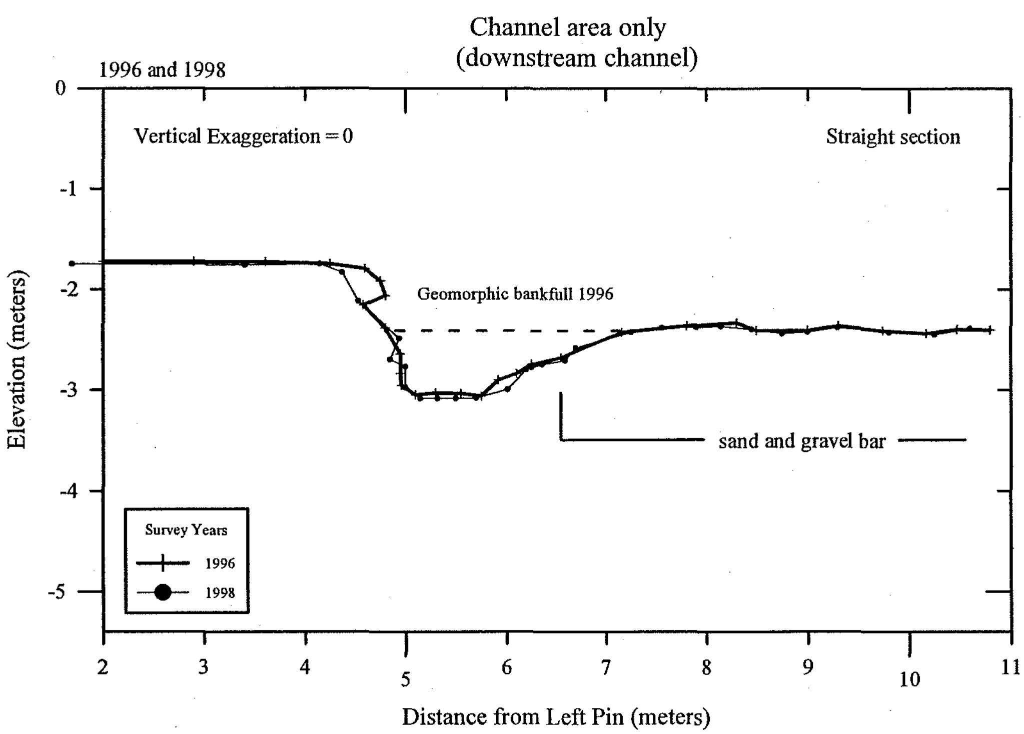


Channel area only

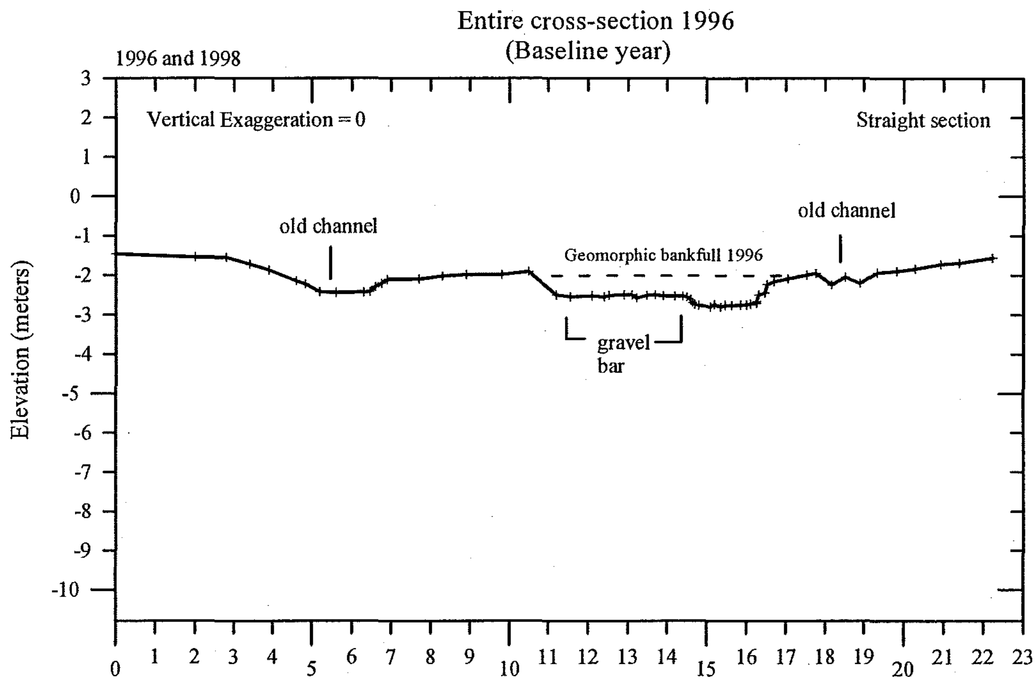


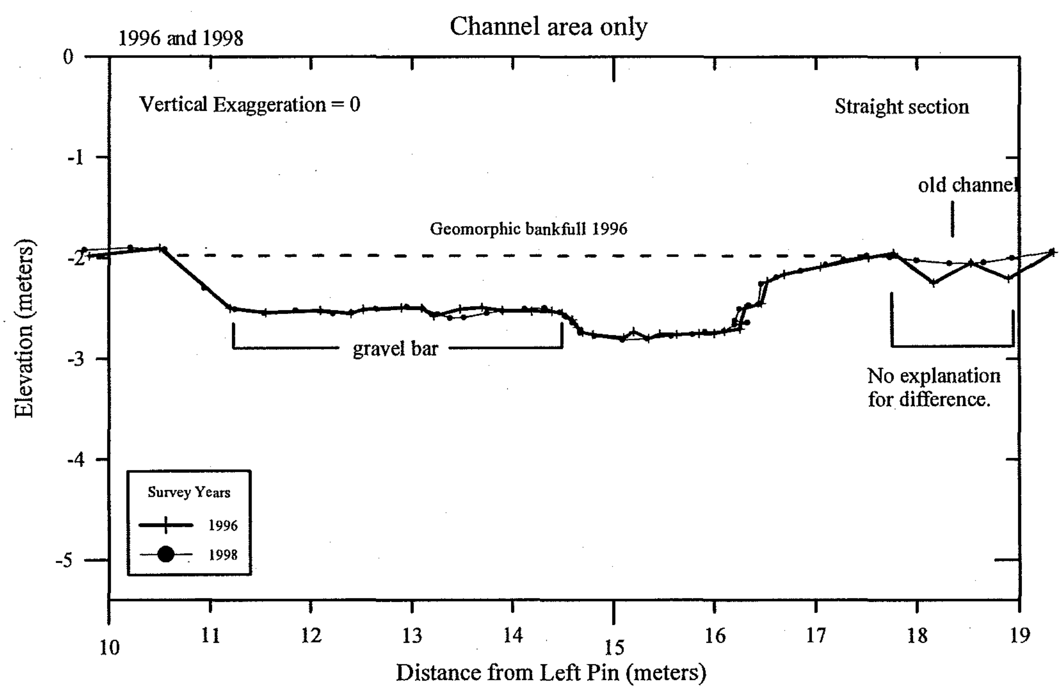
Muddy Creek cross-section 31
Old Cattle Exclosure
1996 and 1998



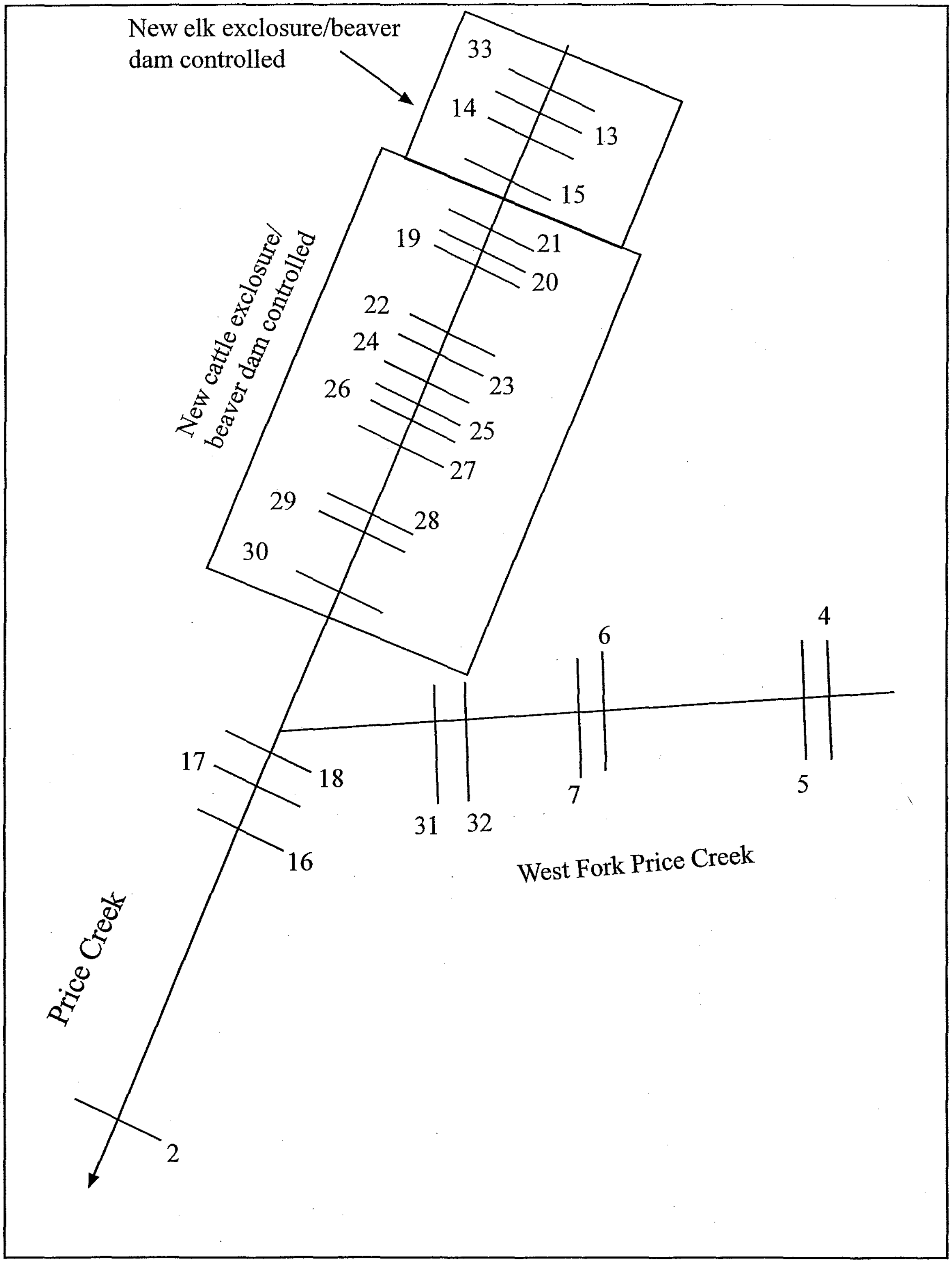


Muddy Creek cross-section 32
Old Cattle Exclosure
1996 and 1998

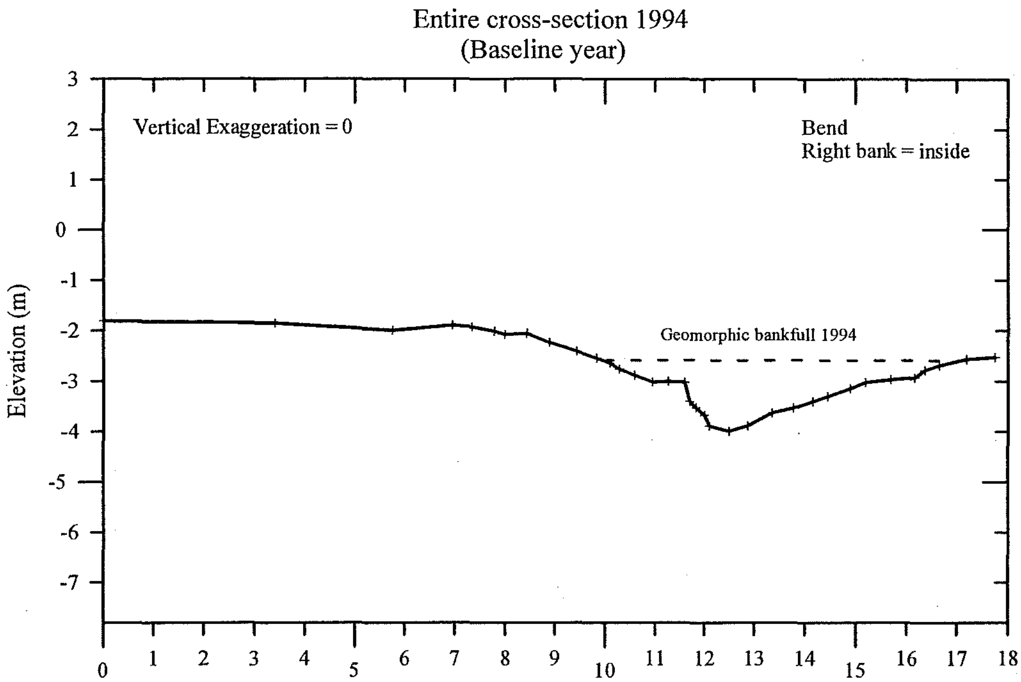


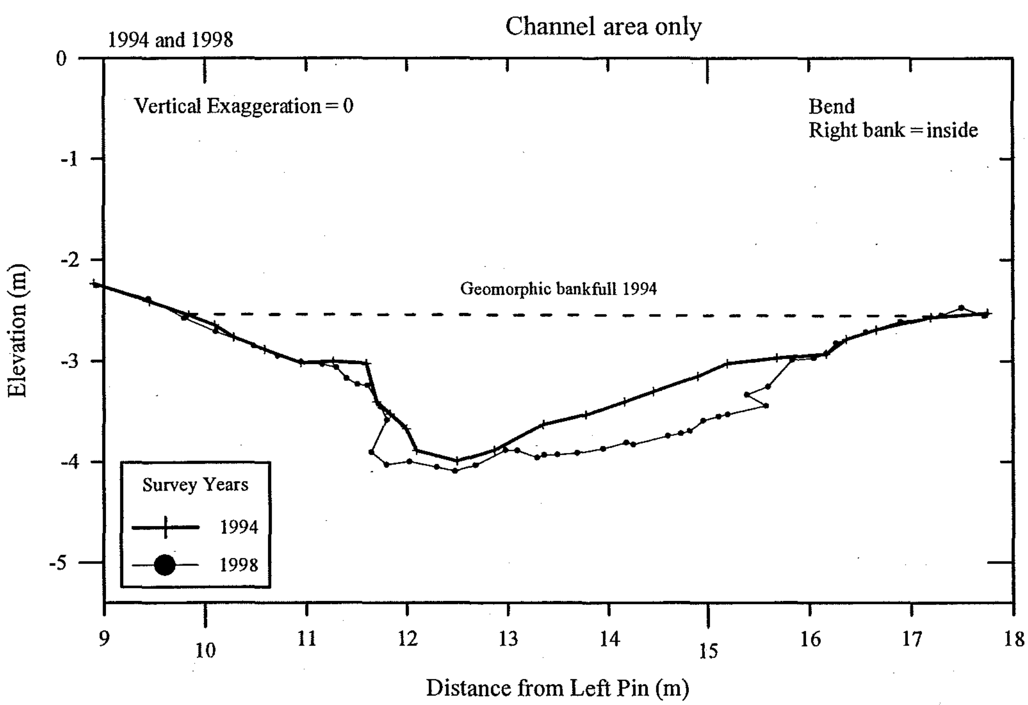


Price Creek, Montana
Relative location of cross-sections with respect to each other.



Price Creek cross-section 2
Riparian Guidelines/Beaver dam controlled
1994 and 1998

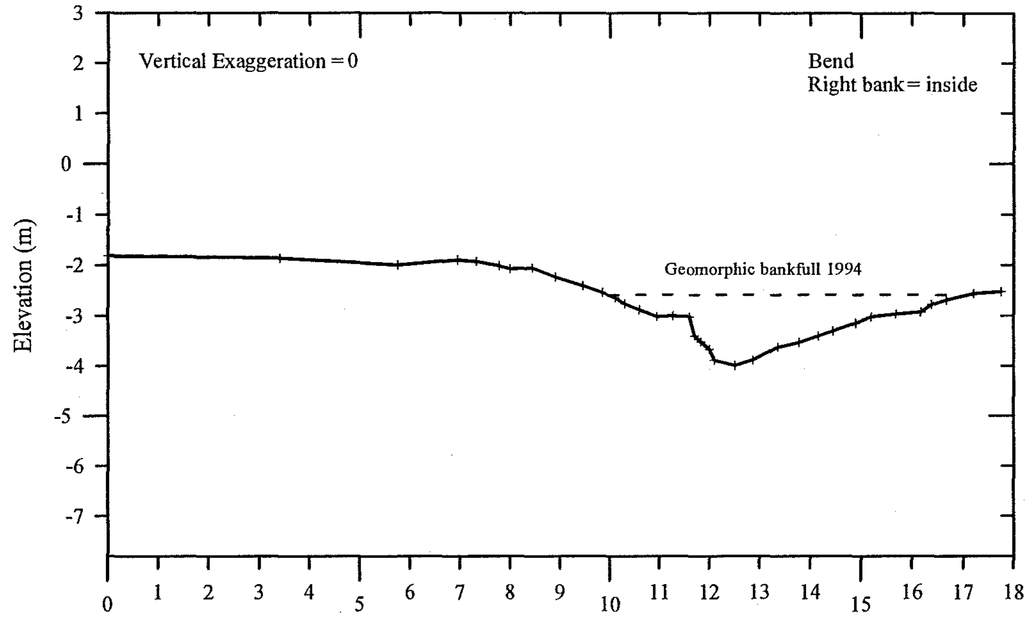




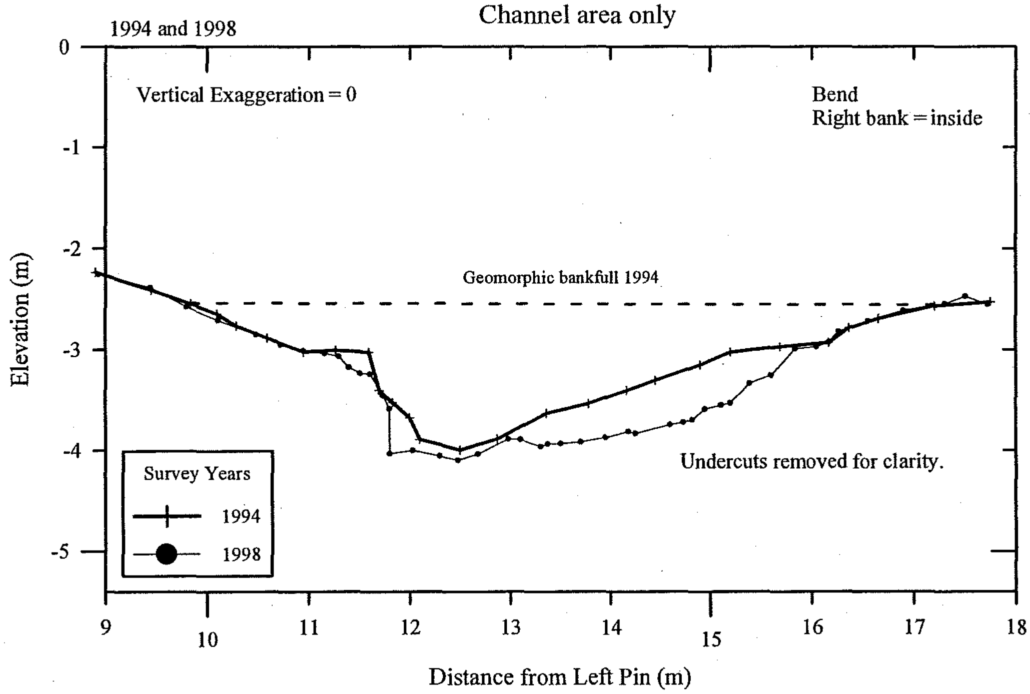
Price Creek cross-section 2 (continued)
Riparian Guidelines/Beaver dam controlled
1994 and 1998

Undercuts removed for clarity.

Entire cross-section 1994
(Baseline year)

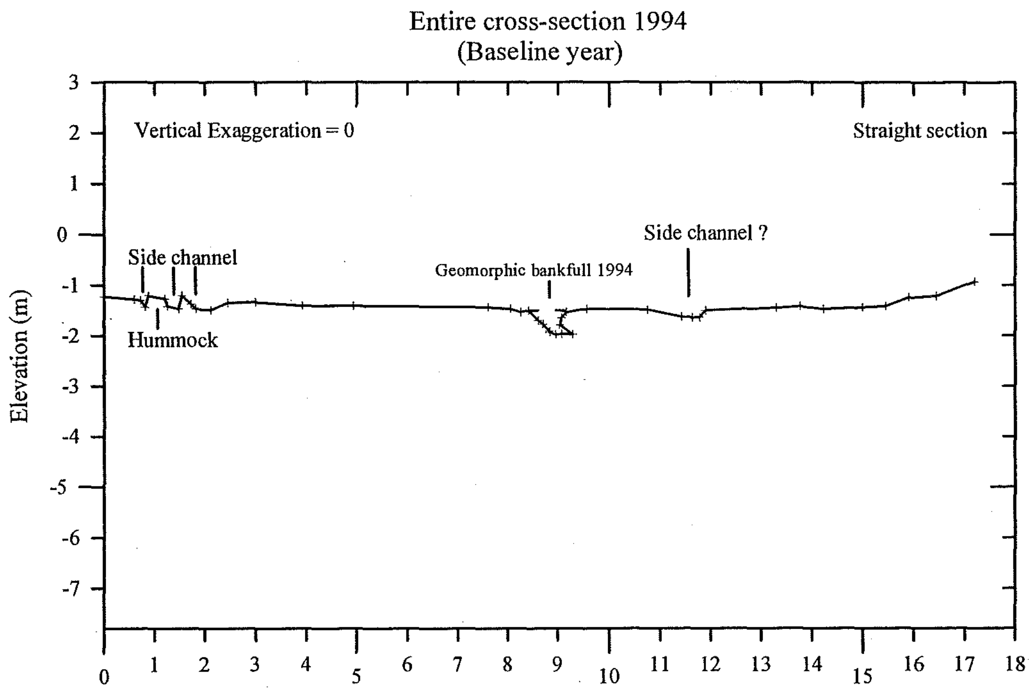


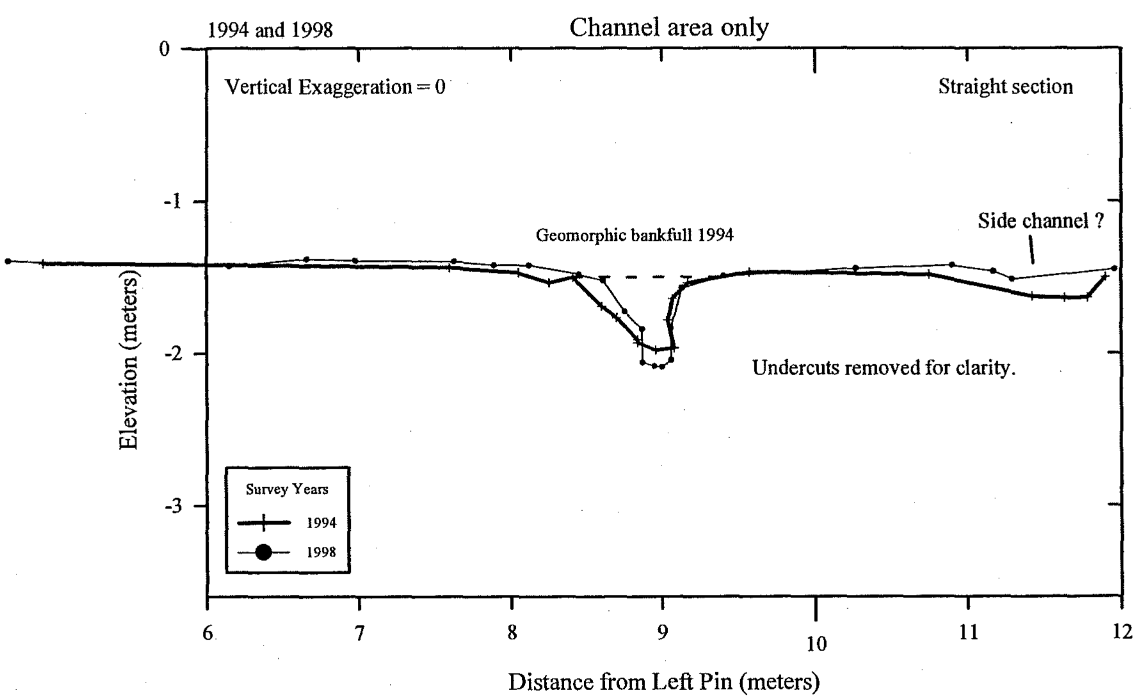
Channel area only



West Fork Price Creek cross-section 4 (continued)
Riparian Guidelines
1994 and 1998

Undercuts removed for clarity.

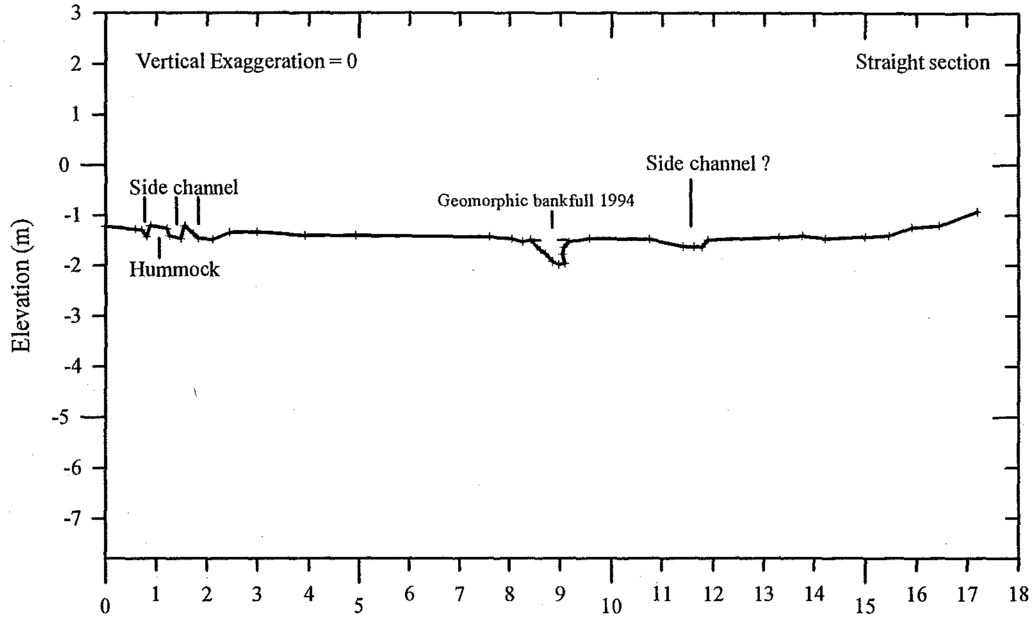




West Fork Price Creek cross-section 4 (continued)
Riparian Guidelines
1994 and 1998

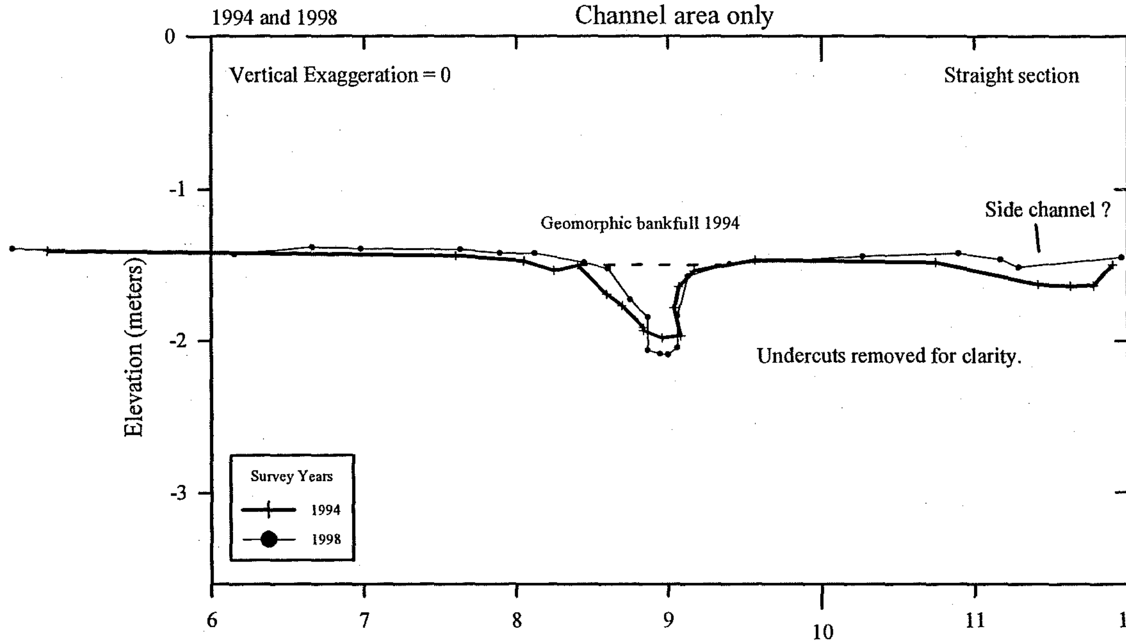
Undercuts removed for clarity.

Entire cross-section 1994
(Baseline year)



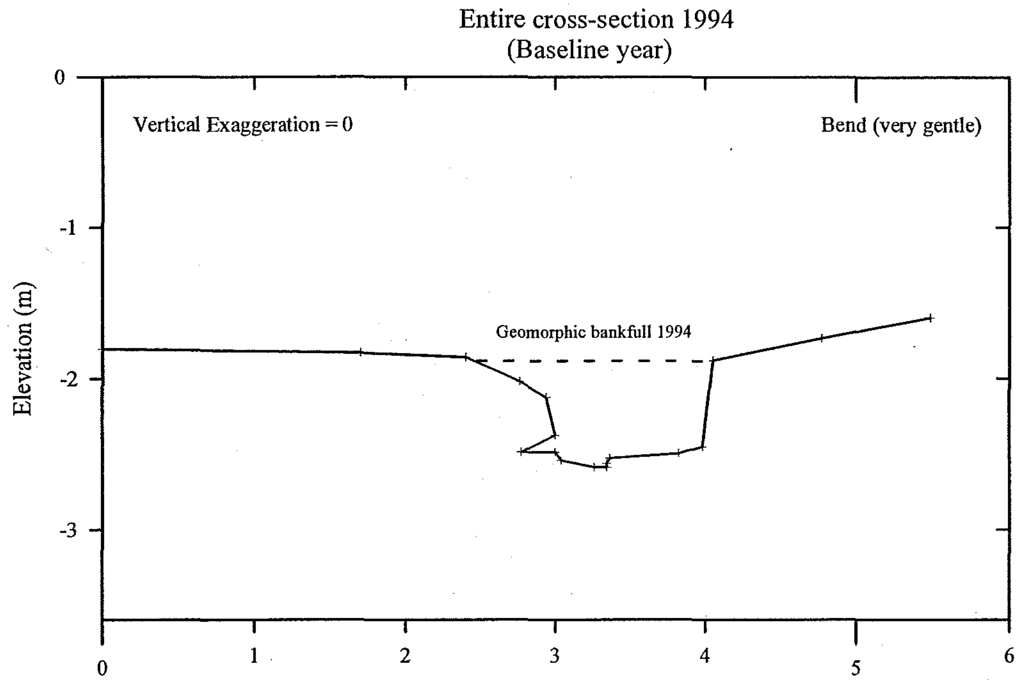
1994 and 1998

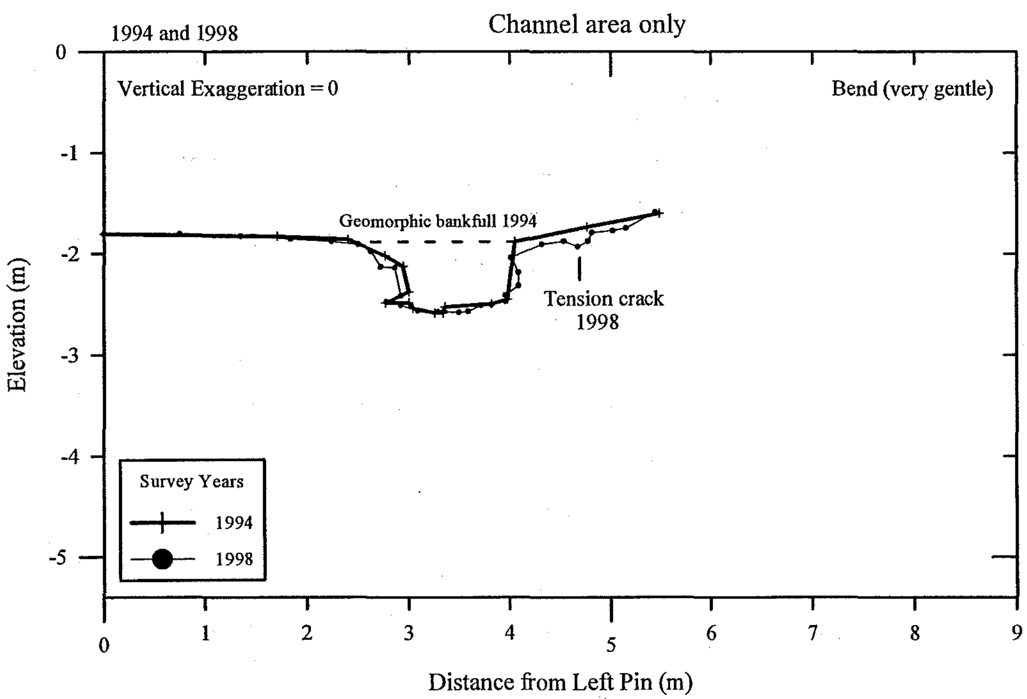
Channel area only



Distance from Left Pin (meters)

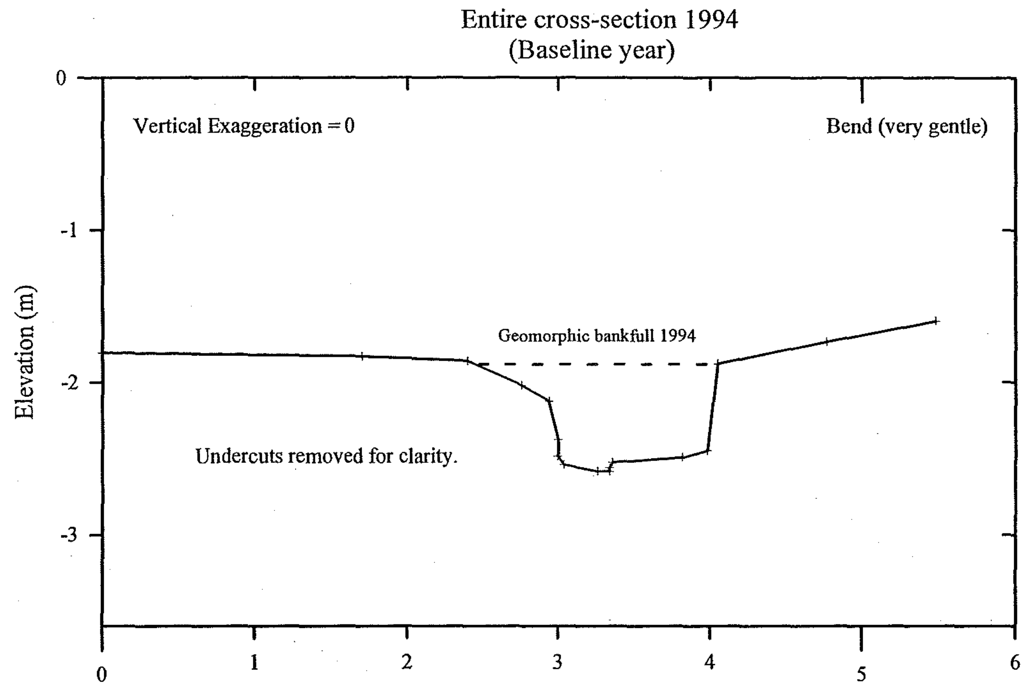
West Fork Price Creek cross-section 5
Riparian Guidelines
1994 and 1998

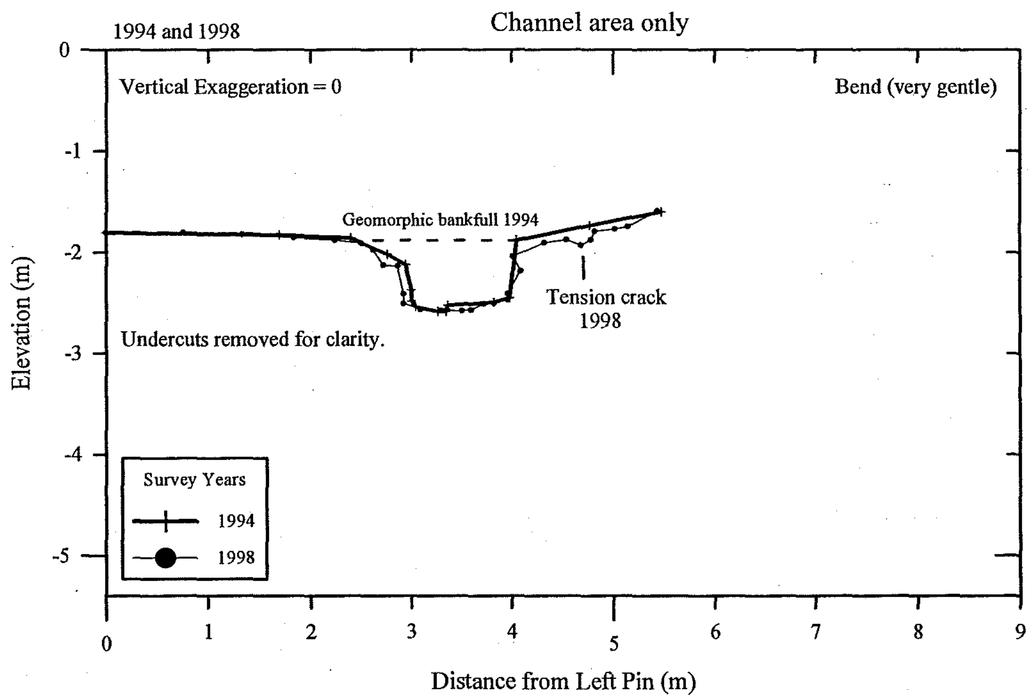




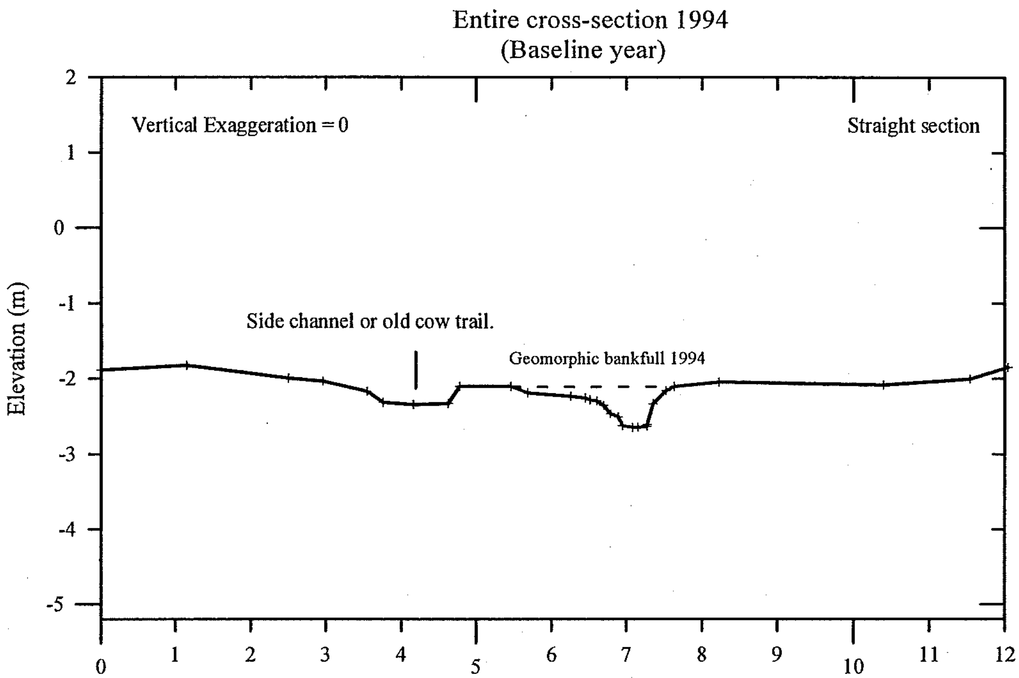
West Fork Price Creek cross-section 5 (continued)
Riparian Guidelines
1994 and 1998

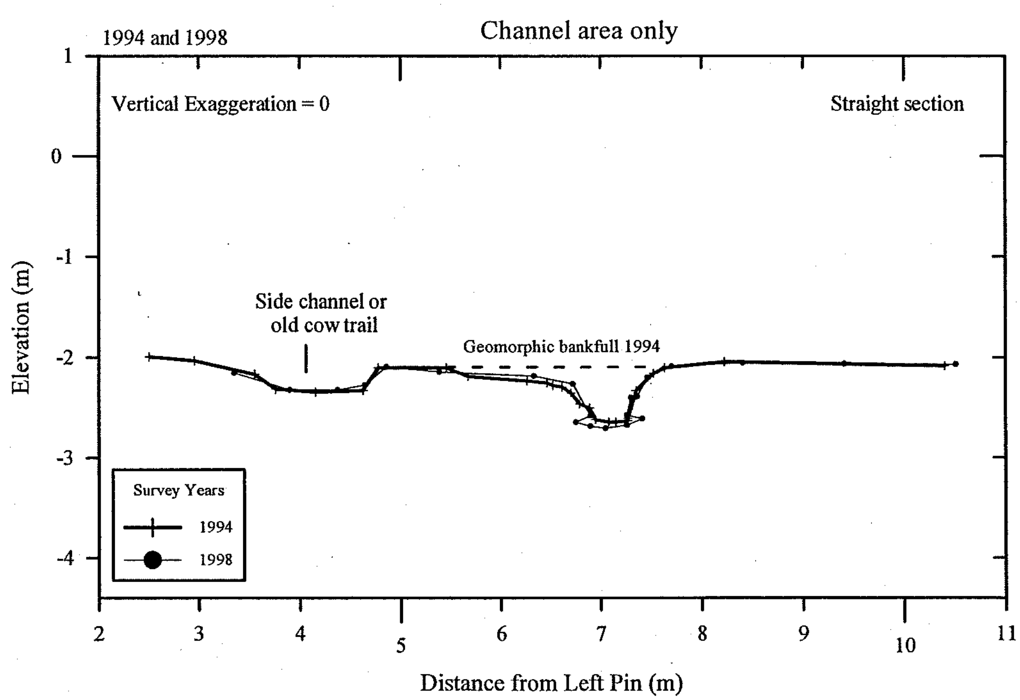
Undercuts removed for clarity.





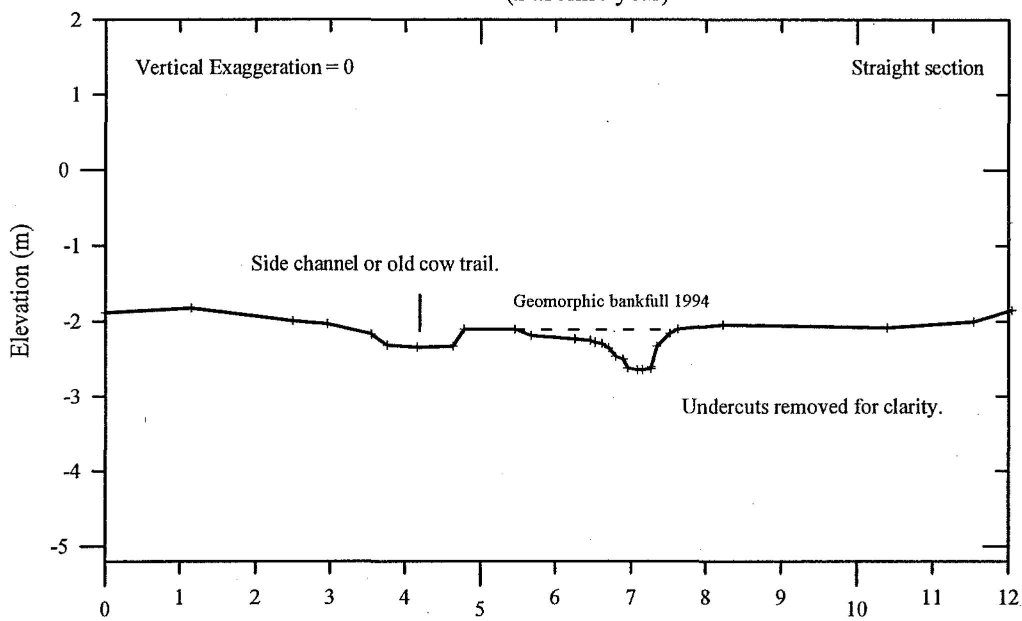
West Fork Price Creek cross-section 6
Riparian Guidelines
1994 and 1998



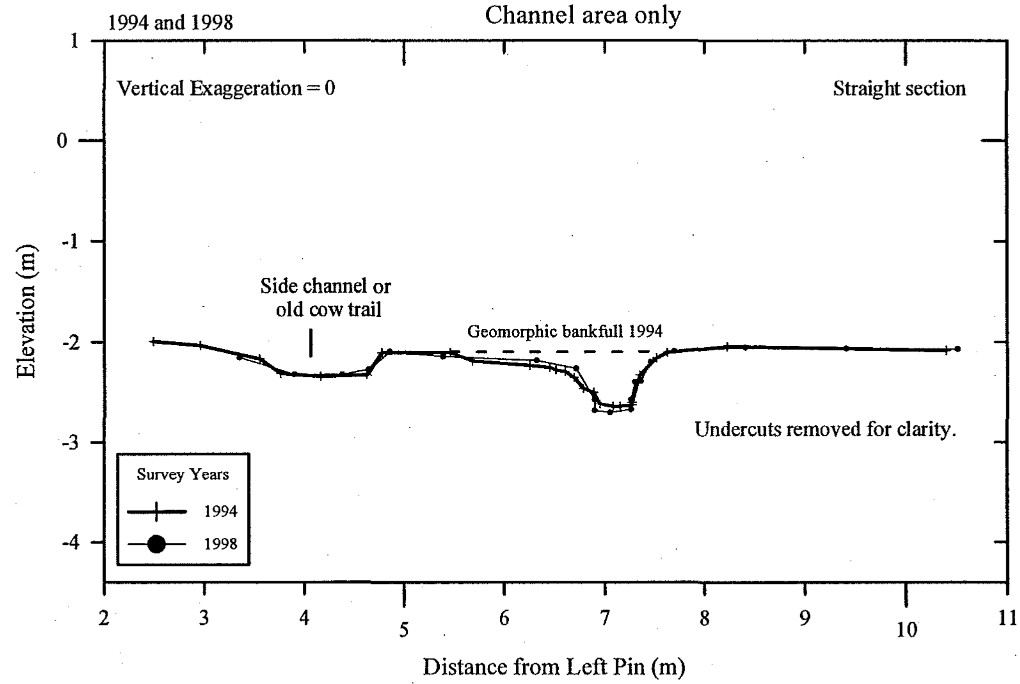


West Fork Price Creek cross-section 6 (continued) Undercuts removed for clarity.
Riparian Guidelines
1994 and 1998

Entire cross-section 1994
(Baseline year)

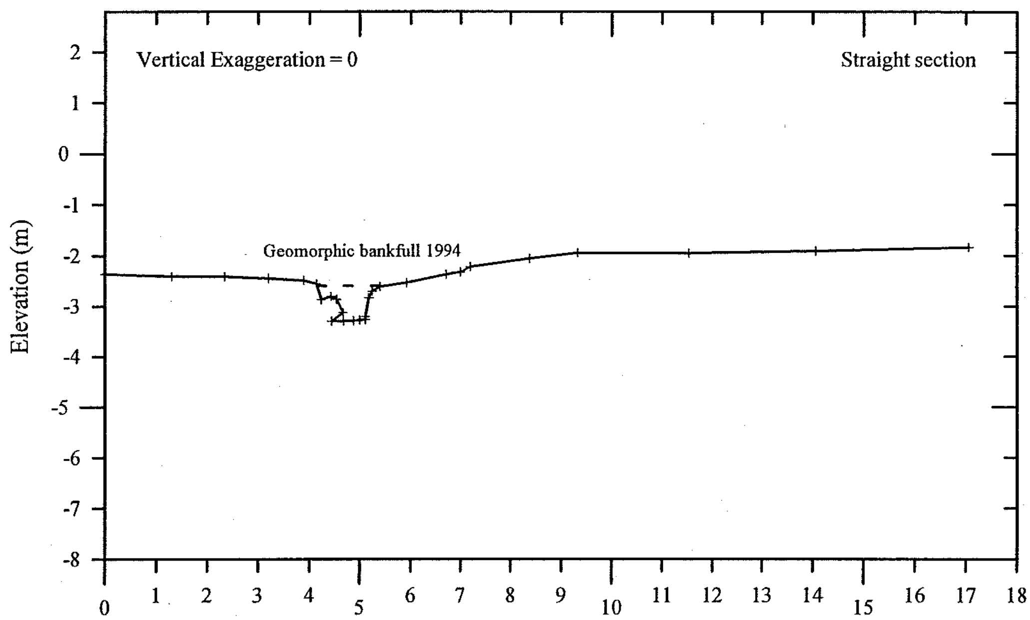


1994 and 1998 Channel area only



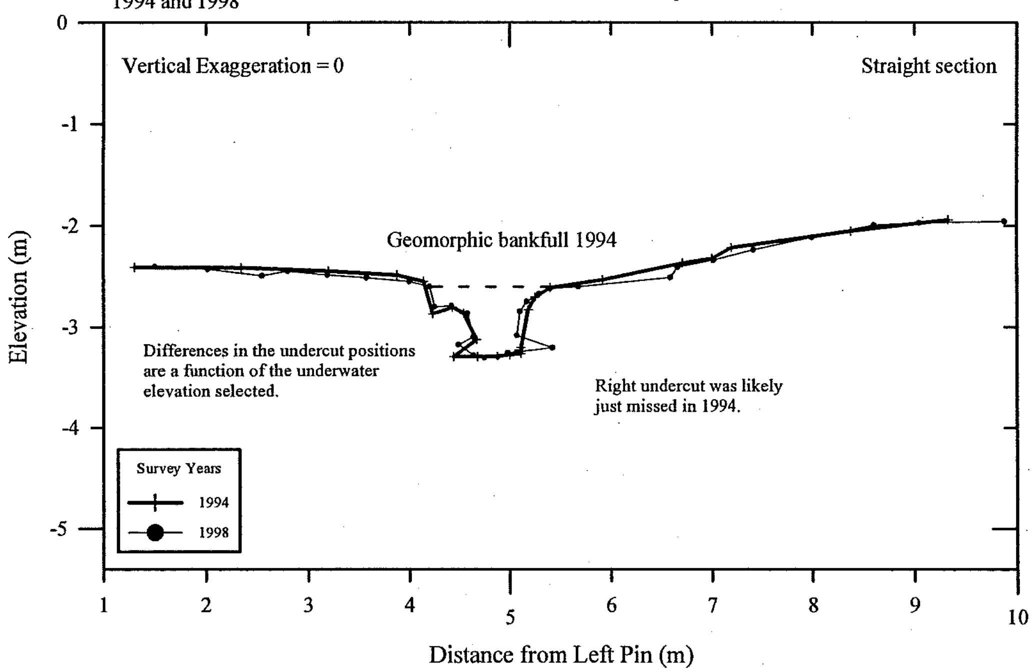
West Fork Price Creek cross-section 7
Riparian Guidelines
1994 and 1998

Entire cross-section 1994
(Baseline year)



Channel area only

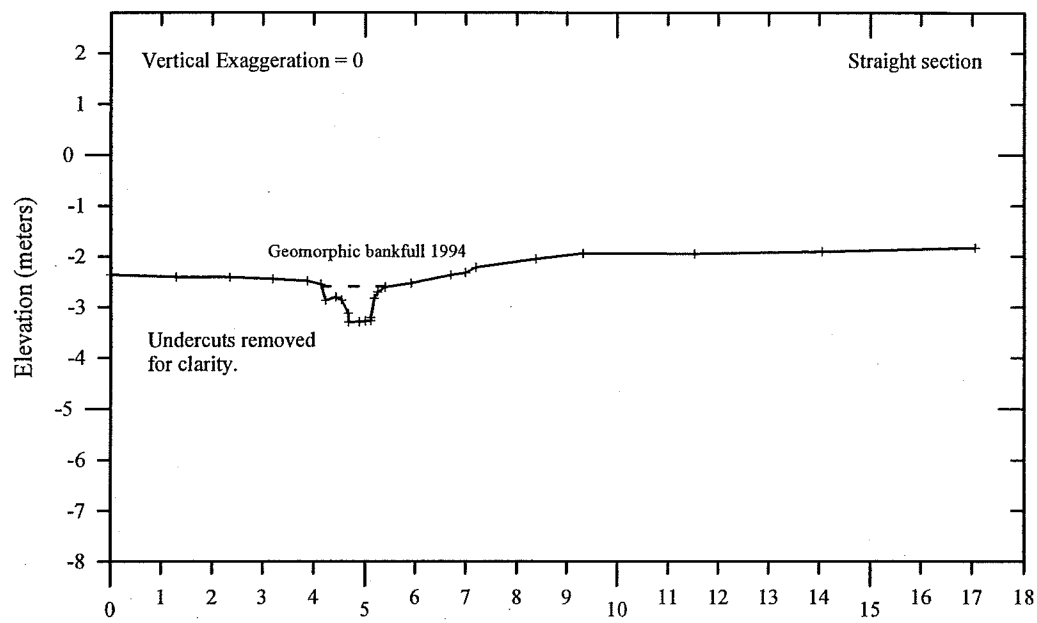
1994 and 1998



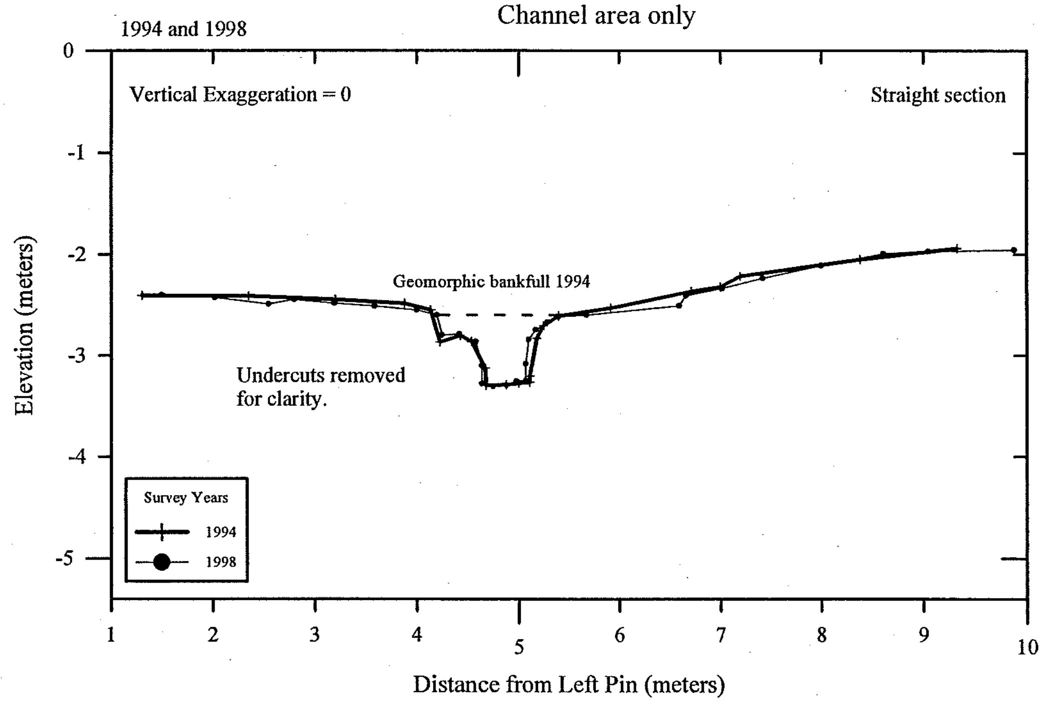
West Fork Price Creek cross-section 7 (continued)
Riparian Guidelines
1994 and 1998

Undercuts removed for clarity.

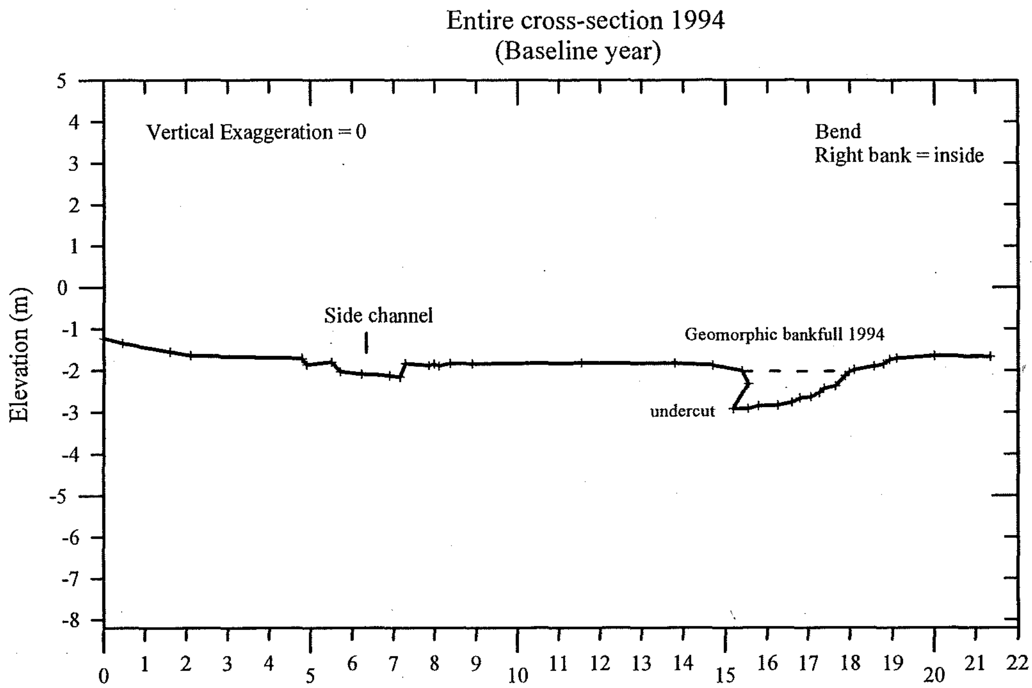
Entire cross-section 1994
(Baseline year)

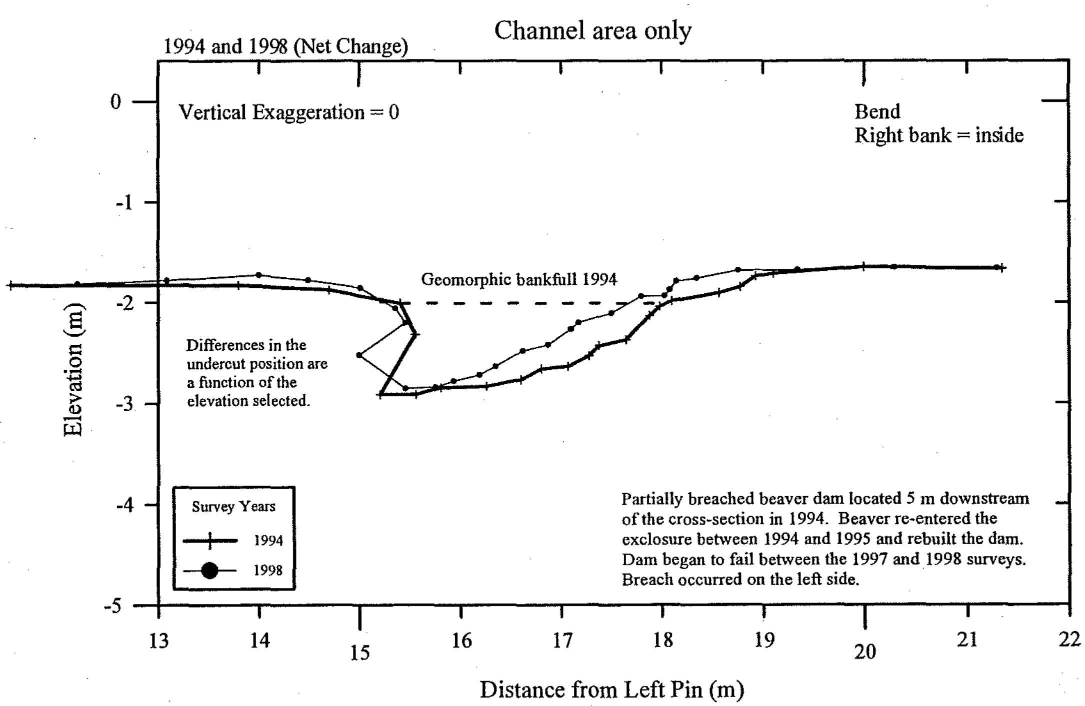


Channel area only

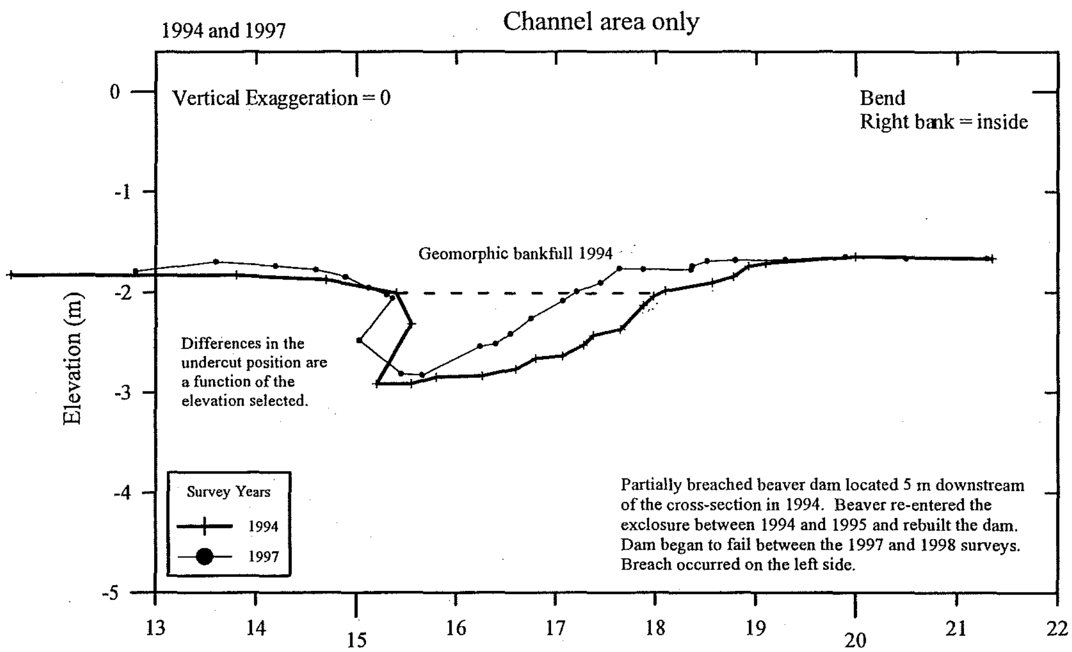


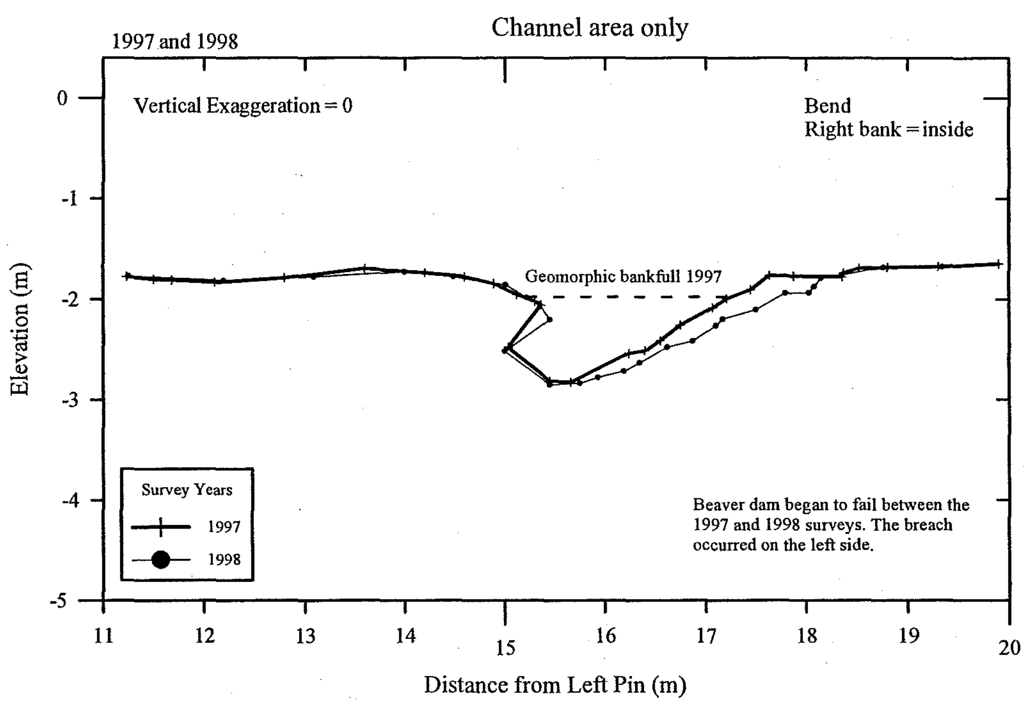
Price Creek cross-section 13
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998





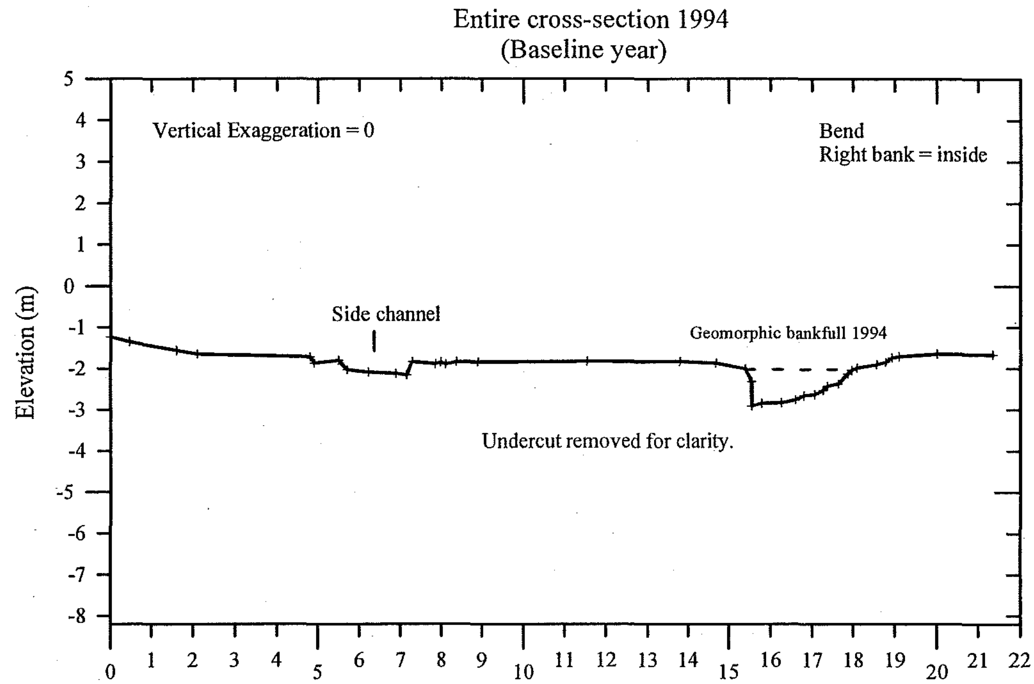
Price Creek cross-section 13 (continued)
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998

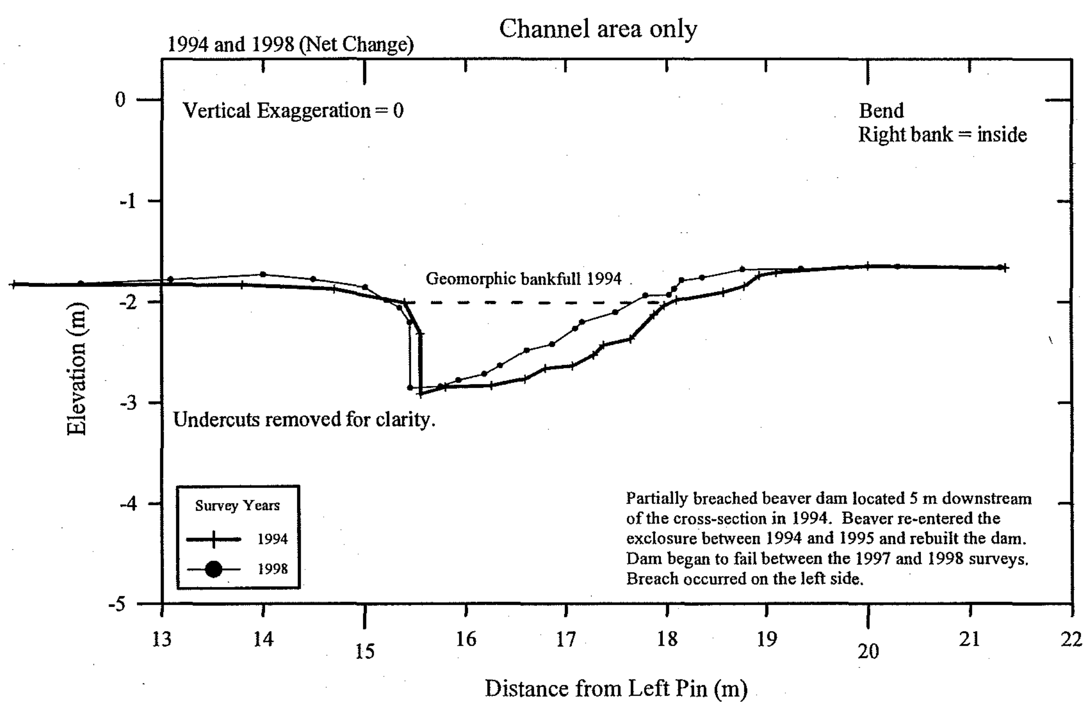




Price Creek cross-section 13 (continued)
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998

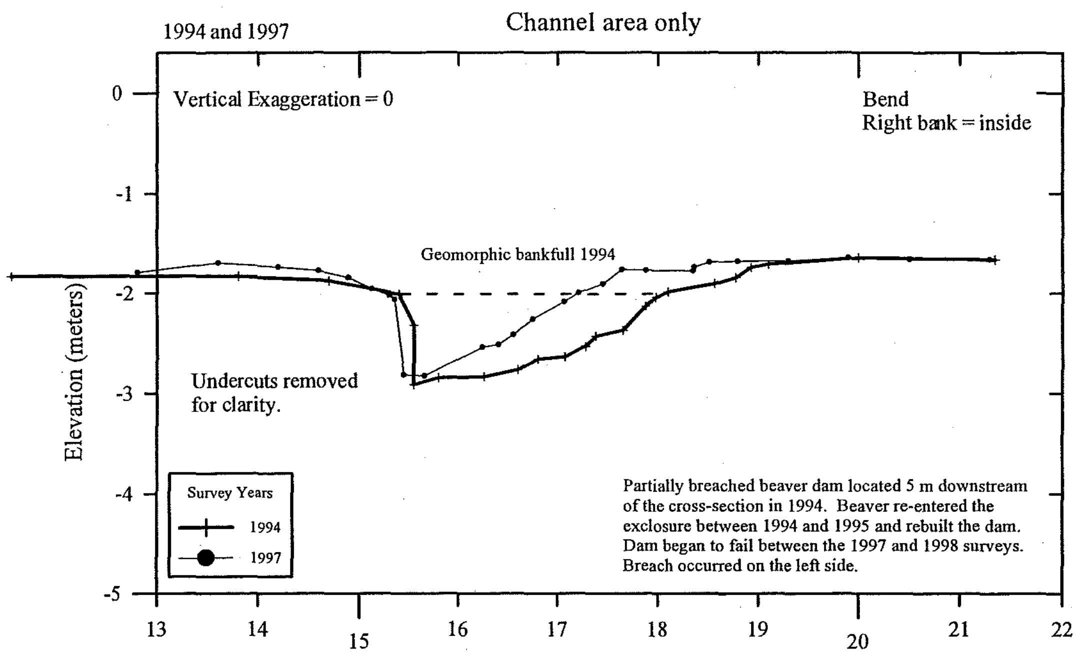
Undercuts removed for clarity.

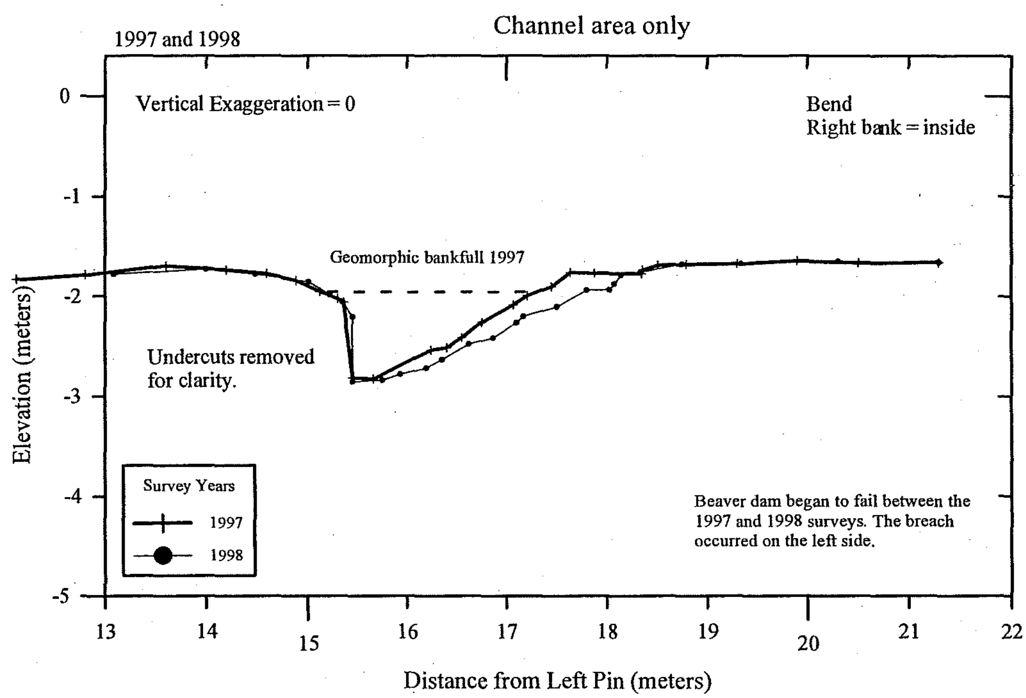




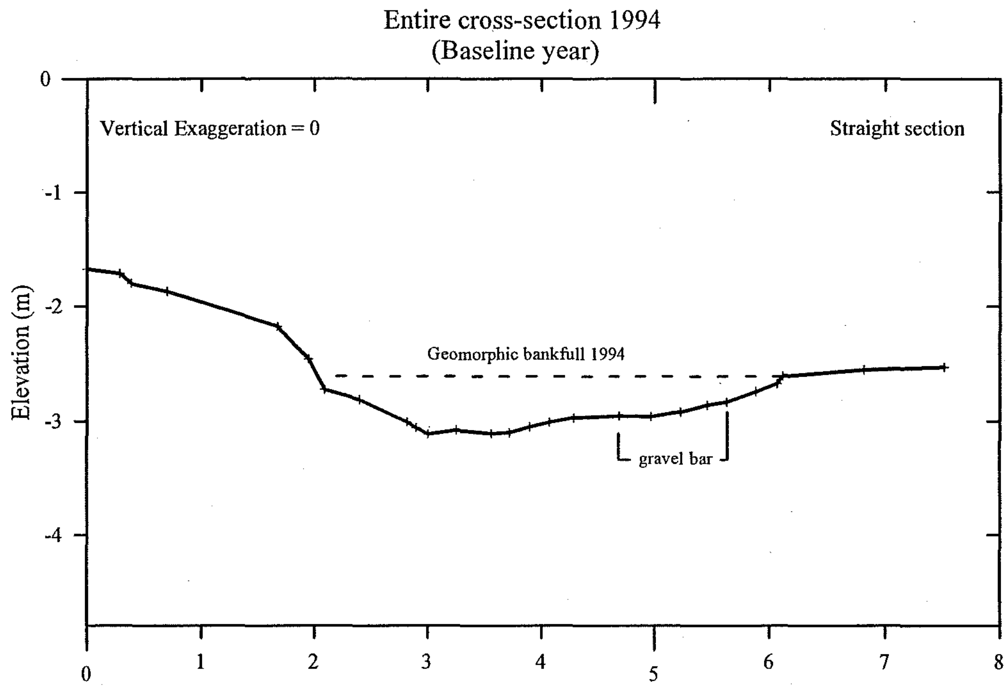
Price Creek cross-section 13 (continued)
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998

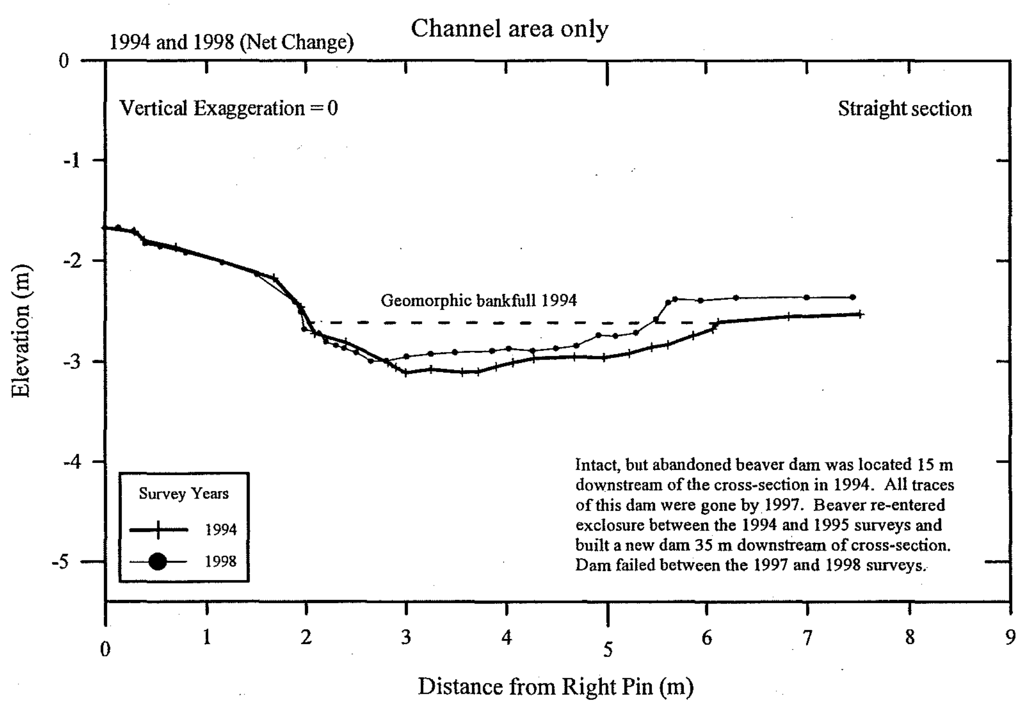
Undercuts removed for clarity.



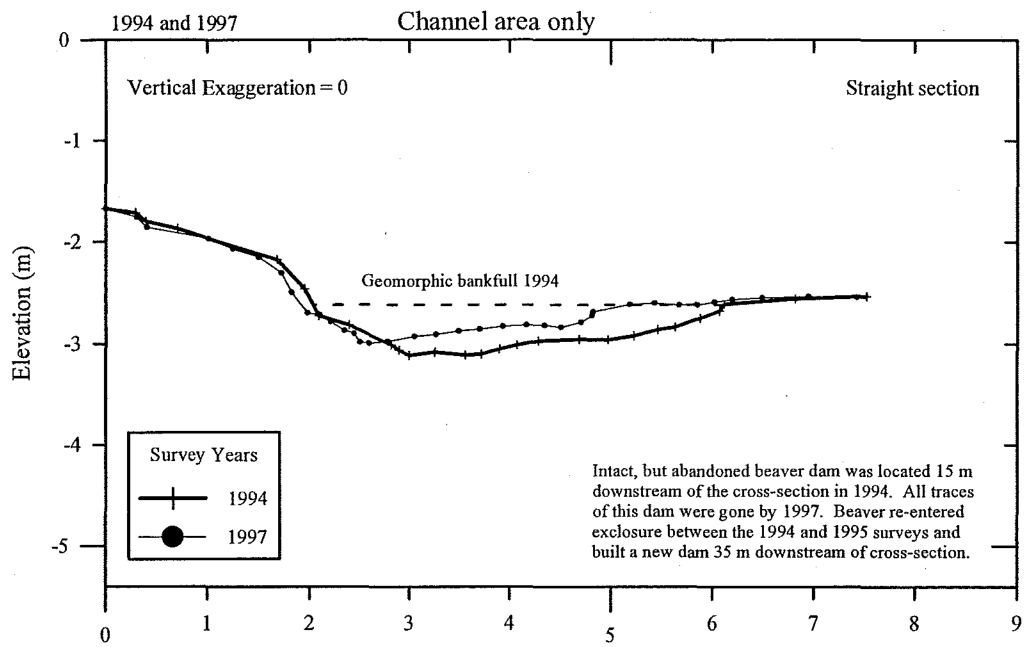


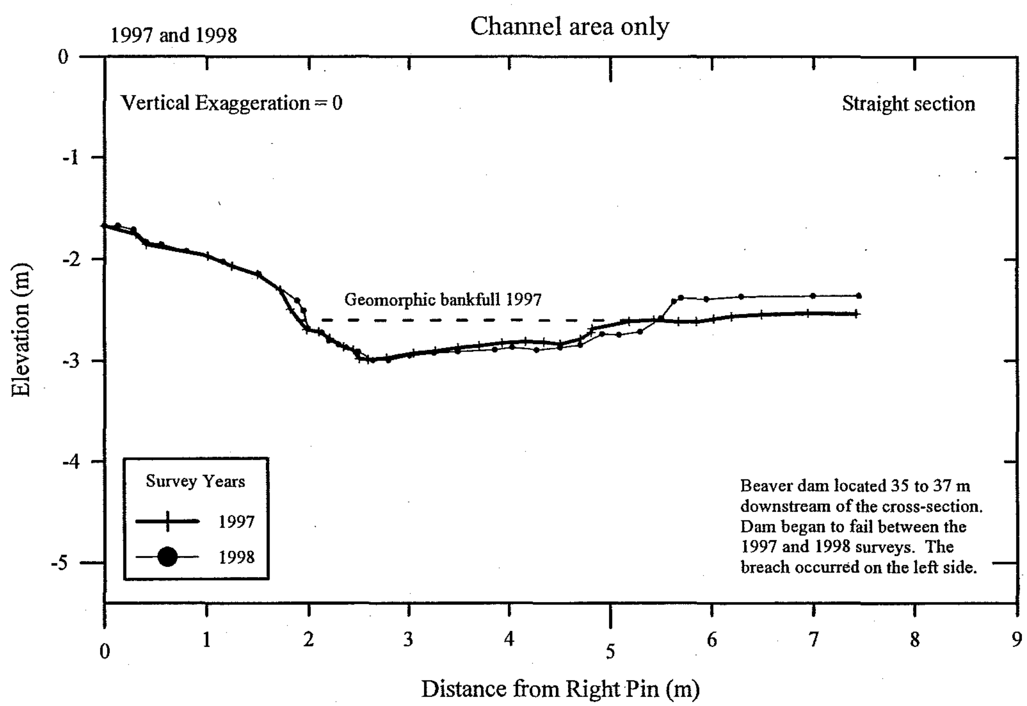
Price Creek cross-section 14
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998



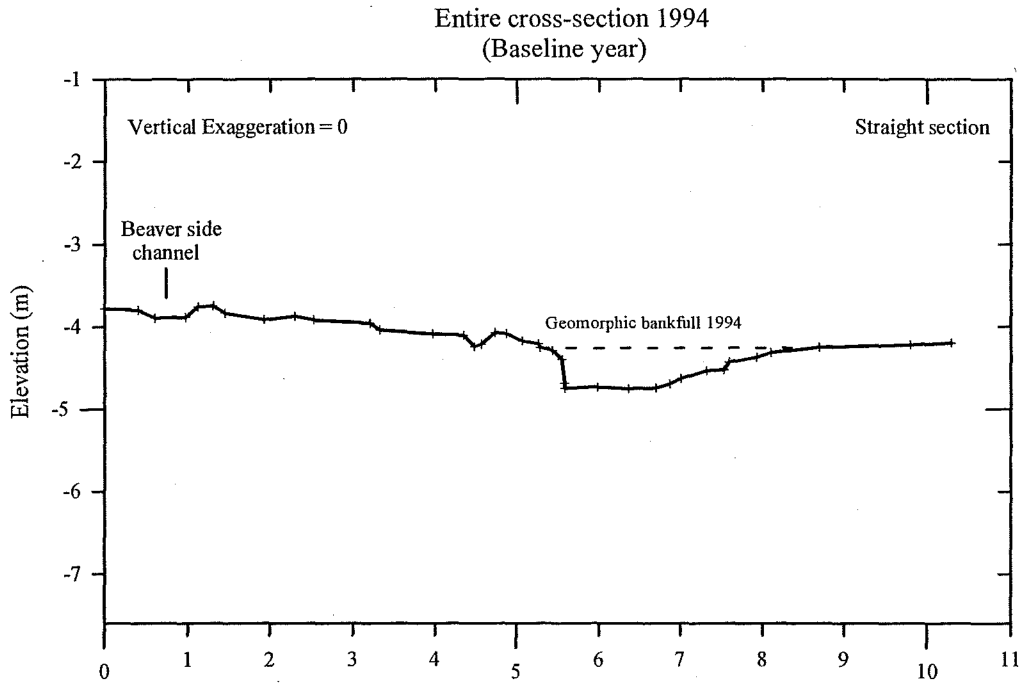


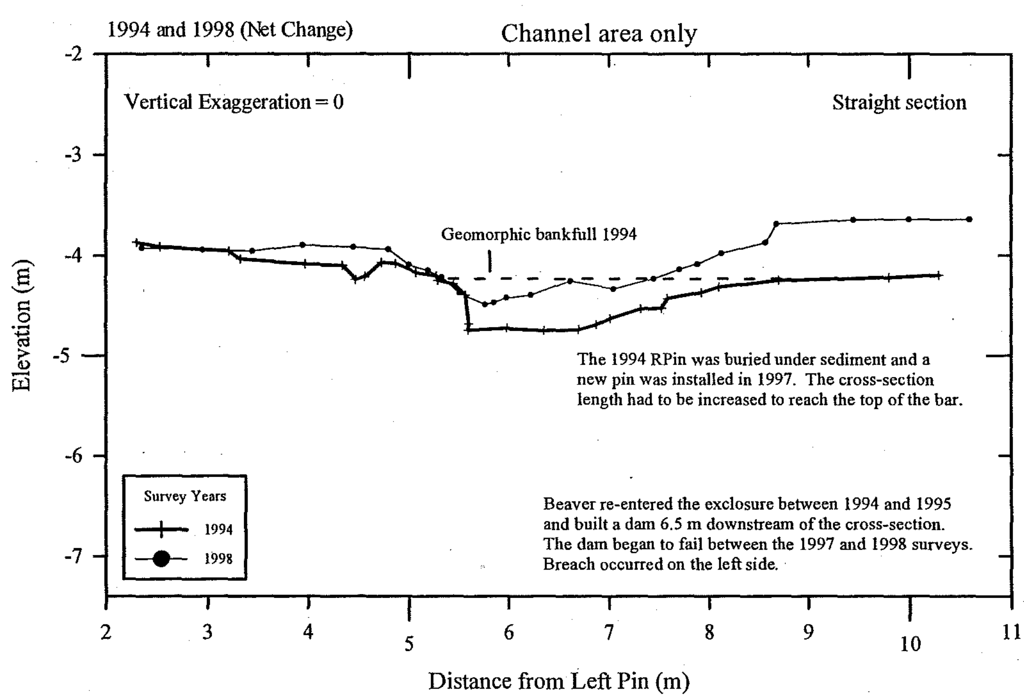
Price Creek cross-section 14 (continued)
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998



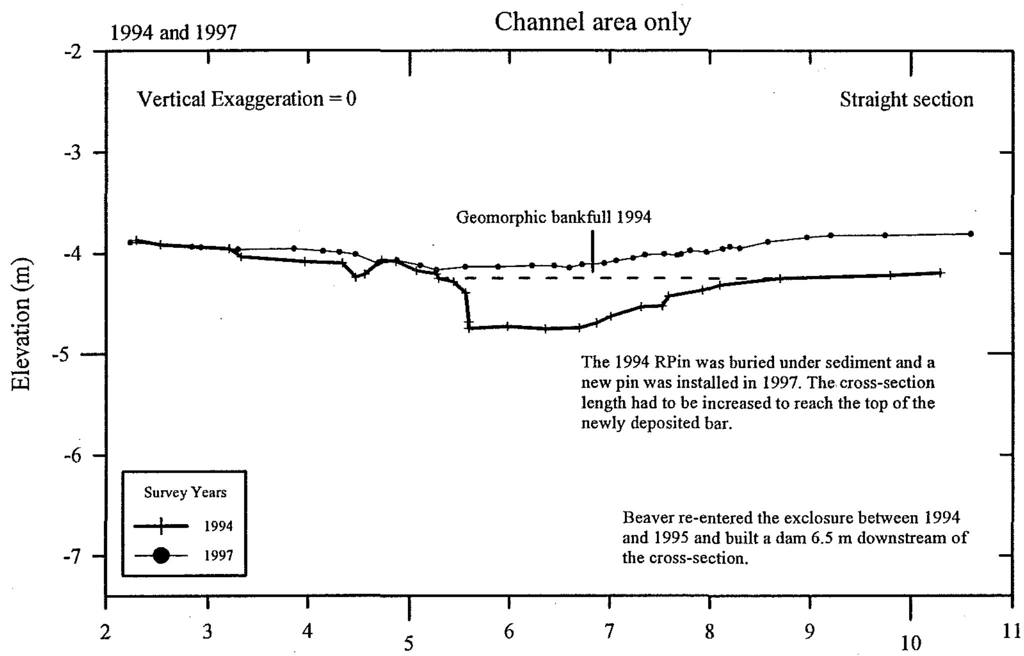


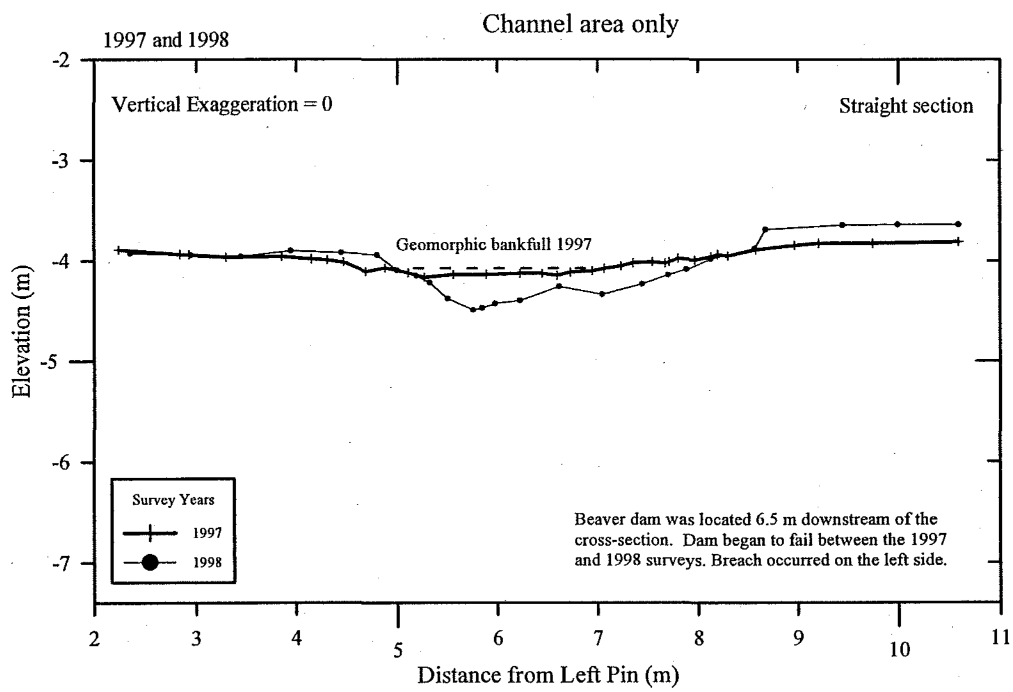
Price Creek cross-section 15
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998



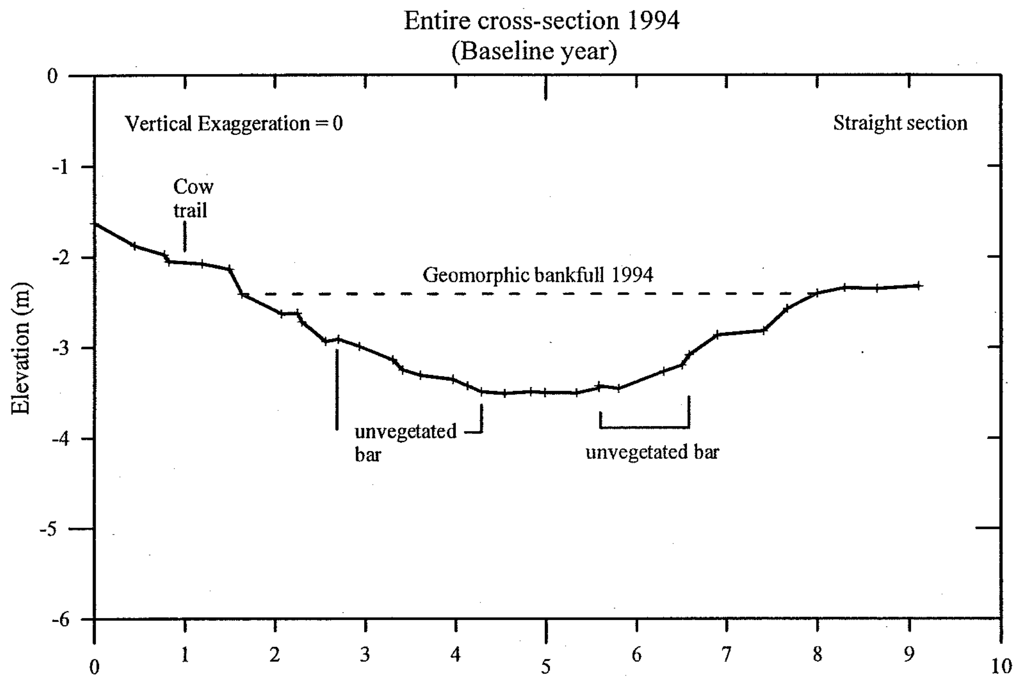


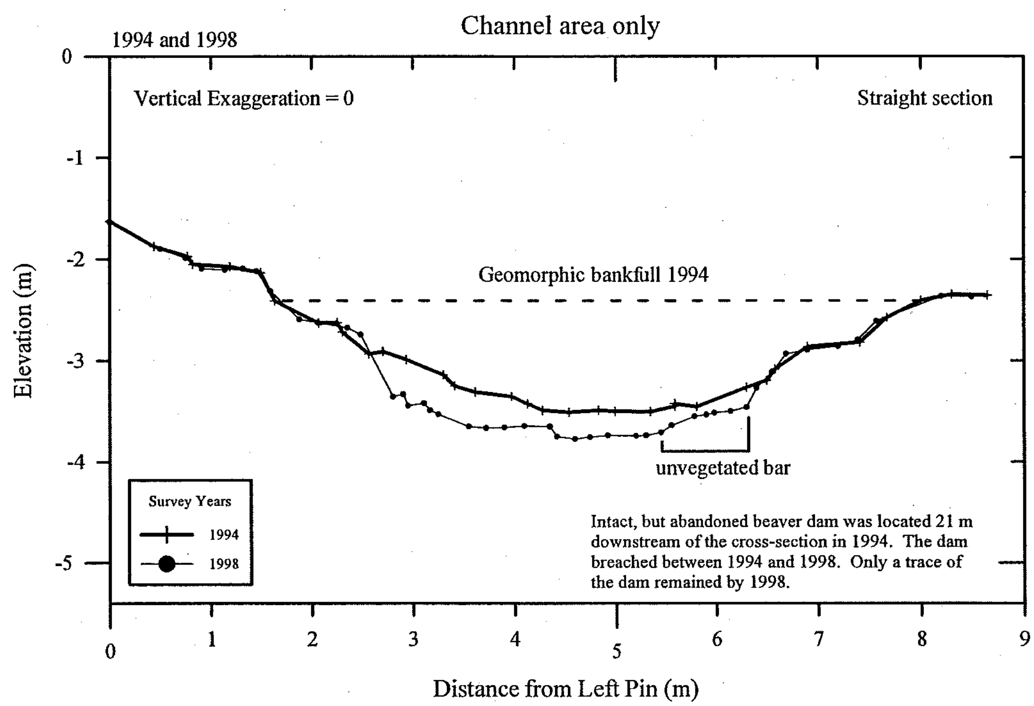
Price Creek cross-section 15 (continued)
New Elk Exclosure/Beaver dam controlled
1994, 1997, and 1998



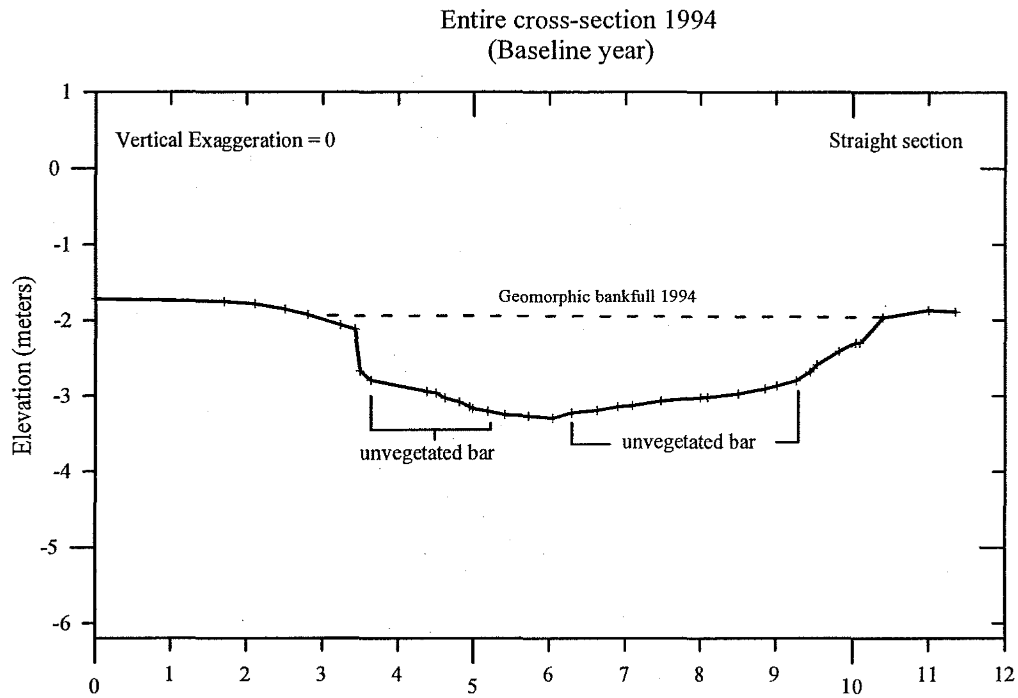


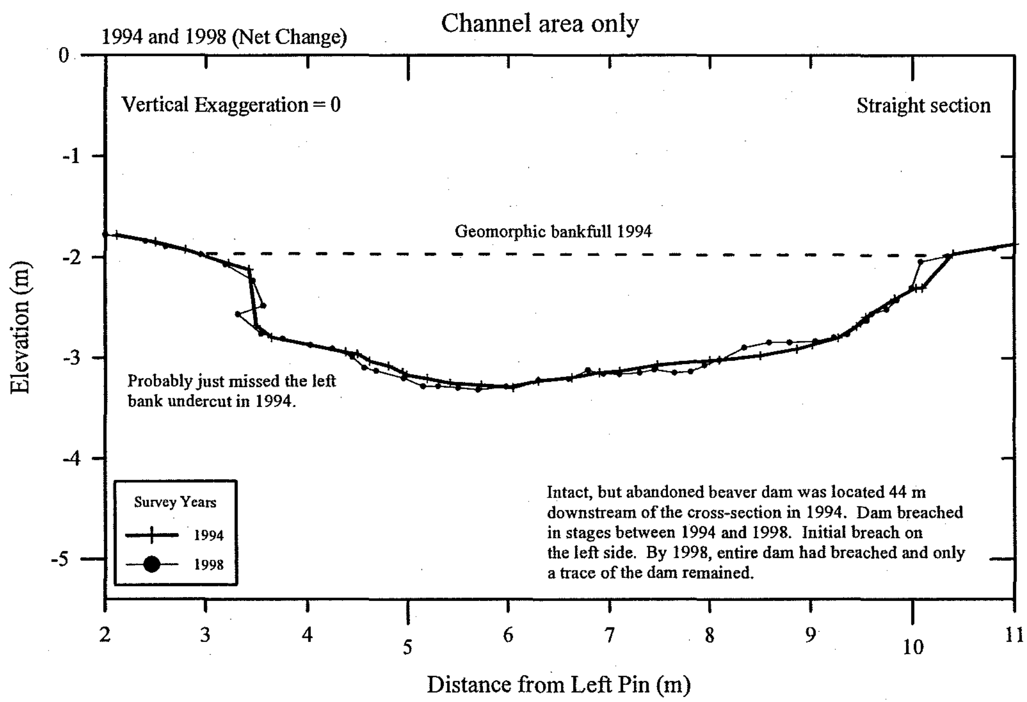
Price Creek cross-section 16
Riparian Guidelines/Beaver dam influence
1994 and 1998



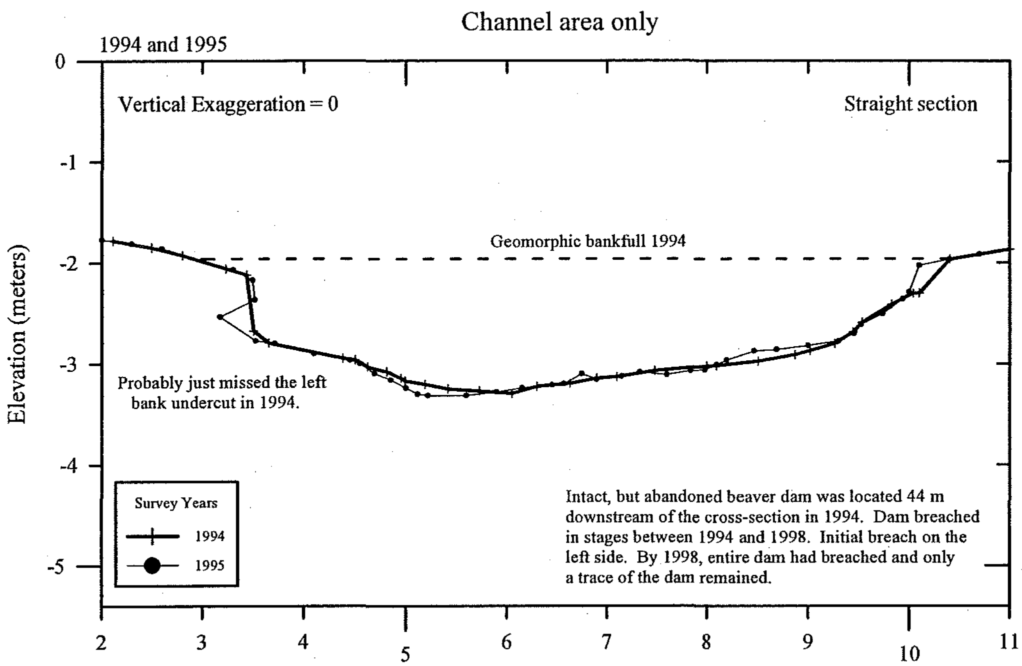


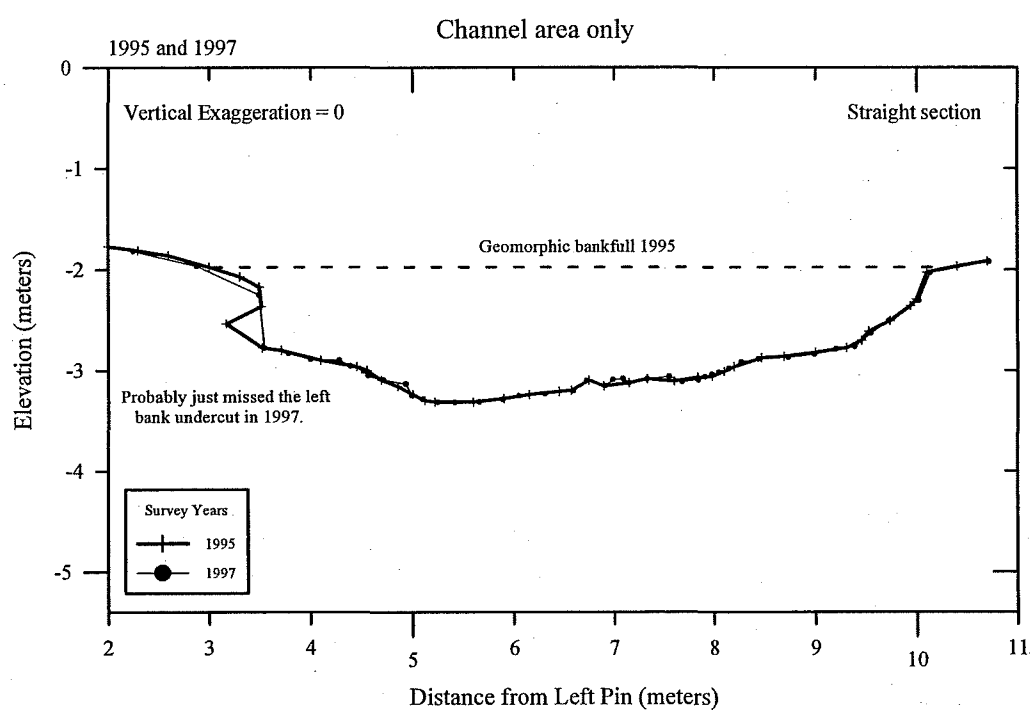
Price Creek cross-section 17
Riparian Guidelines/Beaver dam influence
1994, 1995, 1997, and 1998



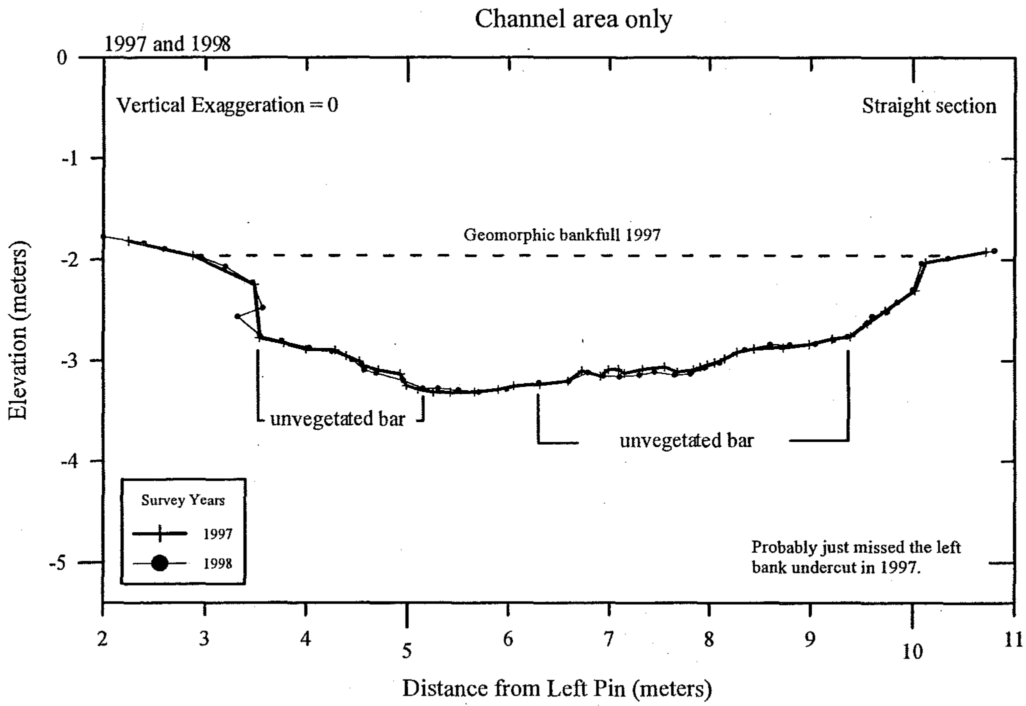


Price Creek cross-section 17 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995, 1997, and 1998





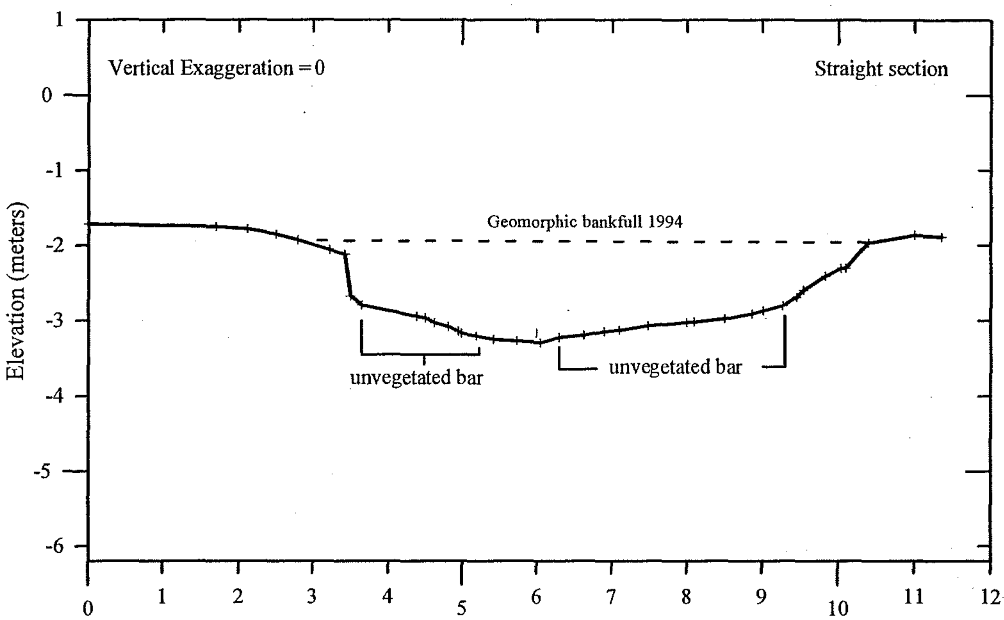
Price Creek cross-section 17 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995, 1997, and 1998



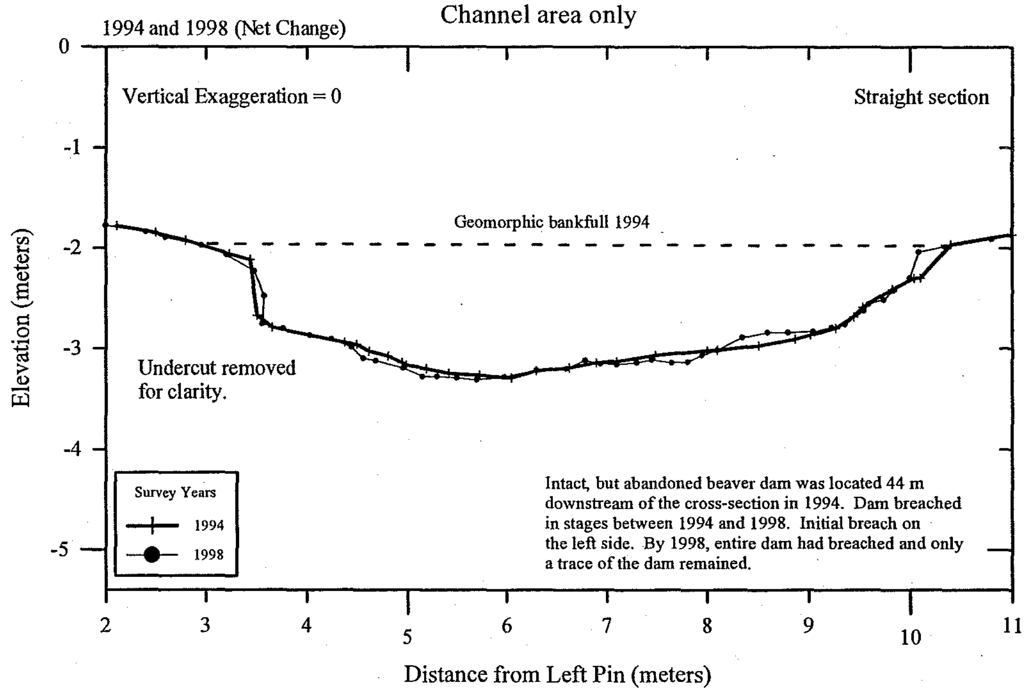
Price Creek cross-section 17 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995, 1997, and 1998

Undercuts removed for clarity.

Entire cross-section 1994
(Baseline year)

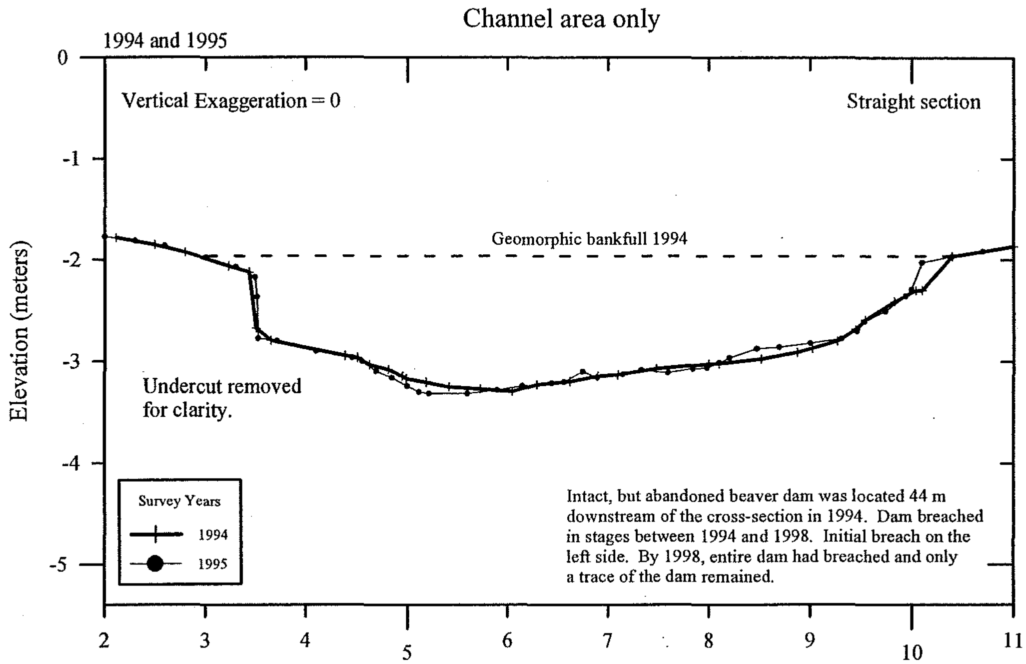


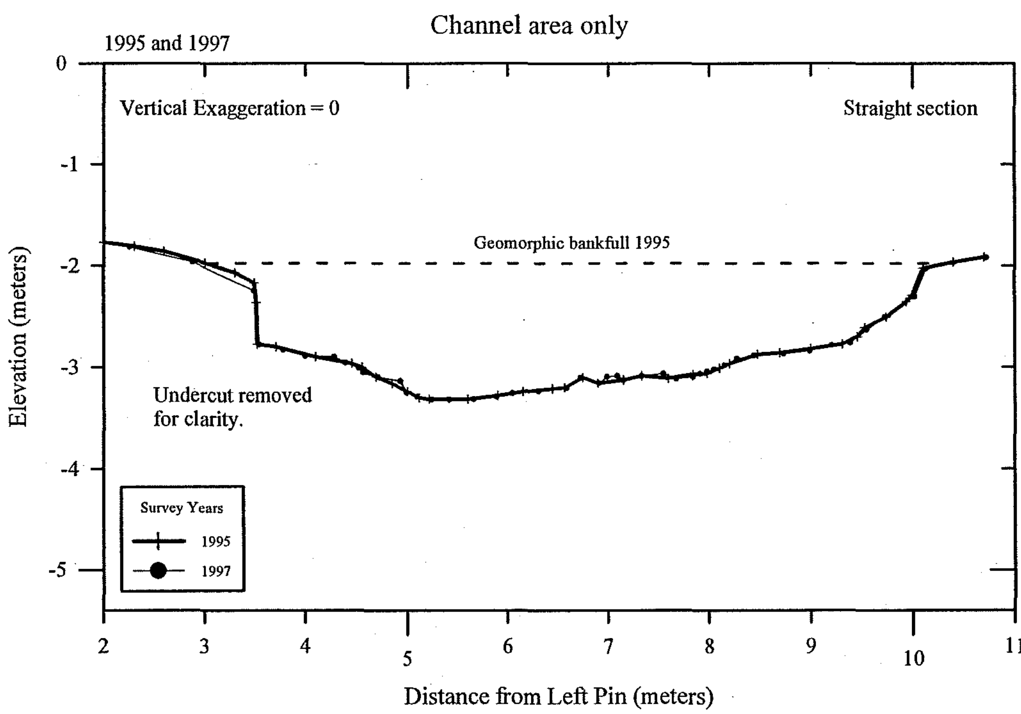
Channel area only



Price Creek cross-section 17 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995, 1997, and 1998

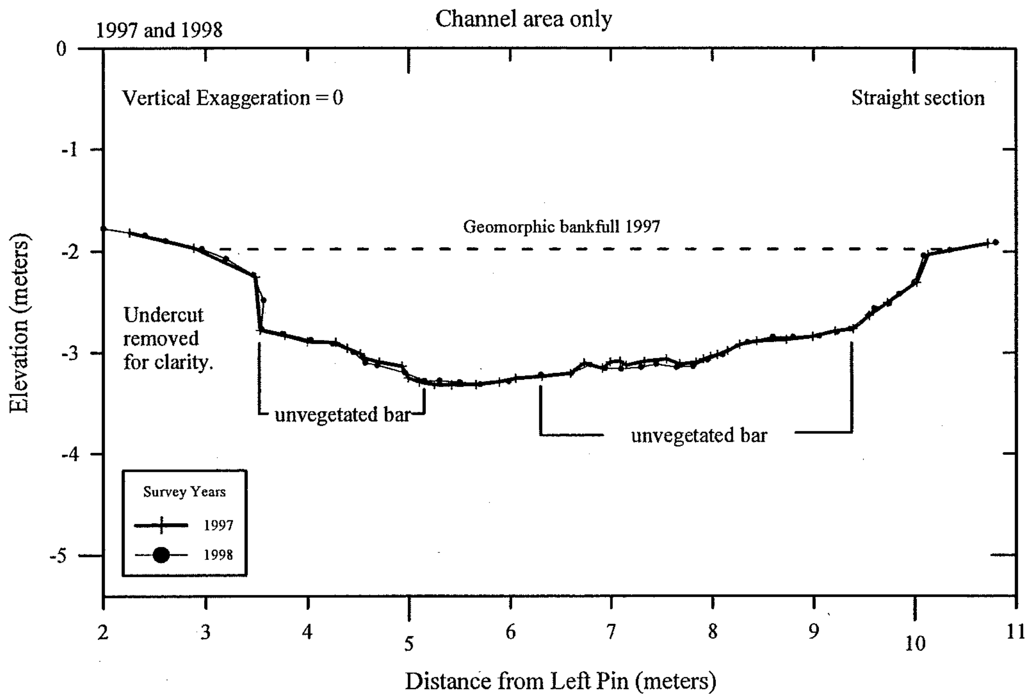
Undercuts removed for clarity.



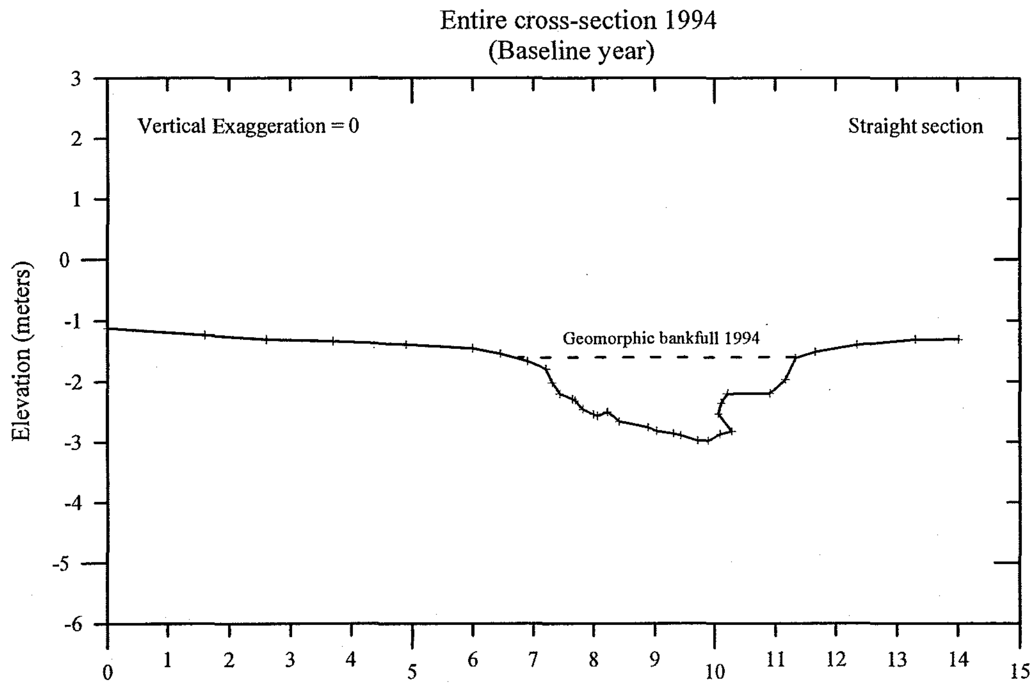


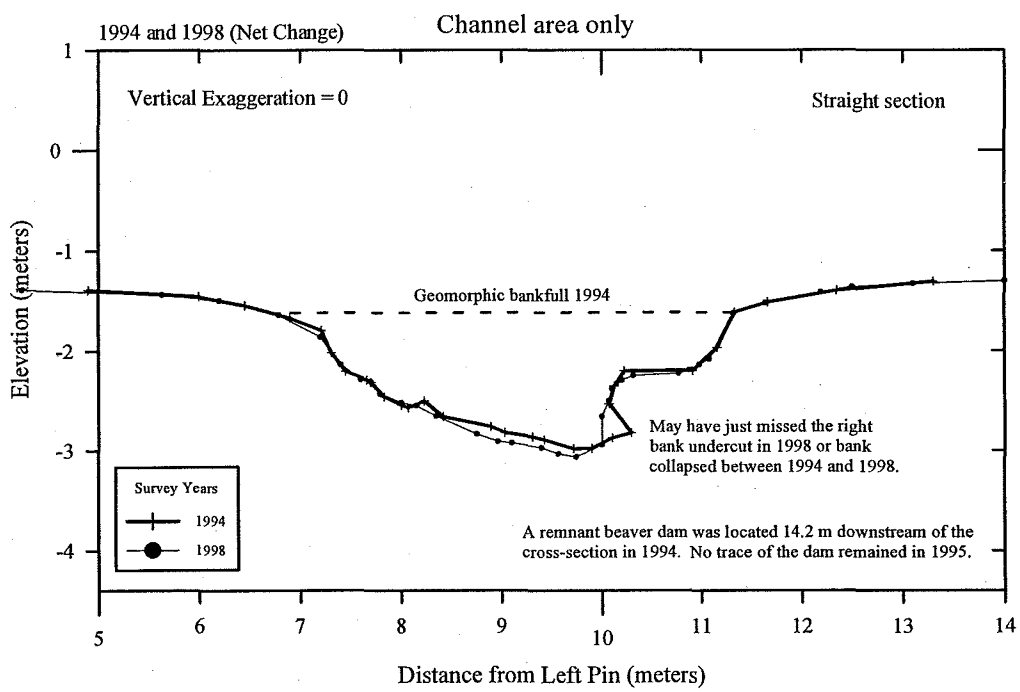
Price Creek cross-section 17 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995, 1997, and 1998

Undercuts removed for clarity.

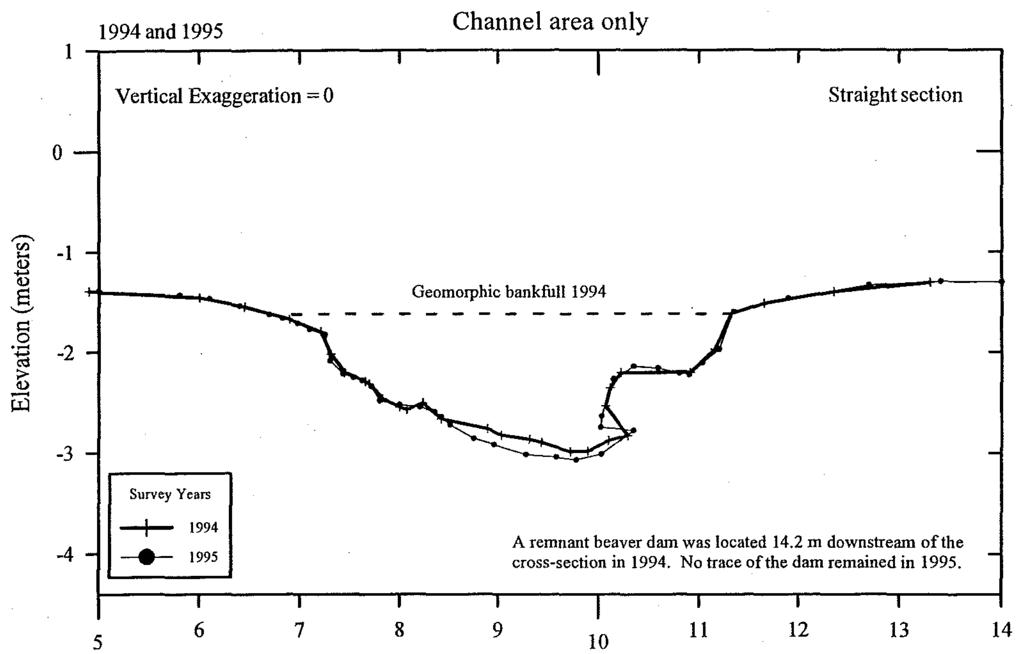


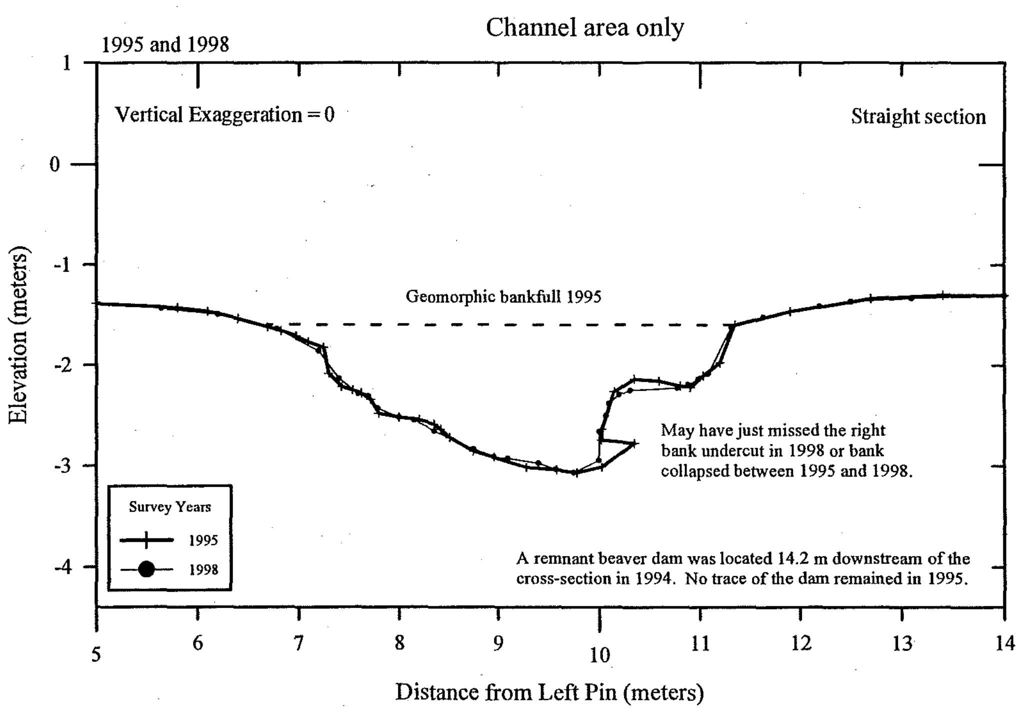
Price Creek cross-section 18
Riparian Guidelines/Beaver dam influence
1994, 1995, and 1998





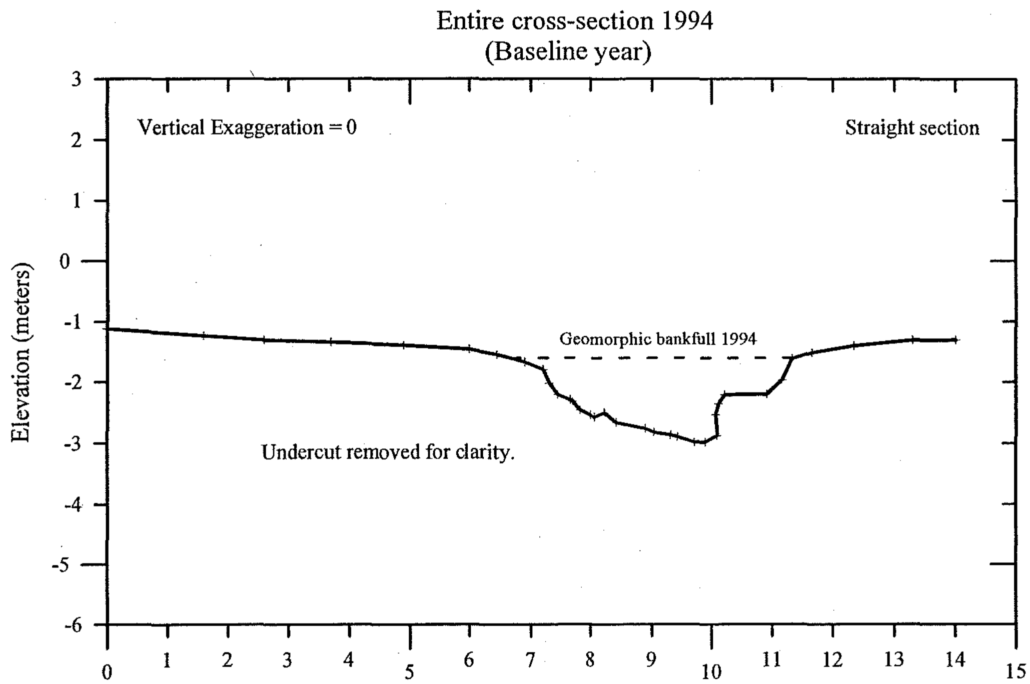
Price Creek cross-section 18 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995, and 1998

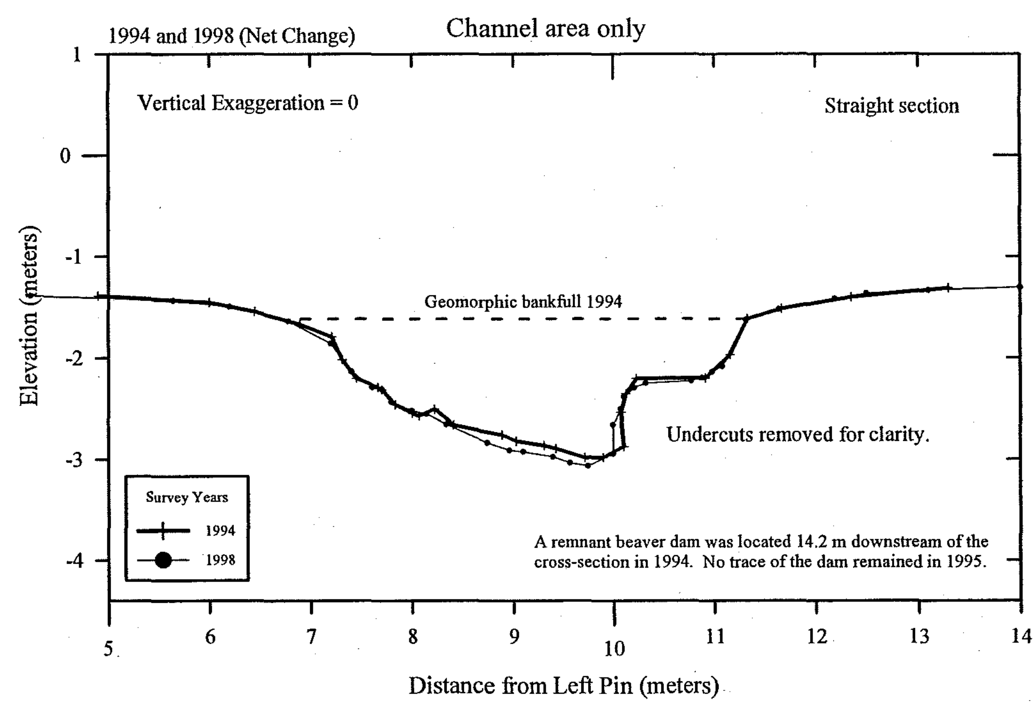




Price Creek cross-section 18 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995 and 1998

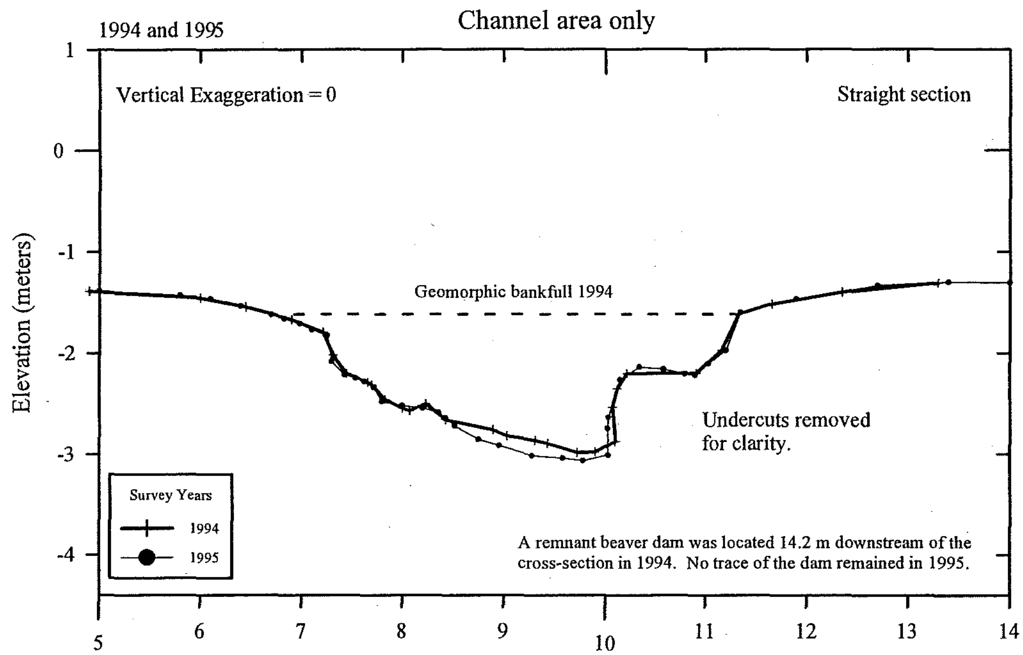
Undercuts removed for clarity.

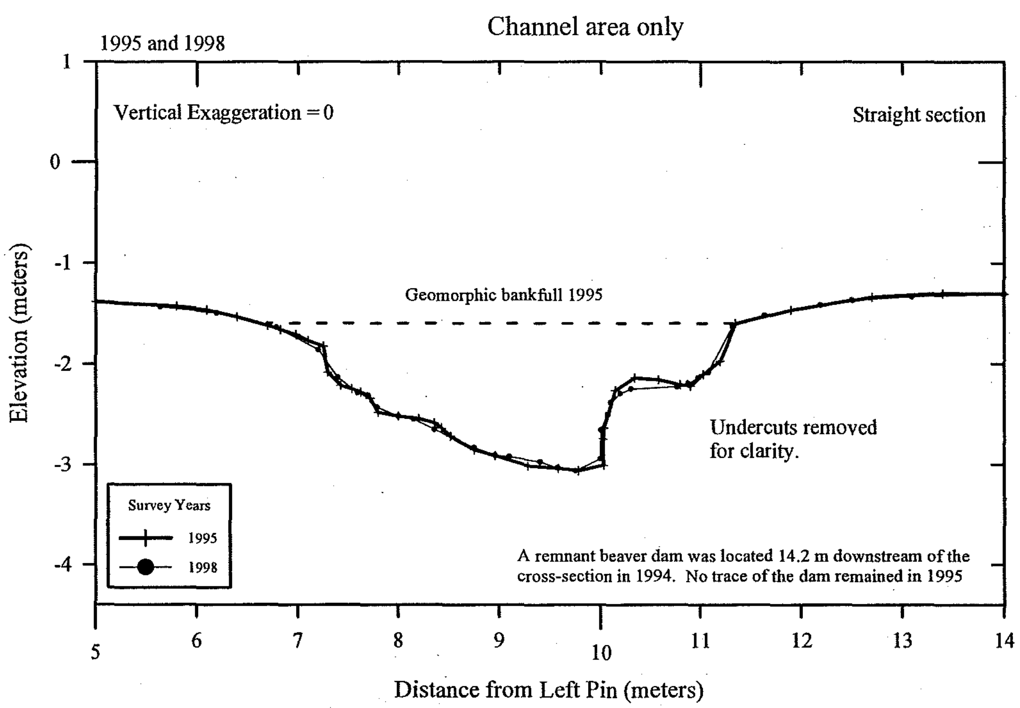




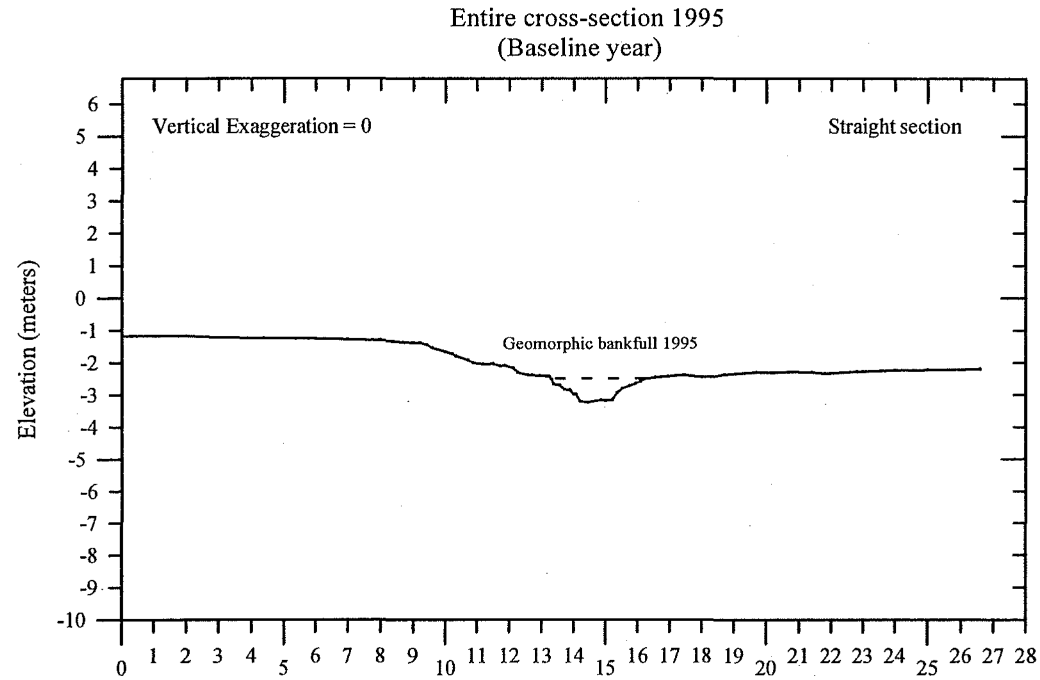
Price Creek cross-section 18 (continued)
Riparian Guidelines/Beaver dam influence
1994, 1995 and 1998

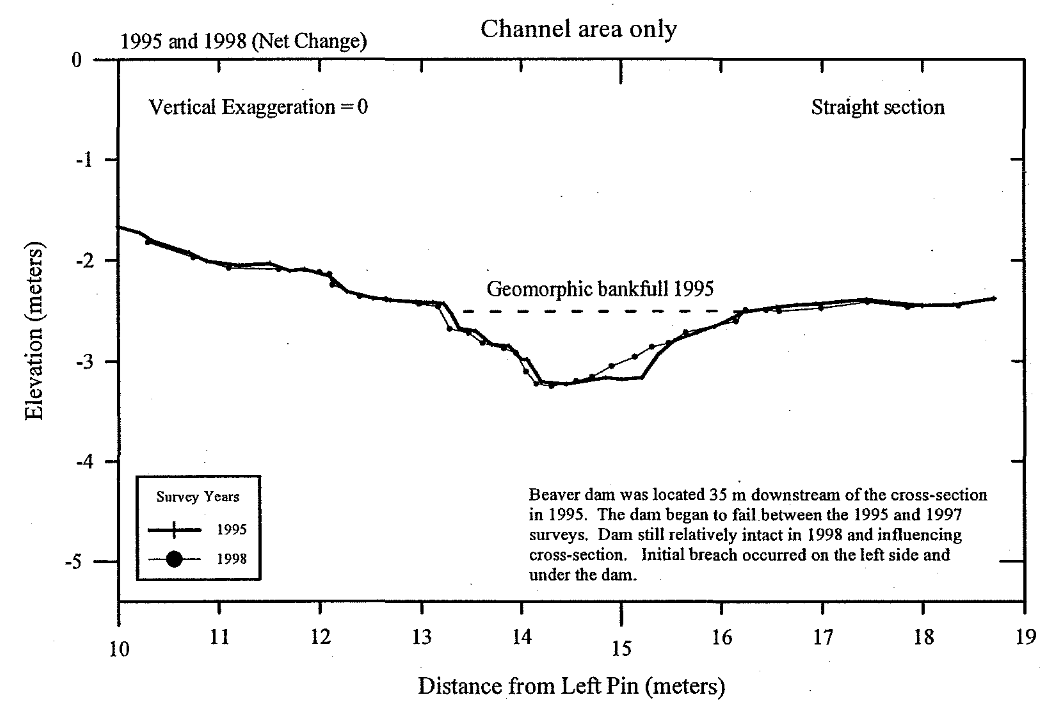
Undercuts removed for clarity.



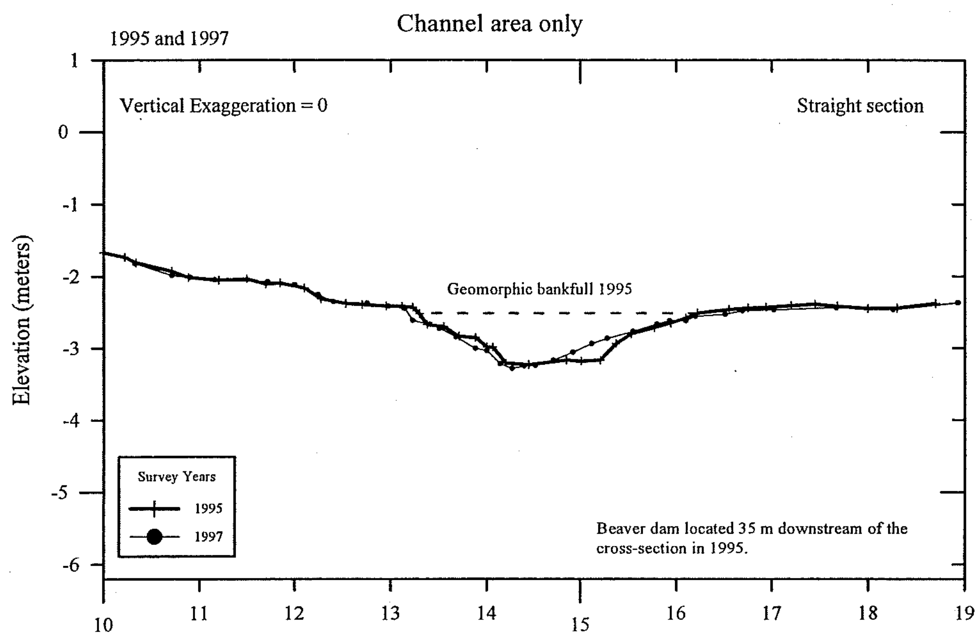


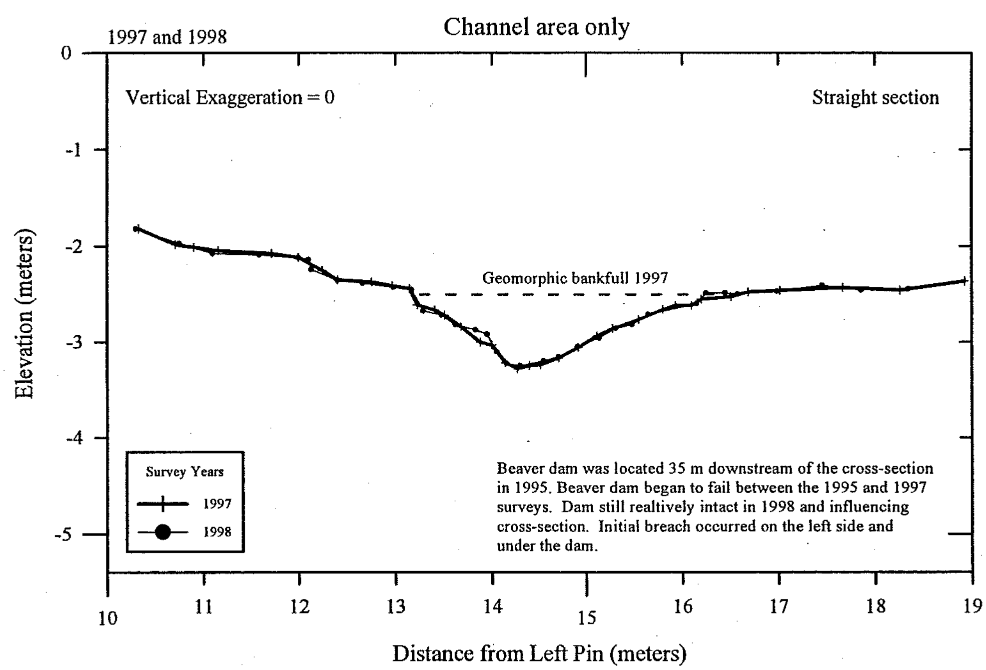
Price Creek cross-section 19
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998



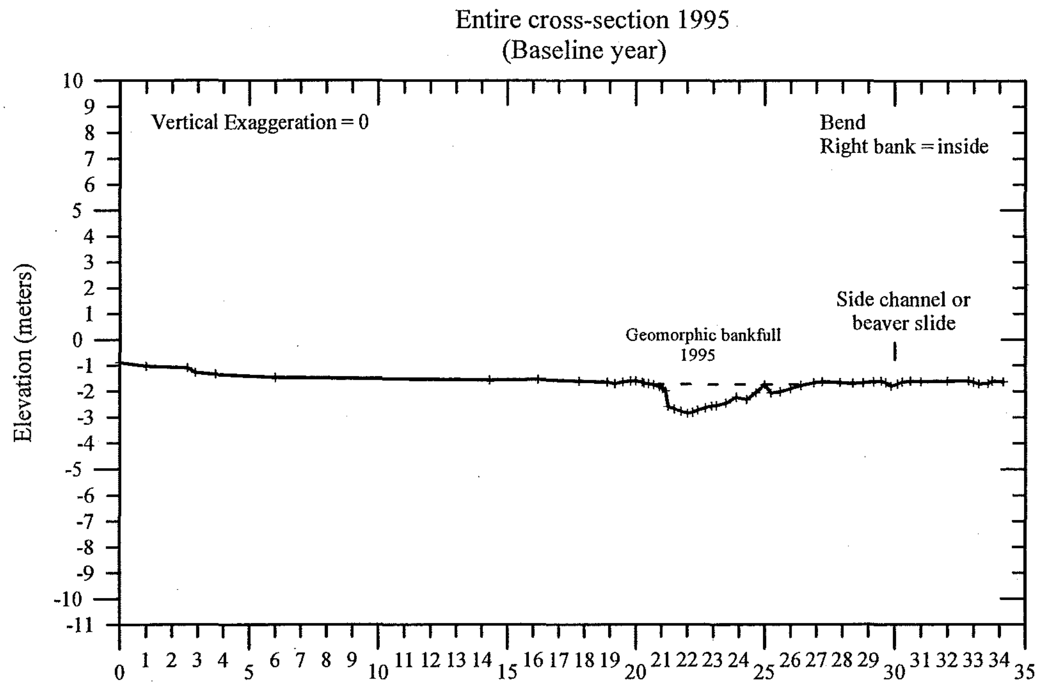


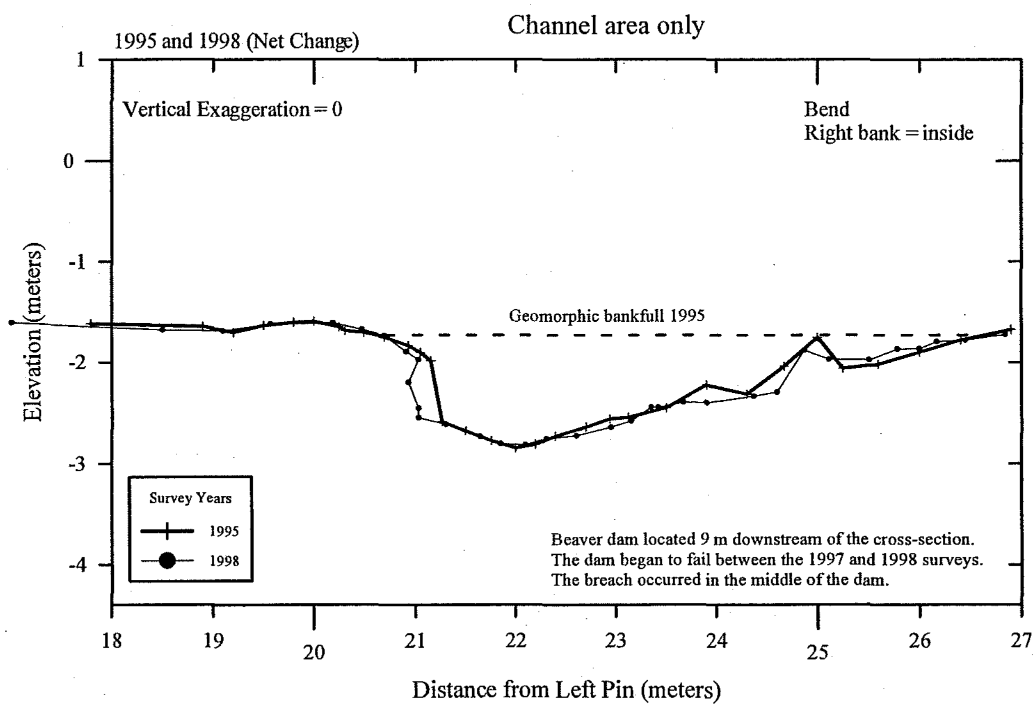
Price Creek cross-section 19 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998



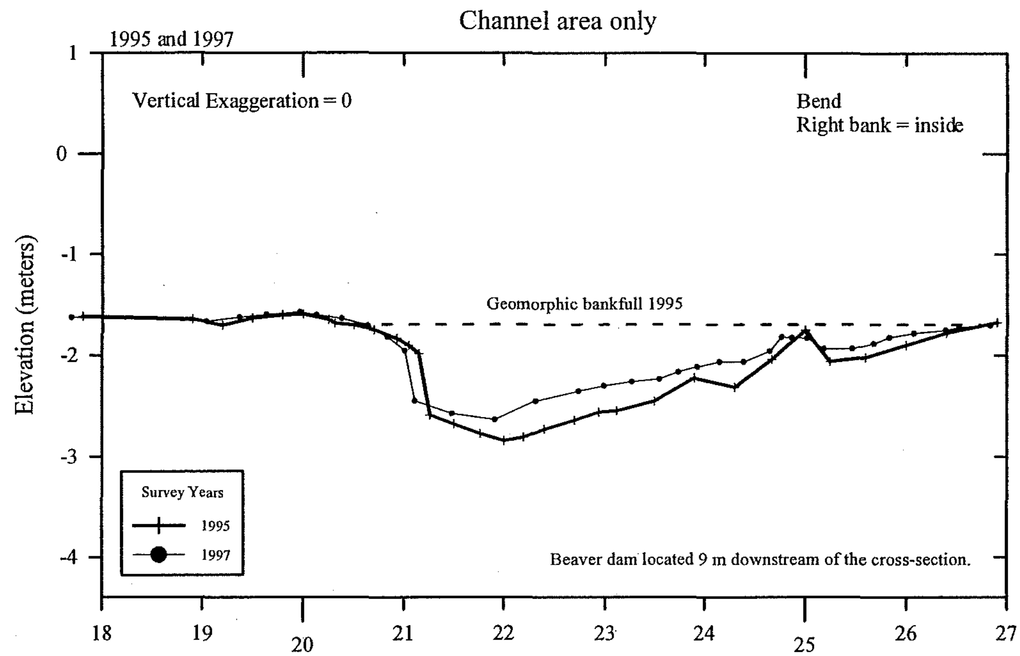


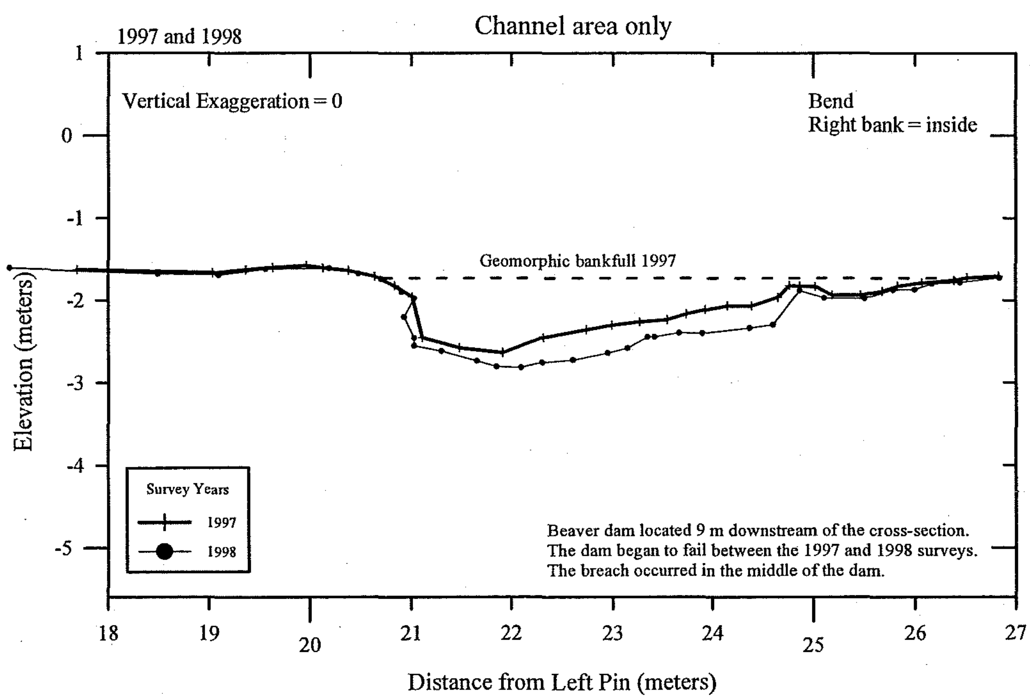
Price Creek cross-section 20
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998



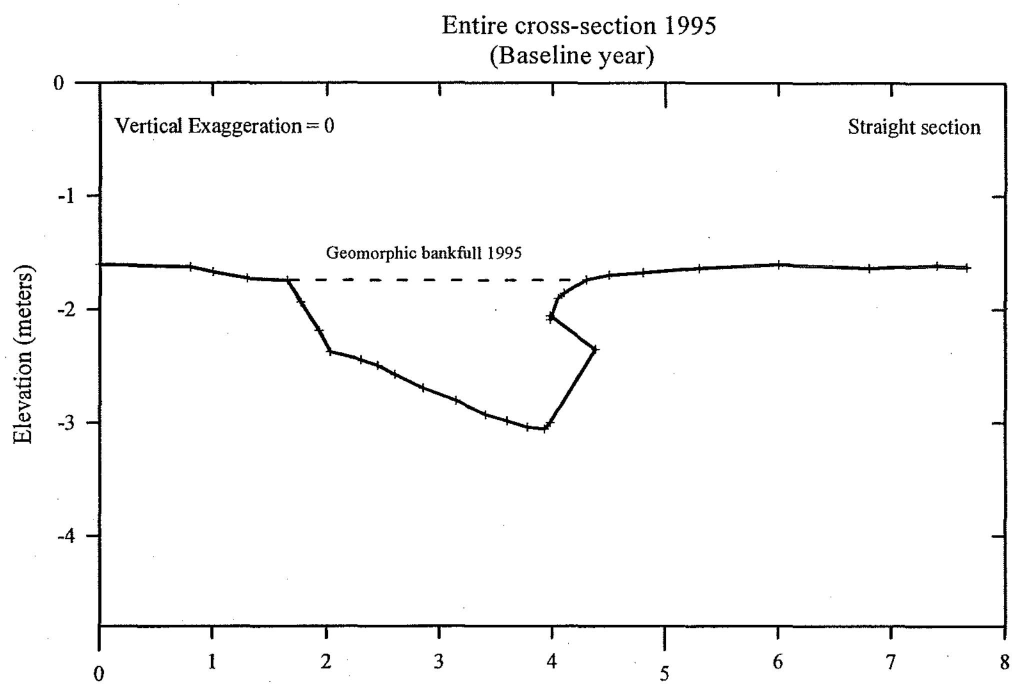


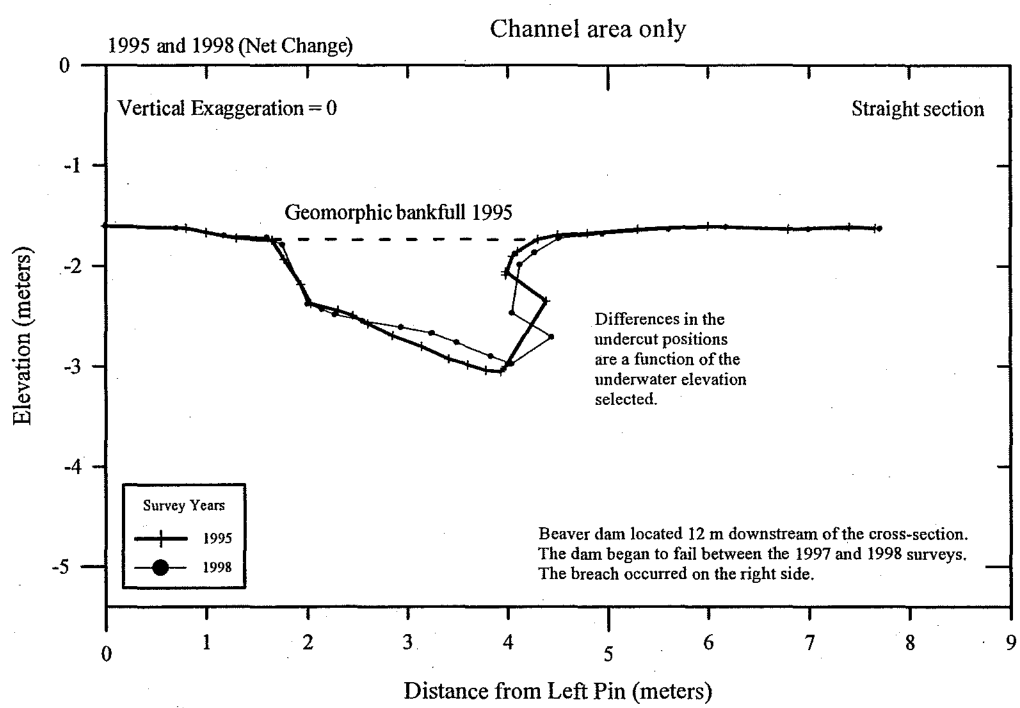
Price Creek cross-section 20 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998



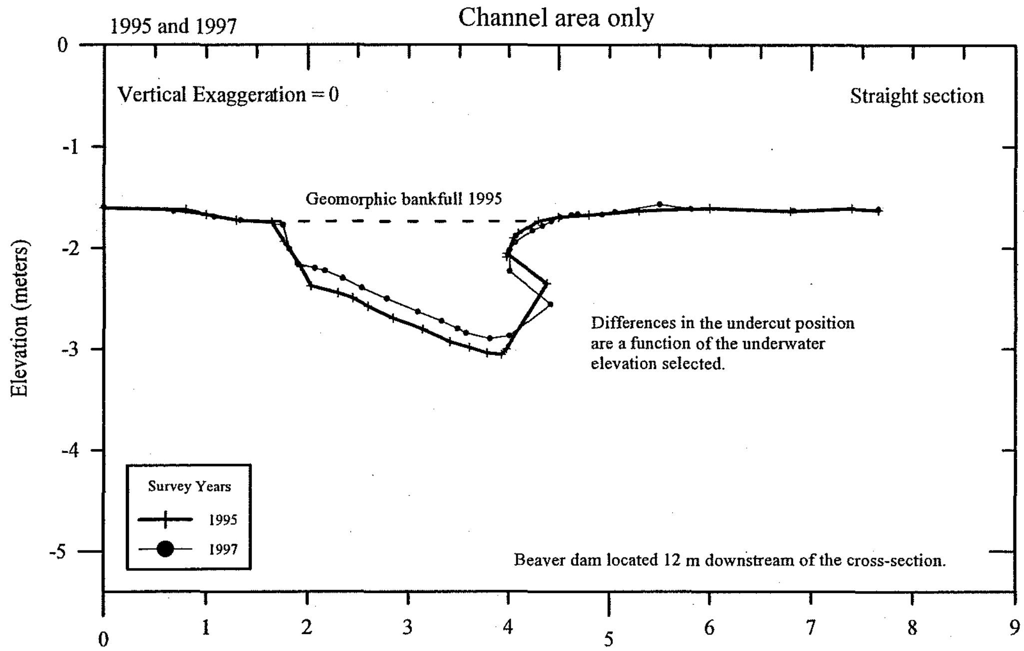


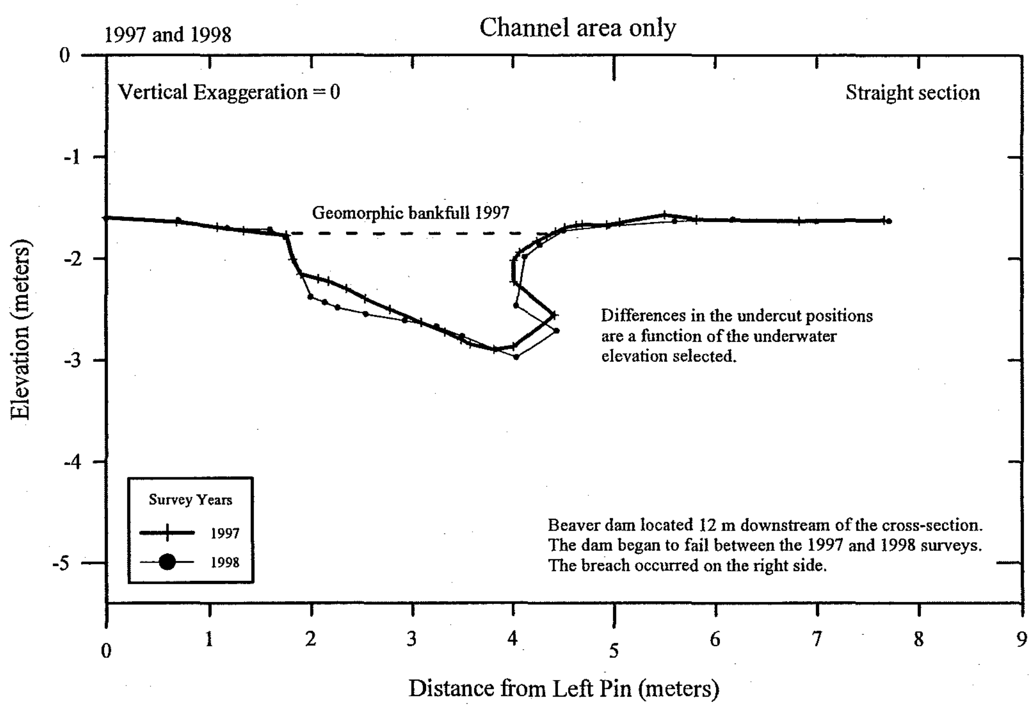
Price Creek cross-section 21
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998





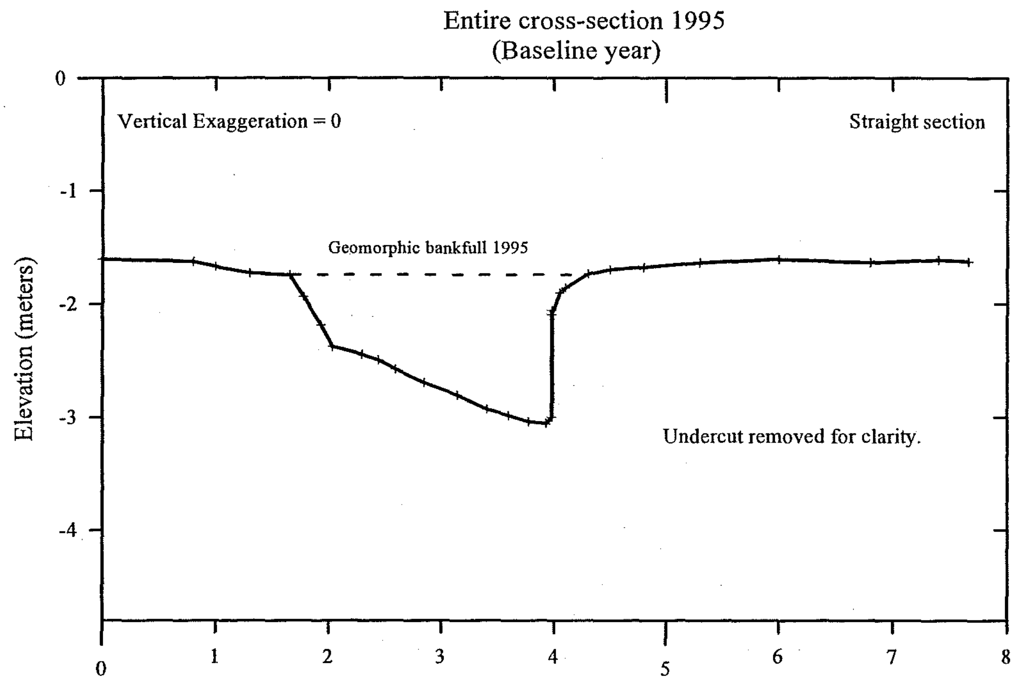
Price Creek cross-section 21 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

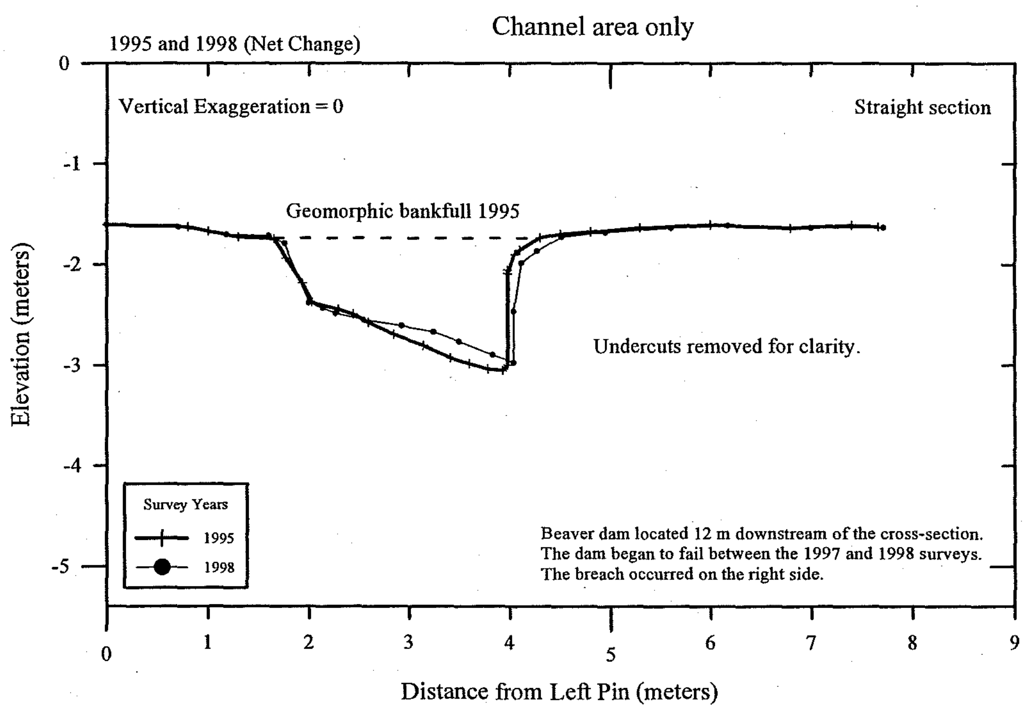




Price Creek cross-section 21 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

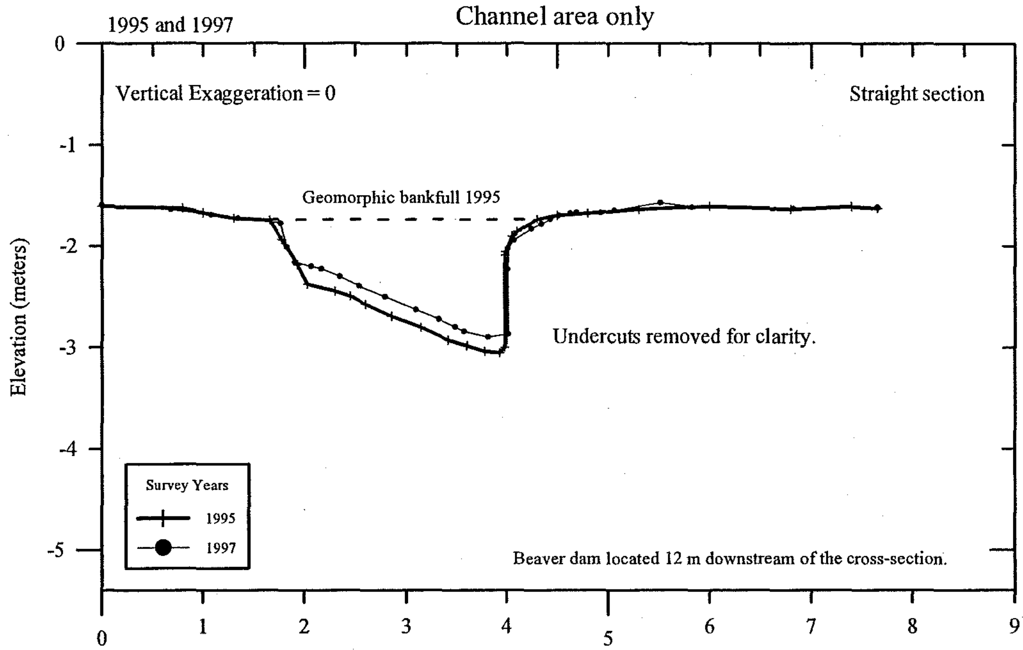
Undercuts removed for clarity

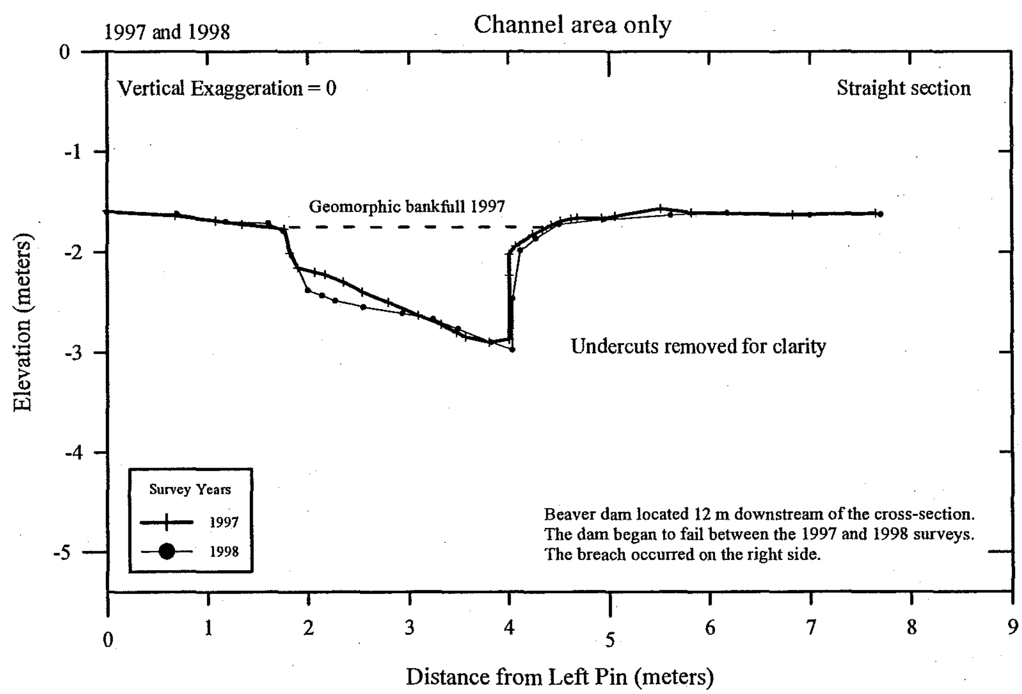




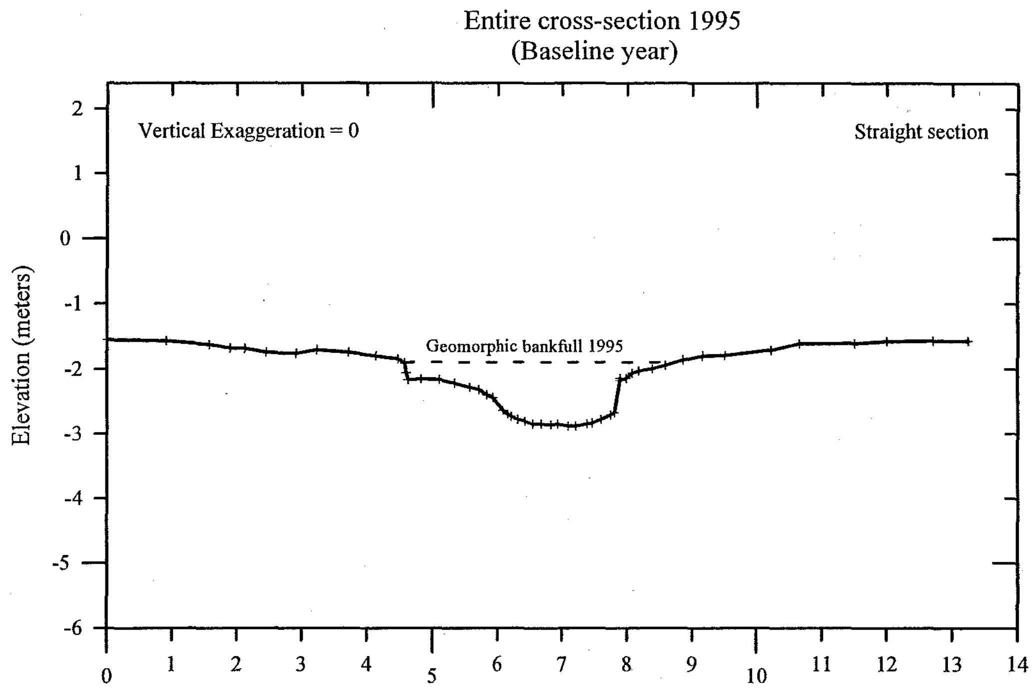
Price Creek cross-section 21 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

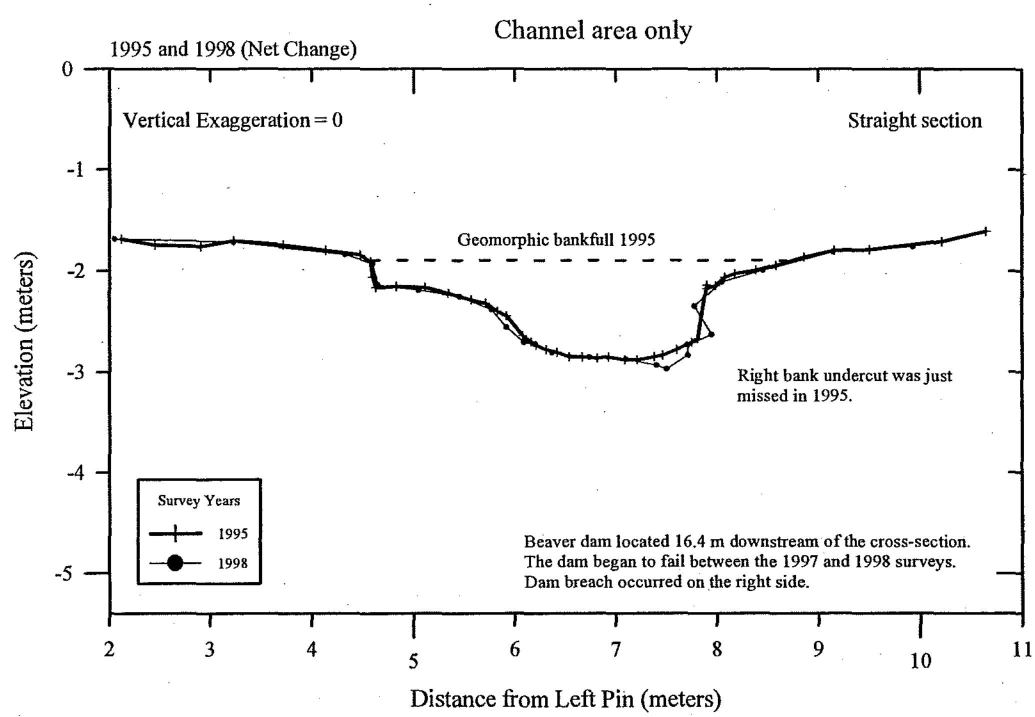
Undercuts removed for clarity.



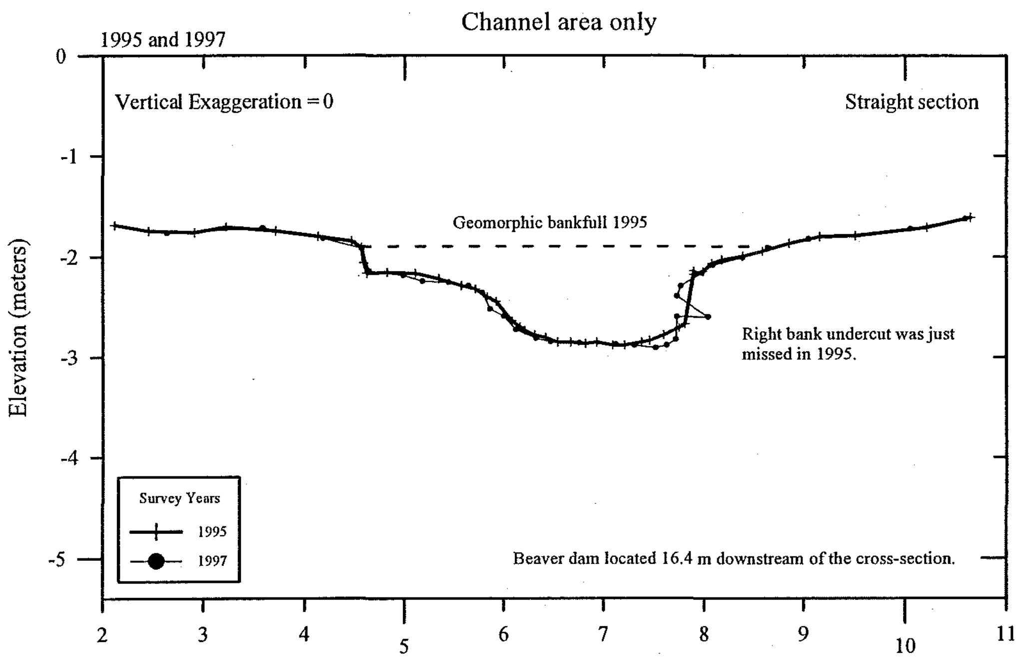


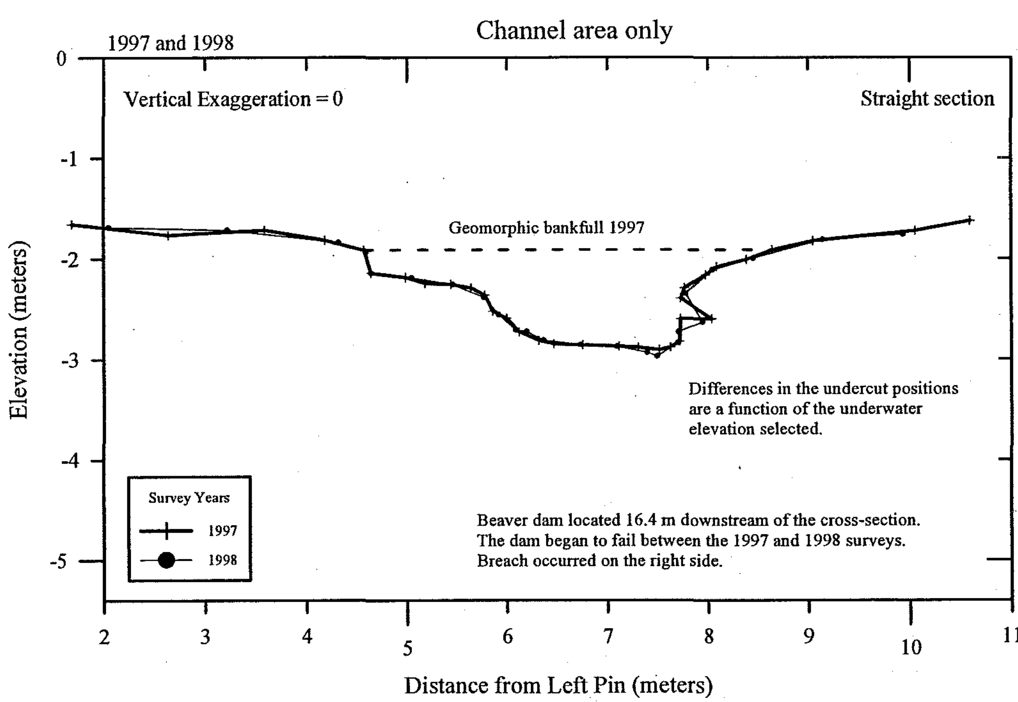
Price Creek cross-section 22
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998





Price Creek cross-section 22 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

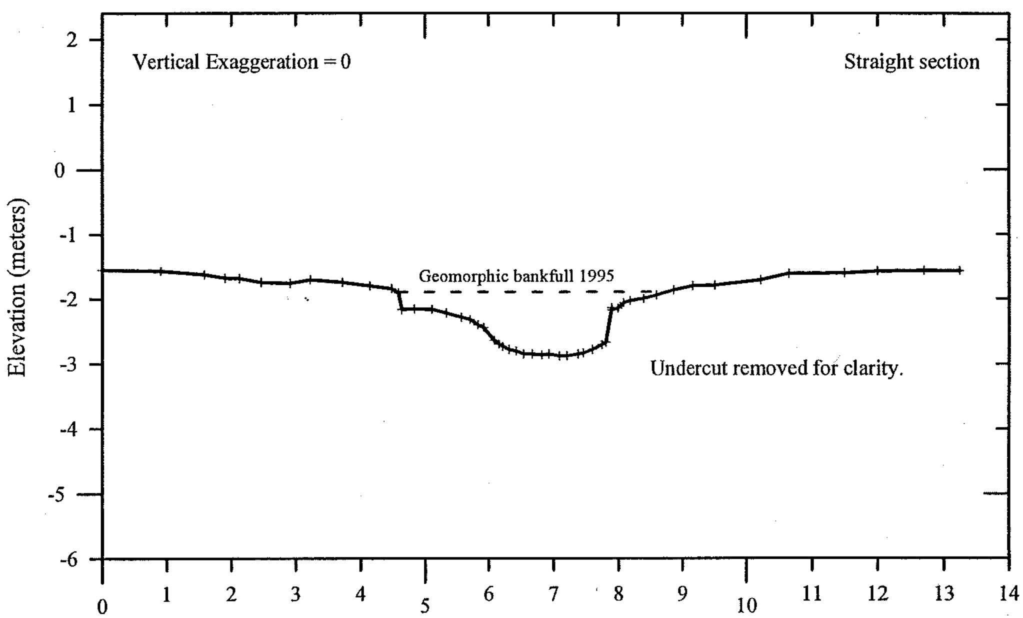




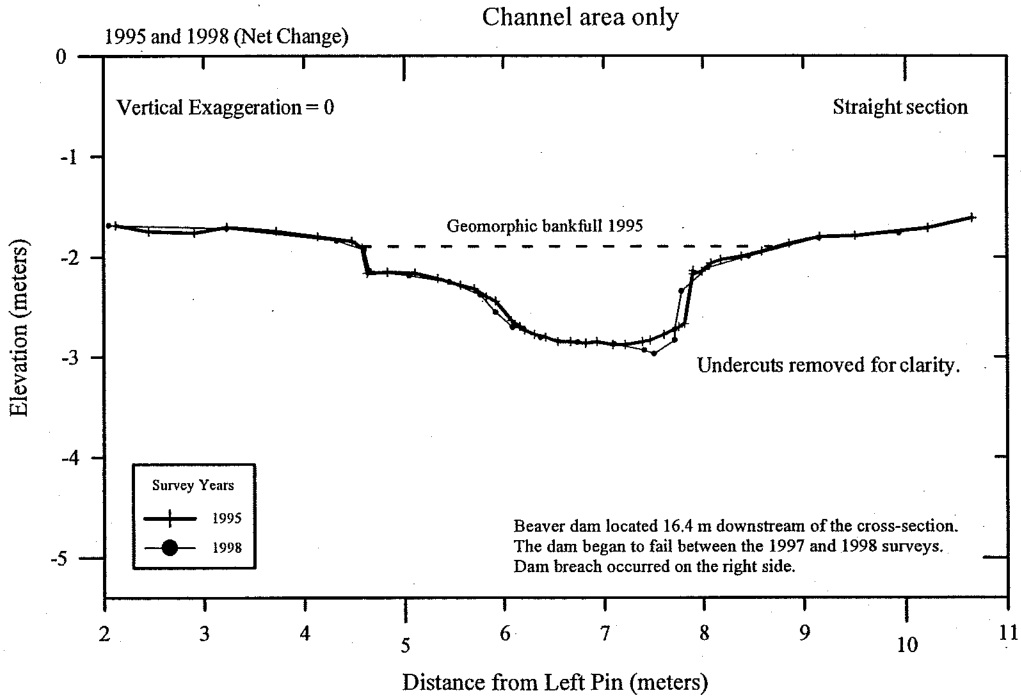
Price Creek cross-section 22 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

Undercuts removed for clarity.

Entire cross-section 1995
(Baseline year)

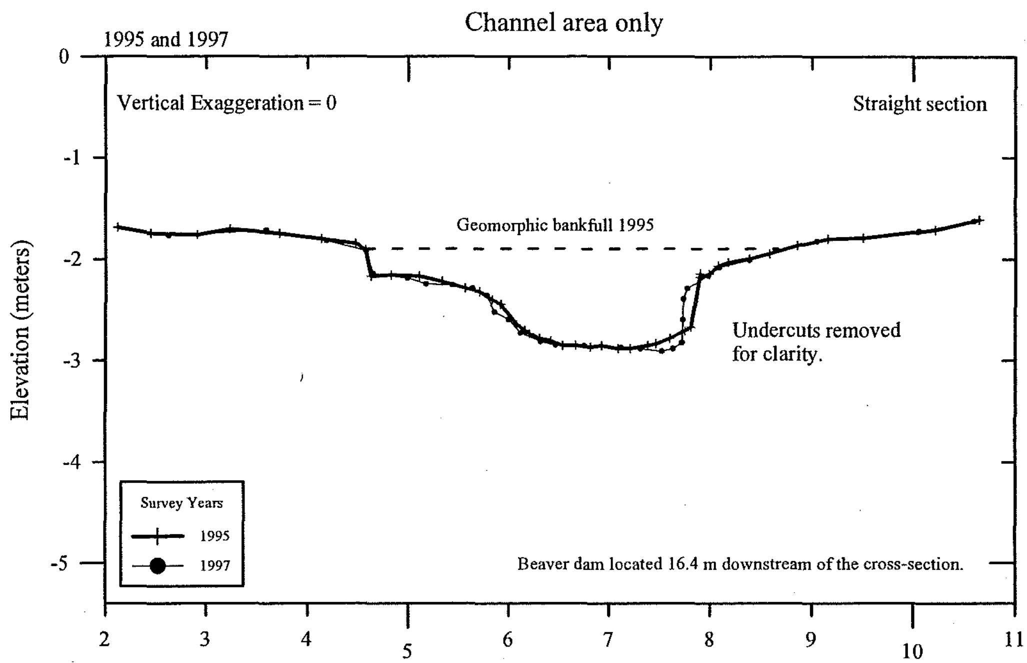


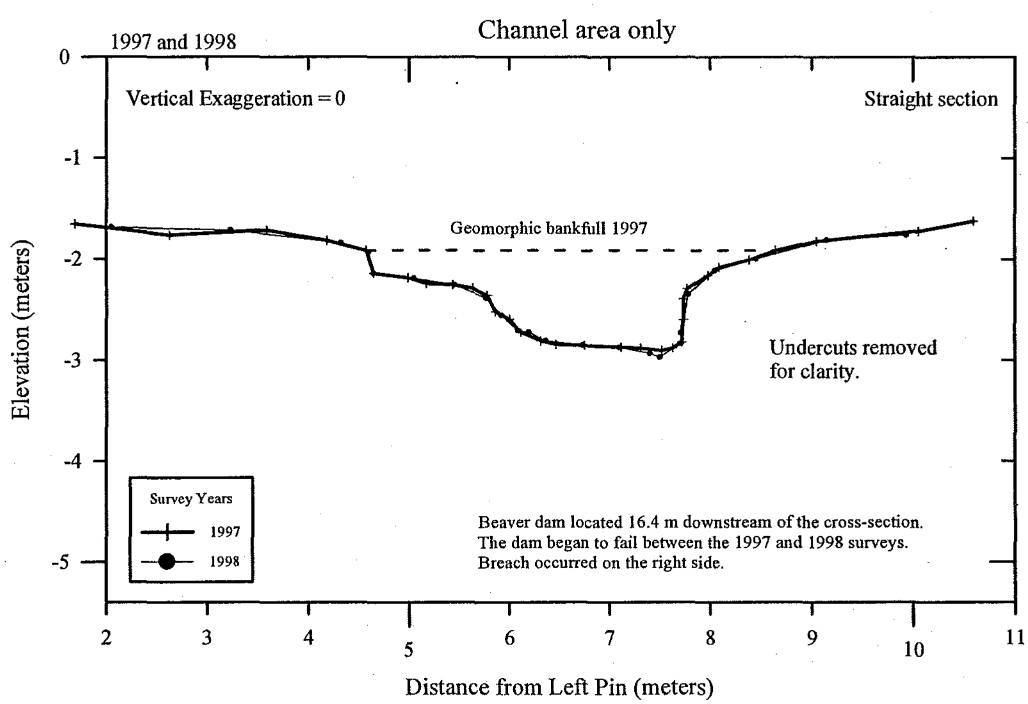
Channel area only



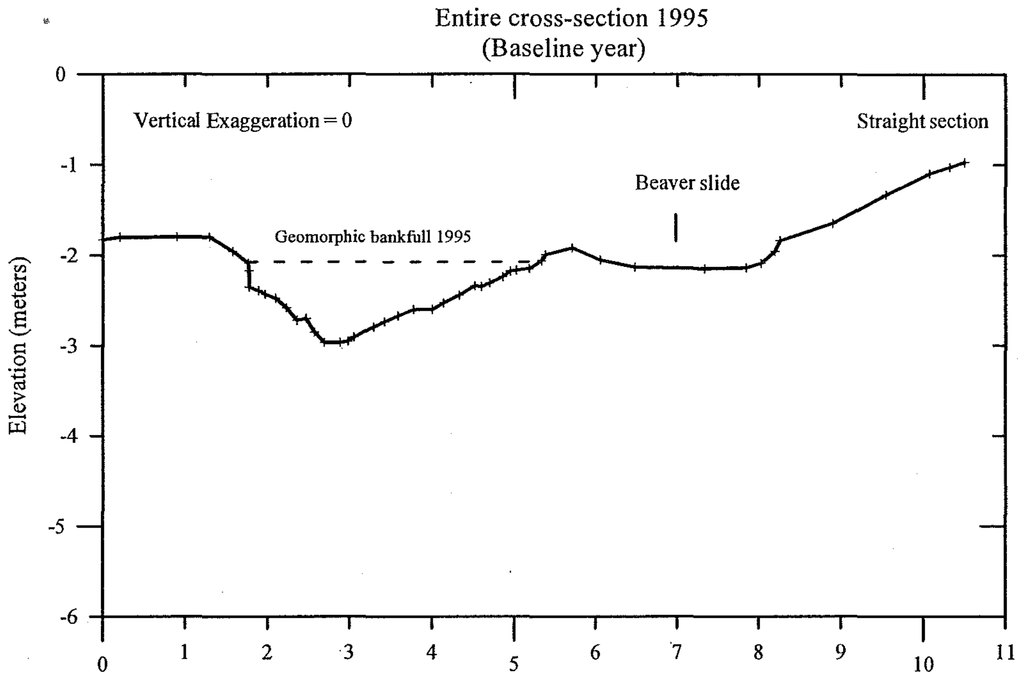
Price Creek cross-section 22 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

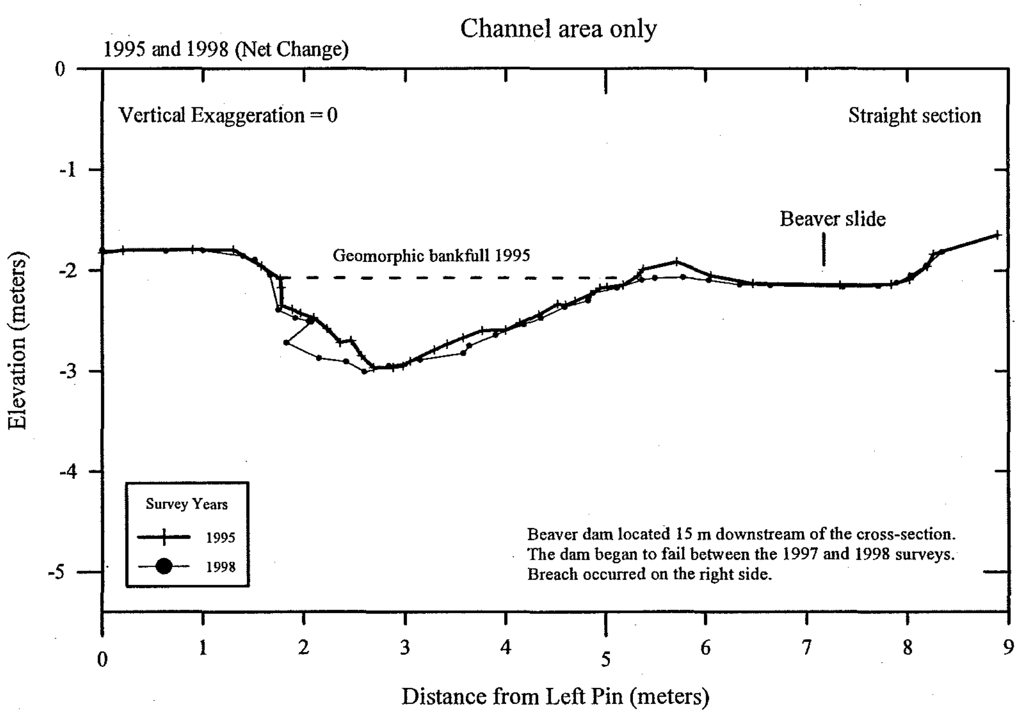
Undercuts removed for clarity.



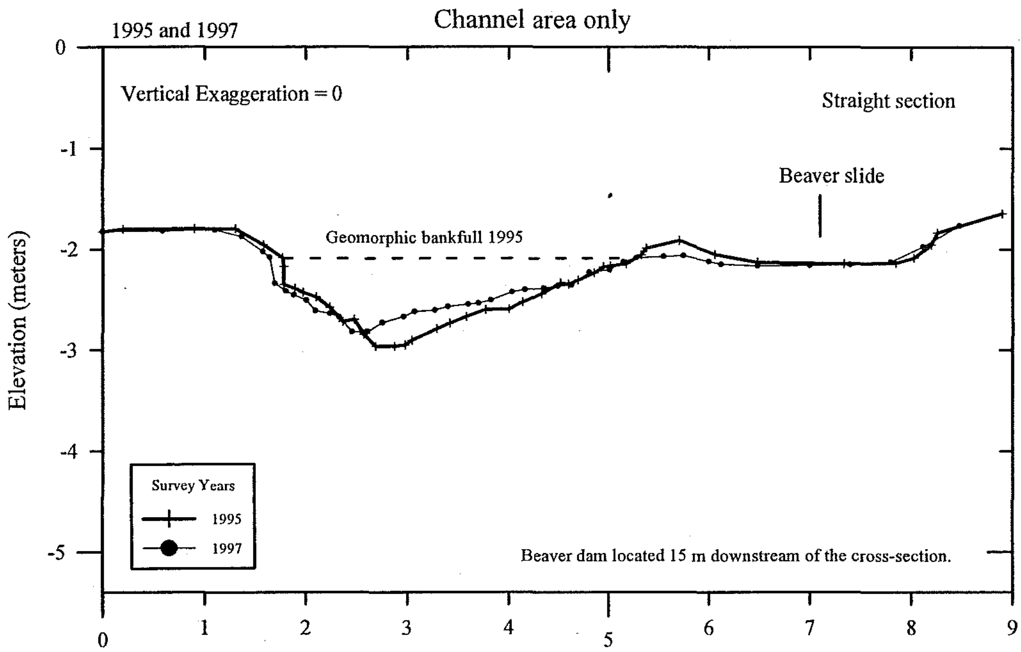


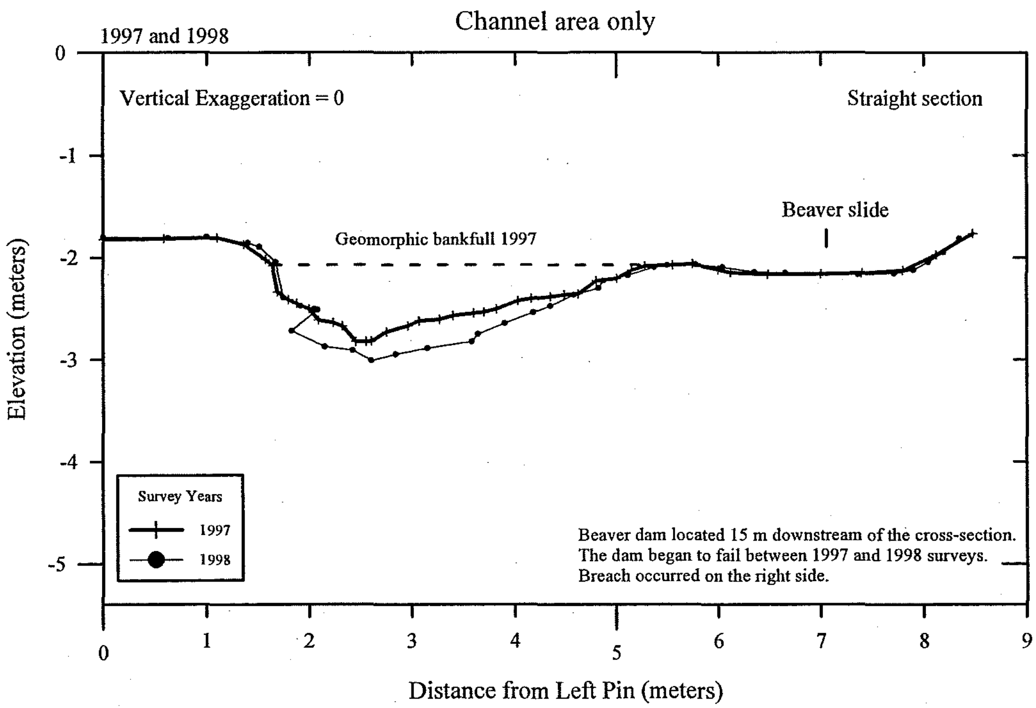
Price Creek cross-section 23
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998





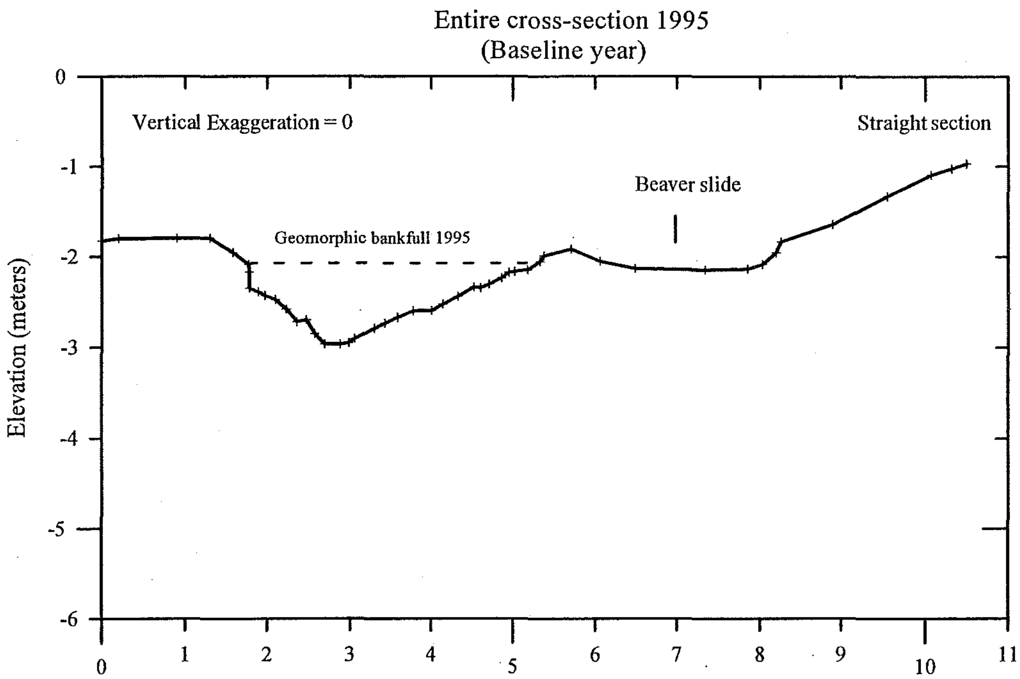
Price Creek cross-section 23 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

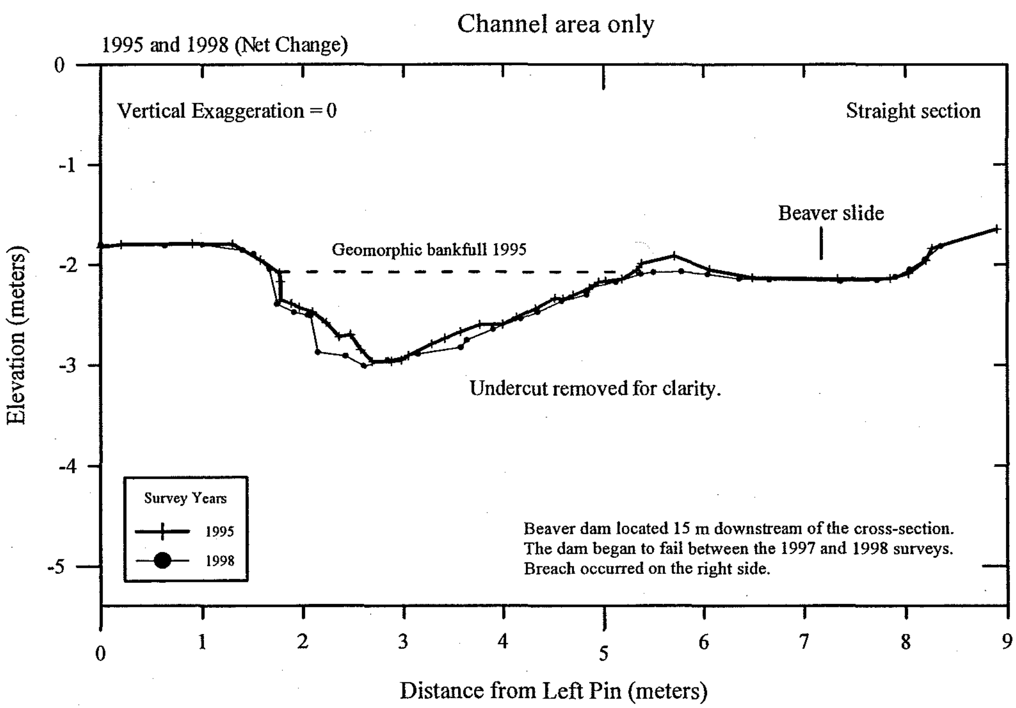




Price Creek cross-section 23 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

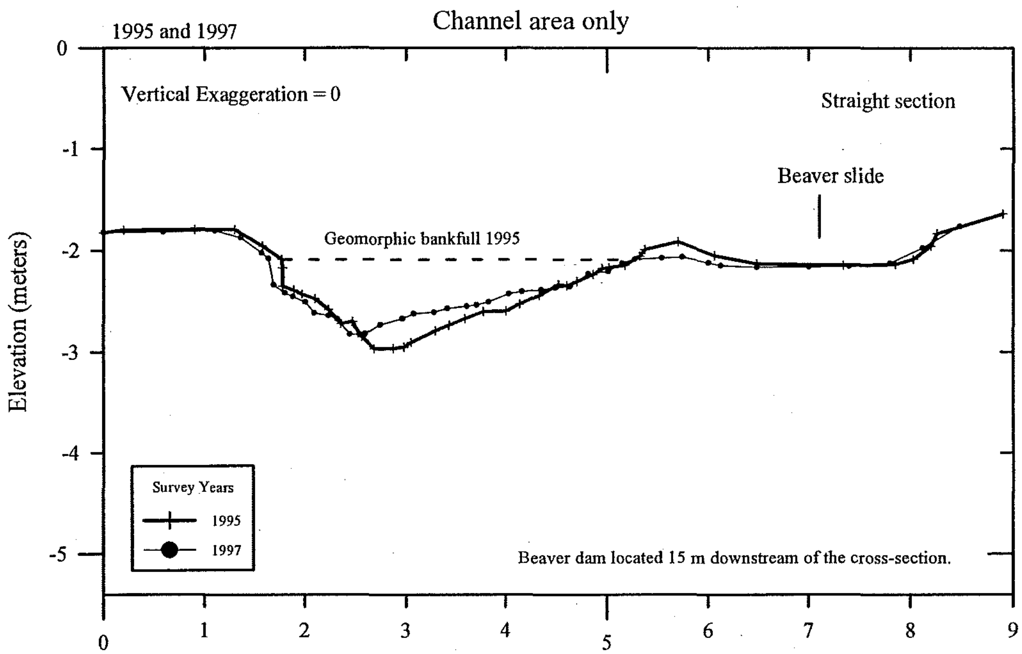
Undercut removed for clarity.

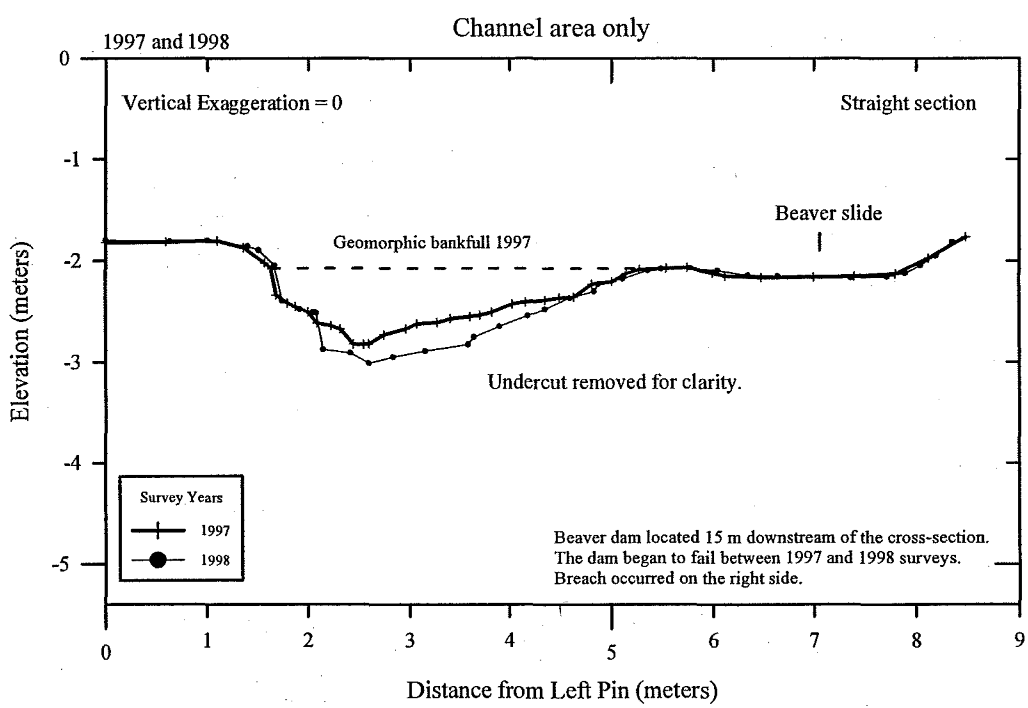




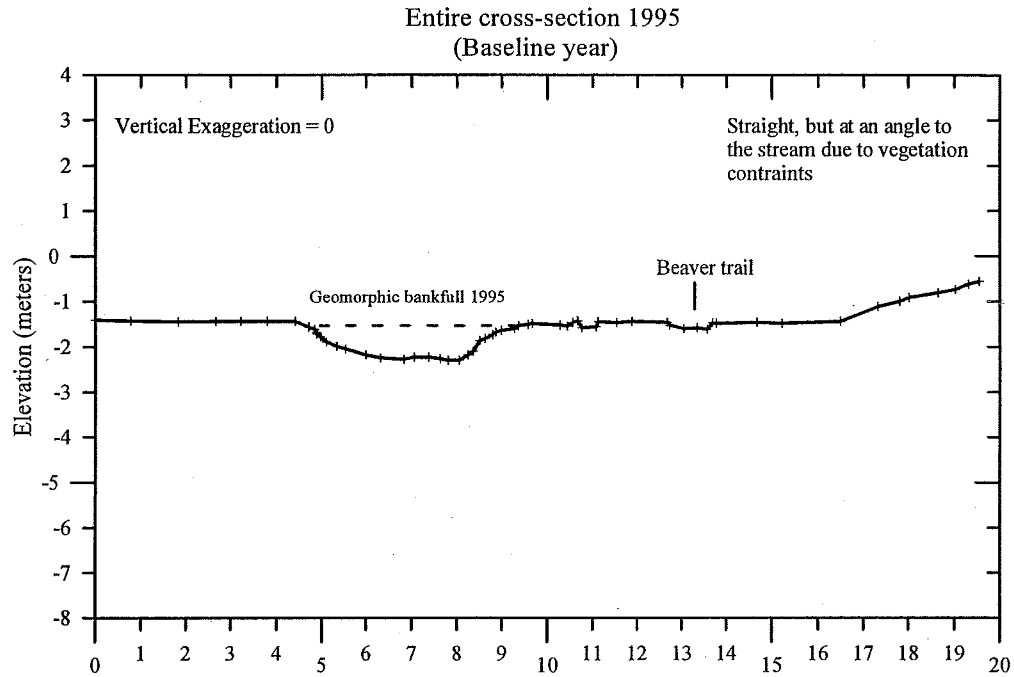
Price Creek cross-section 23 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

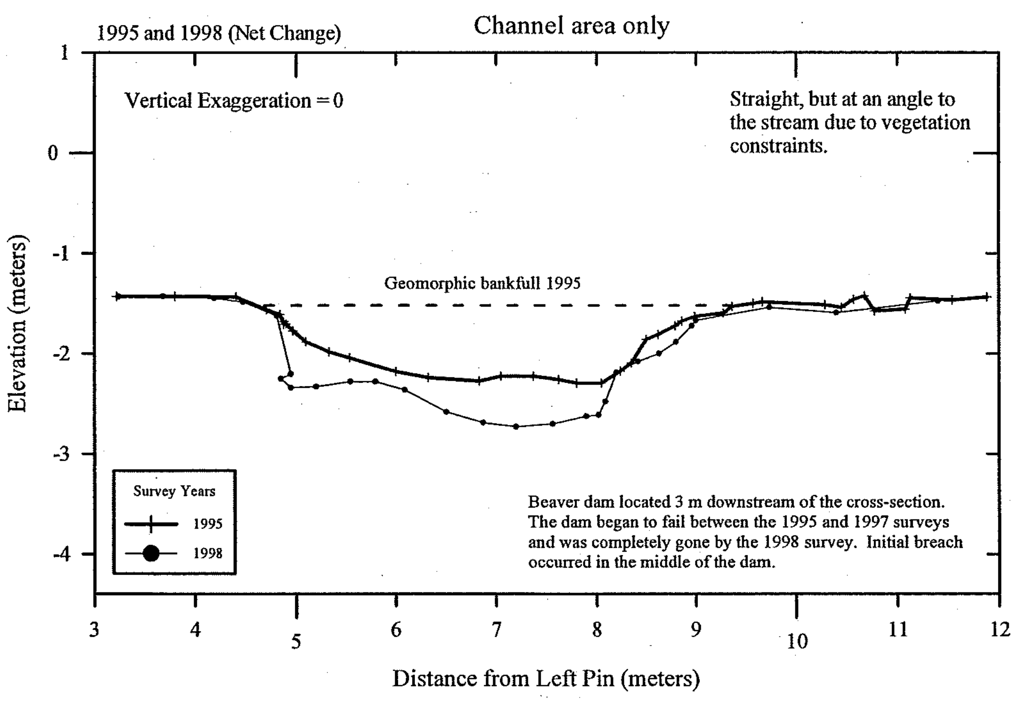
Undercut removed for clarity.



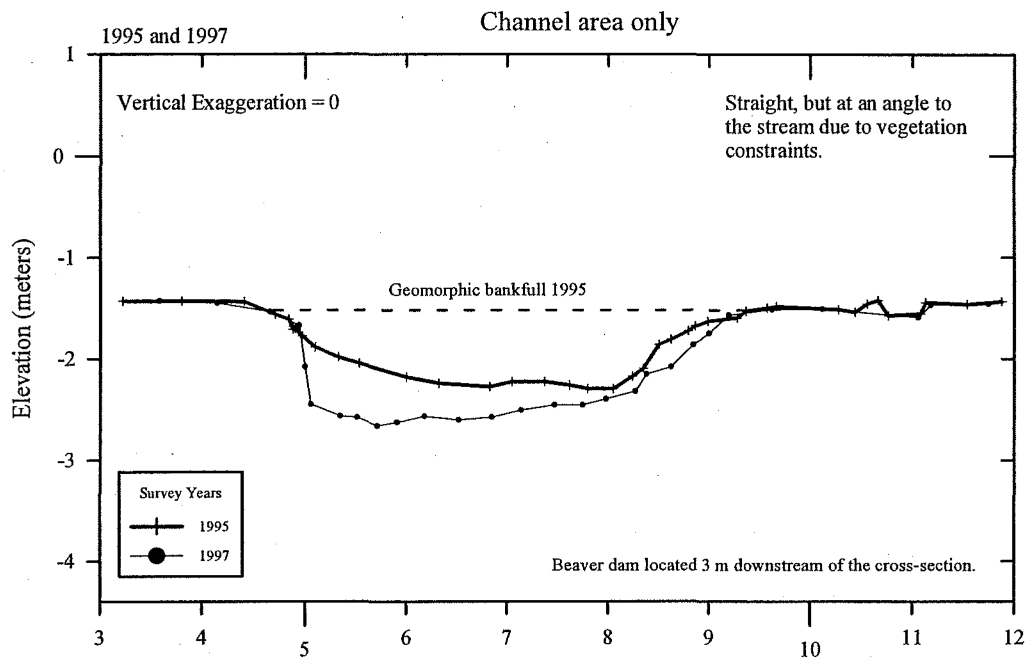


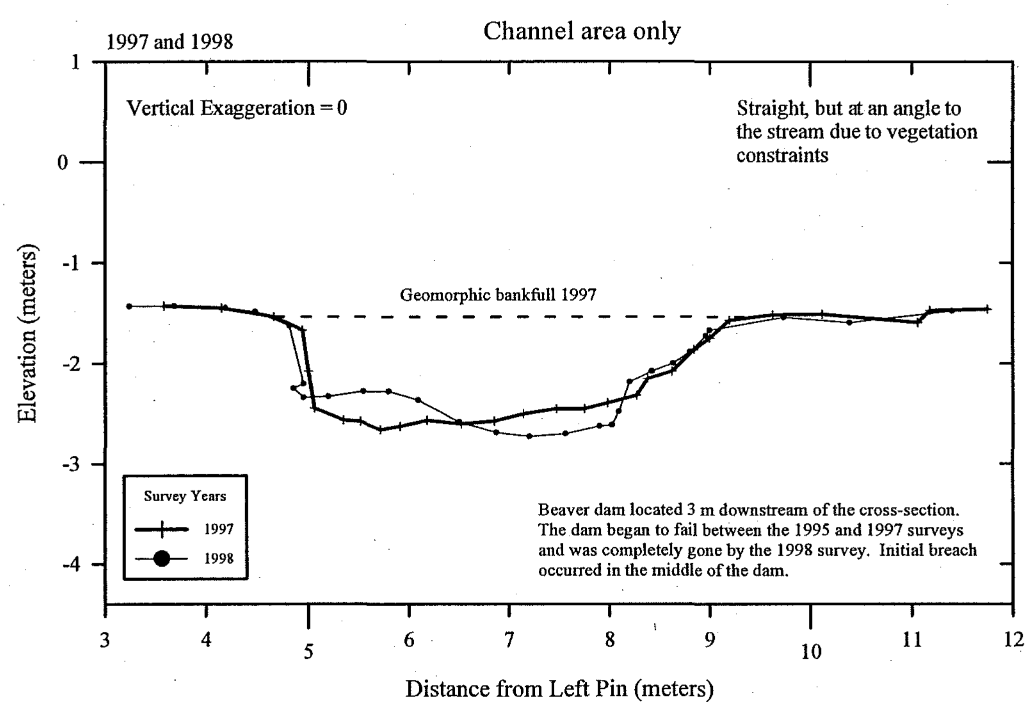
Price Creek cross-section 24
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998





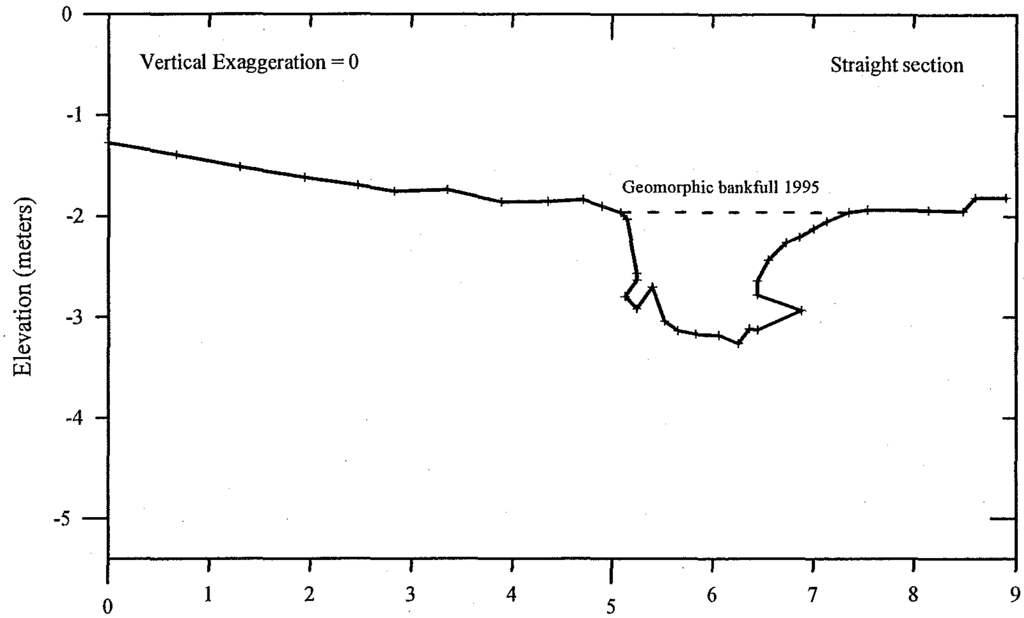
Price Creek cross-section 24 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998



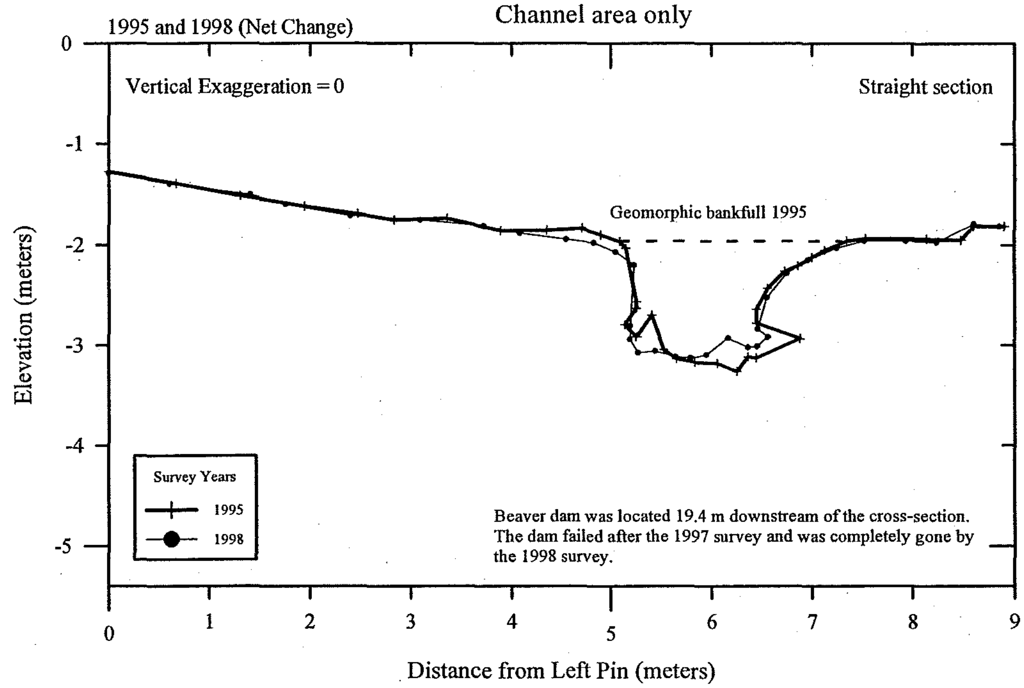


Price Creek cross-section 25
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

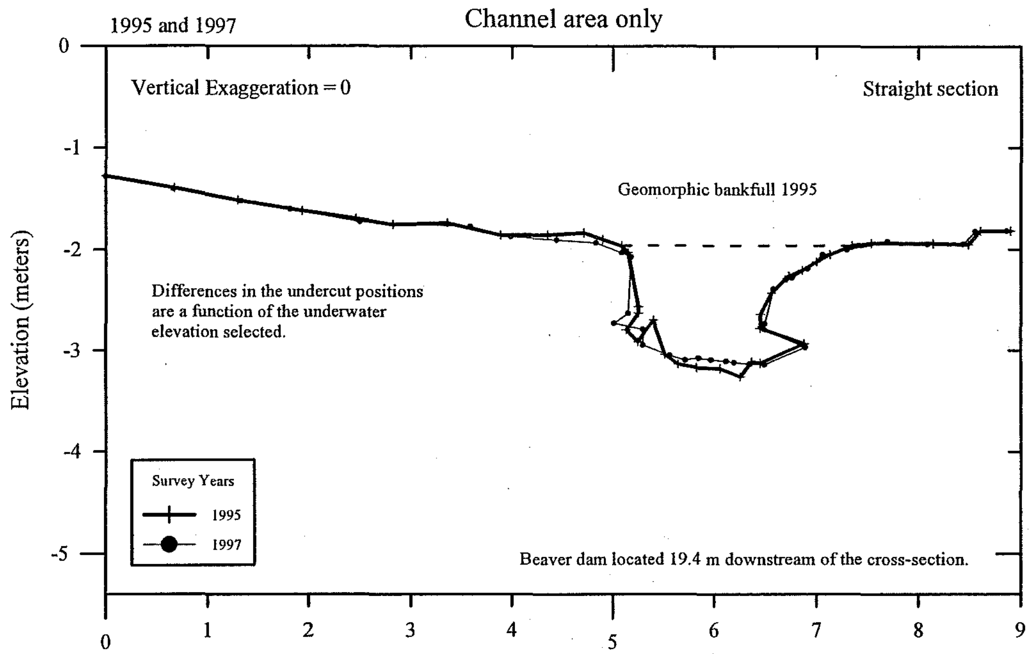
Entire cross-section 1995
(Baseline year)

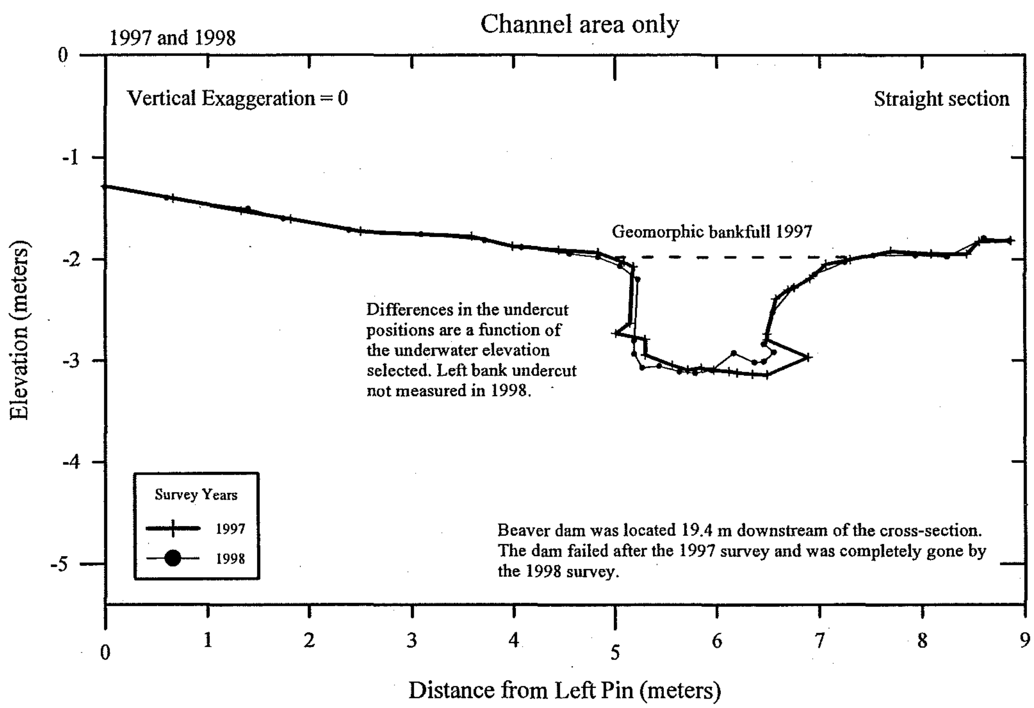


Channel area only



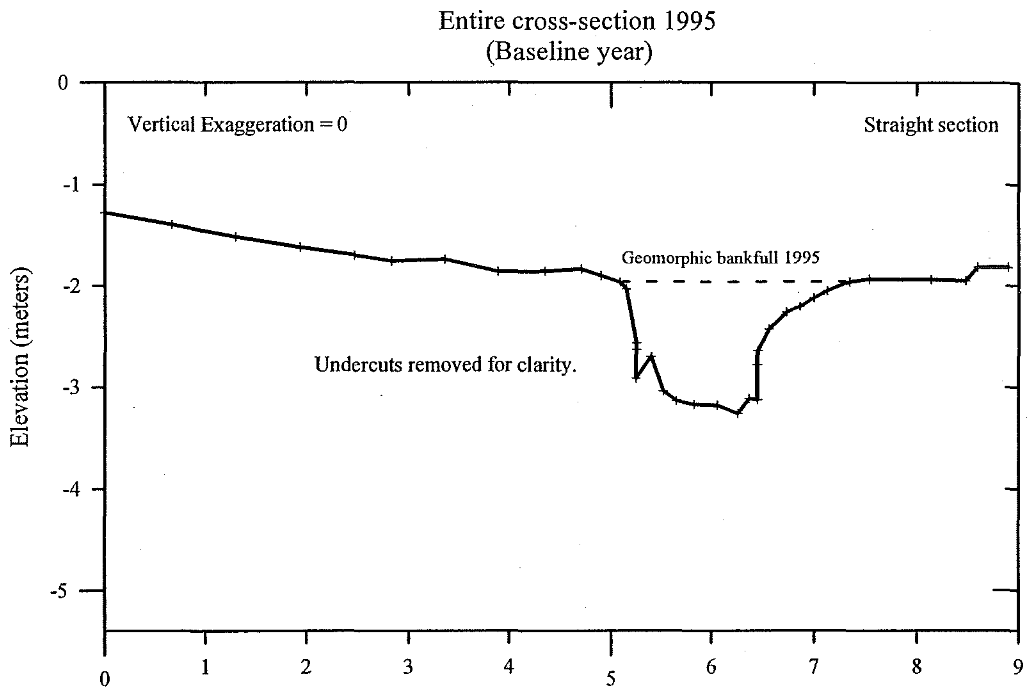
Price Creek cross-section 25 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

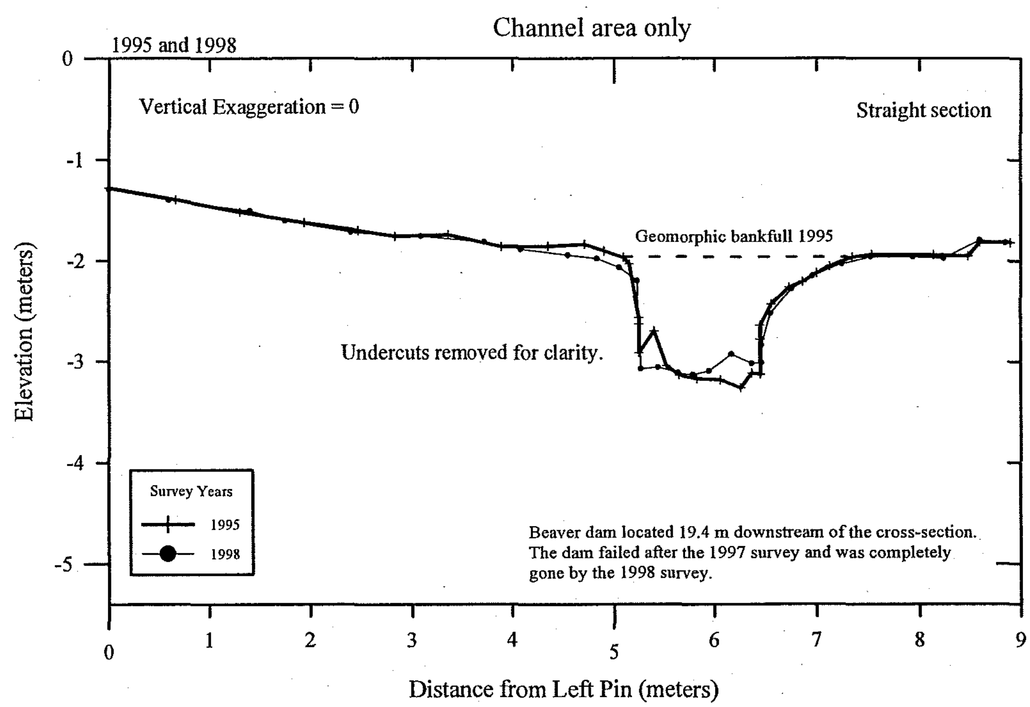




Price Creek cross-section 25 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

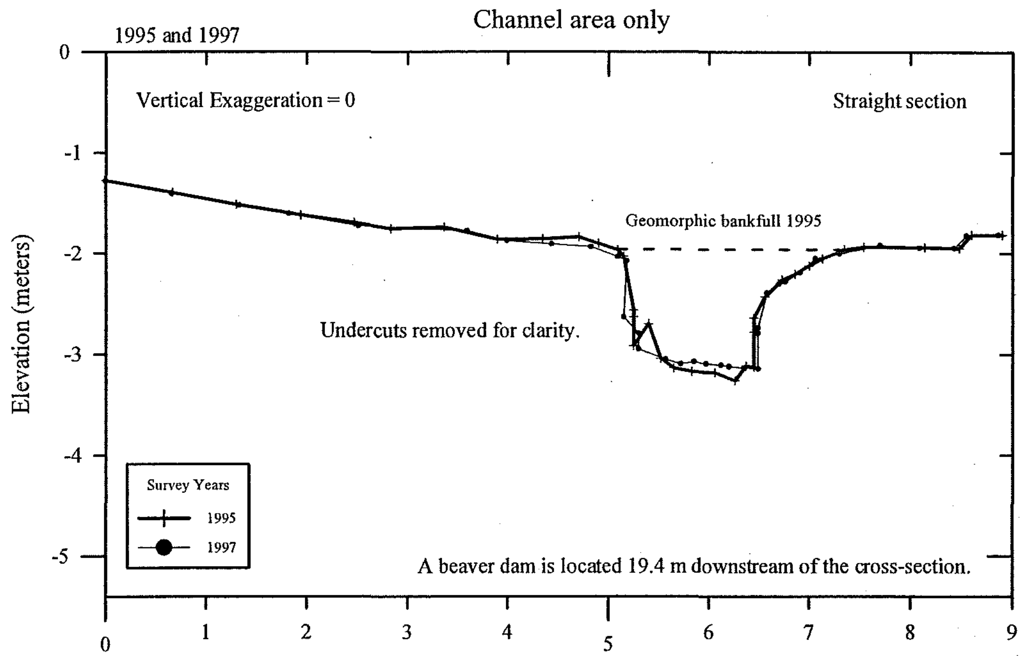
Undercuts removed for clarity.

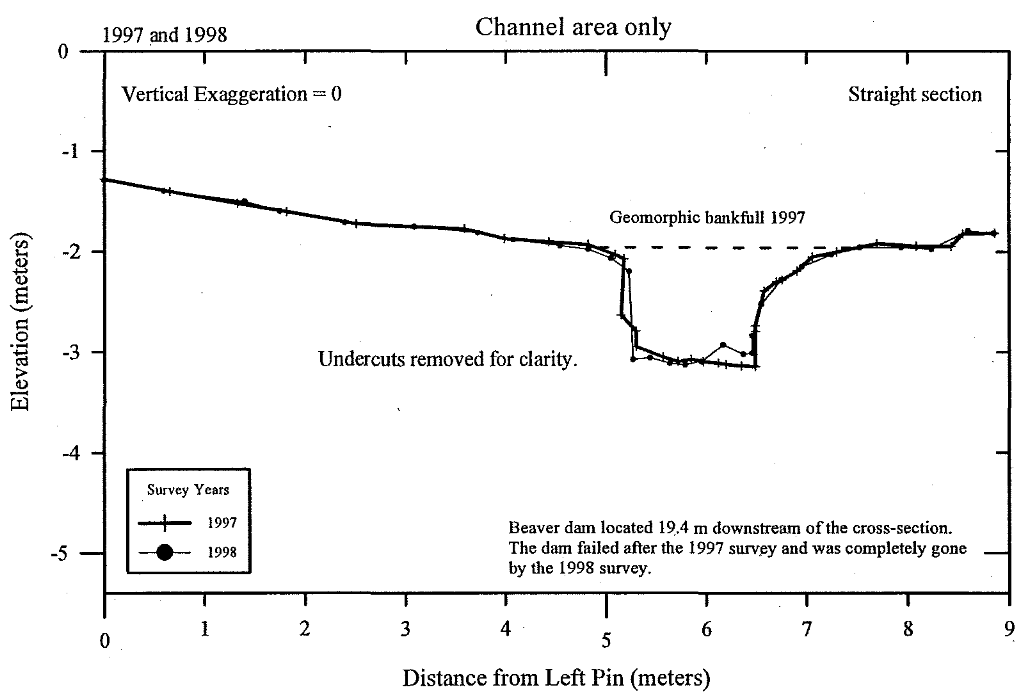




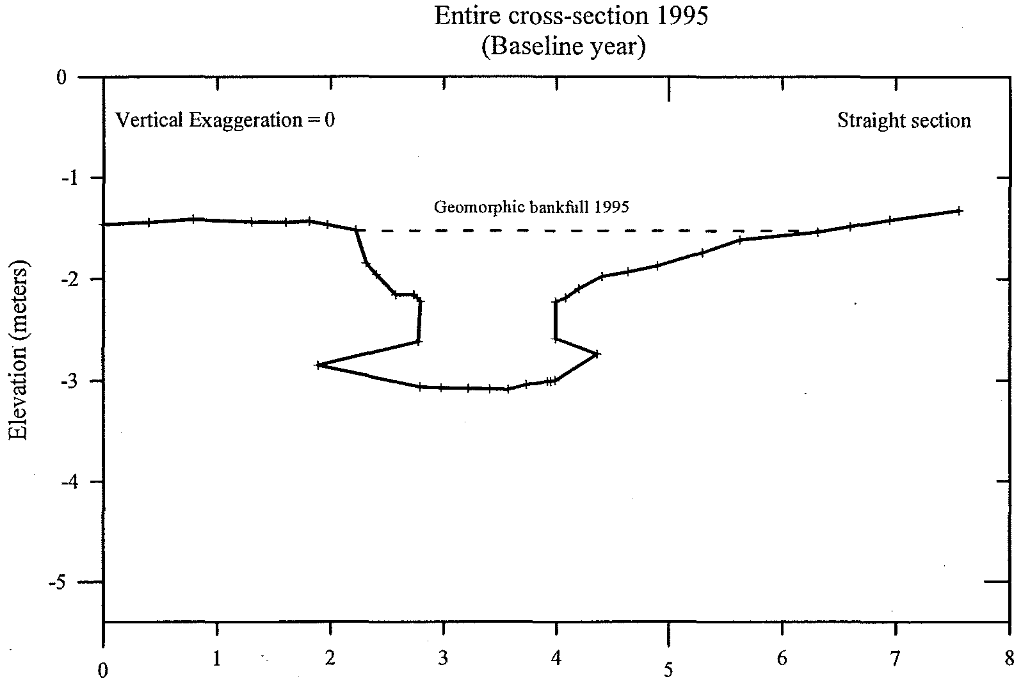
Price Creek cross-section 25 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

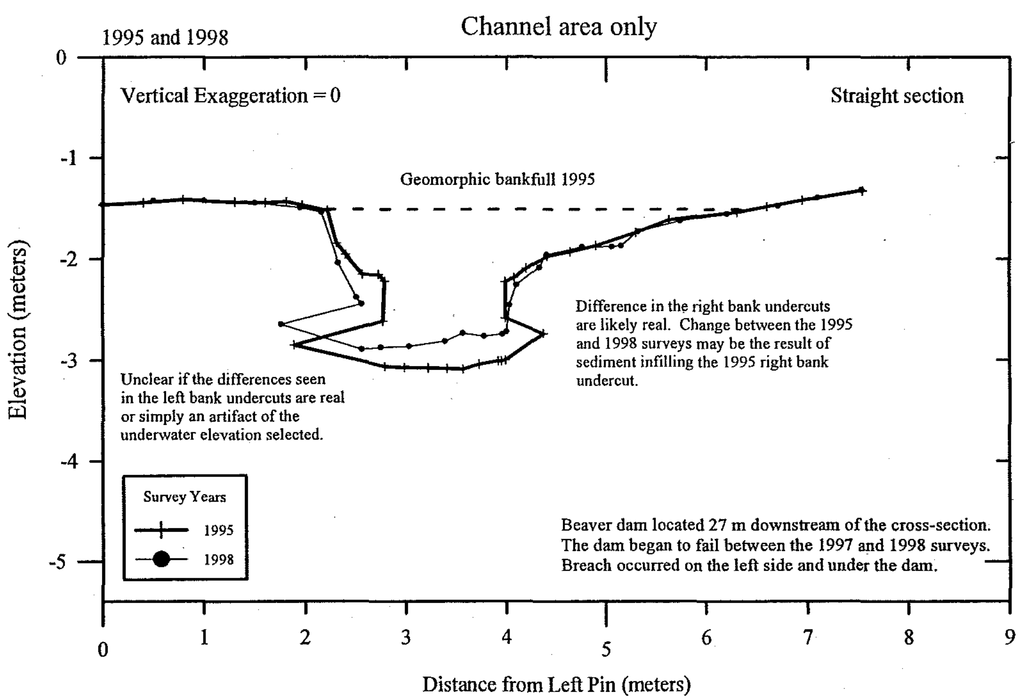
Undercuts removed for clarity.



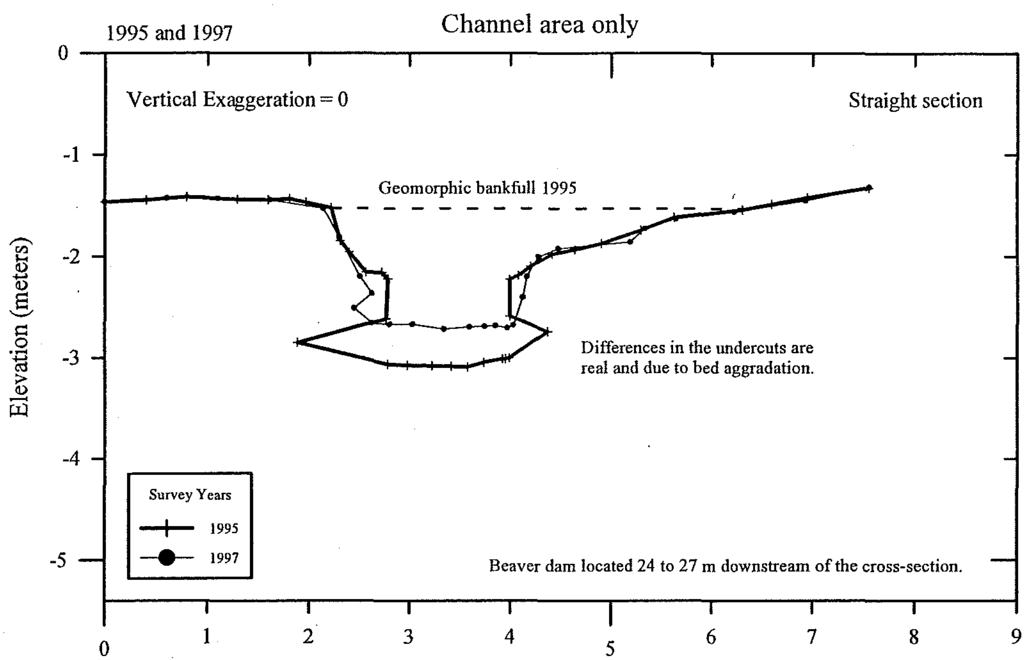


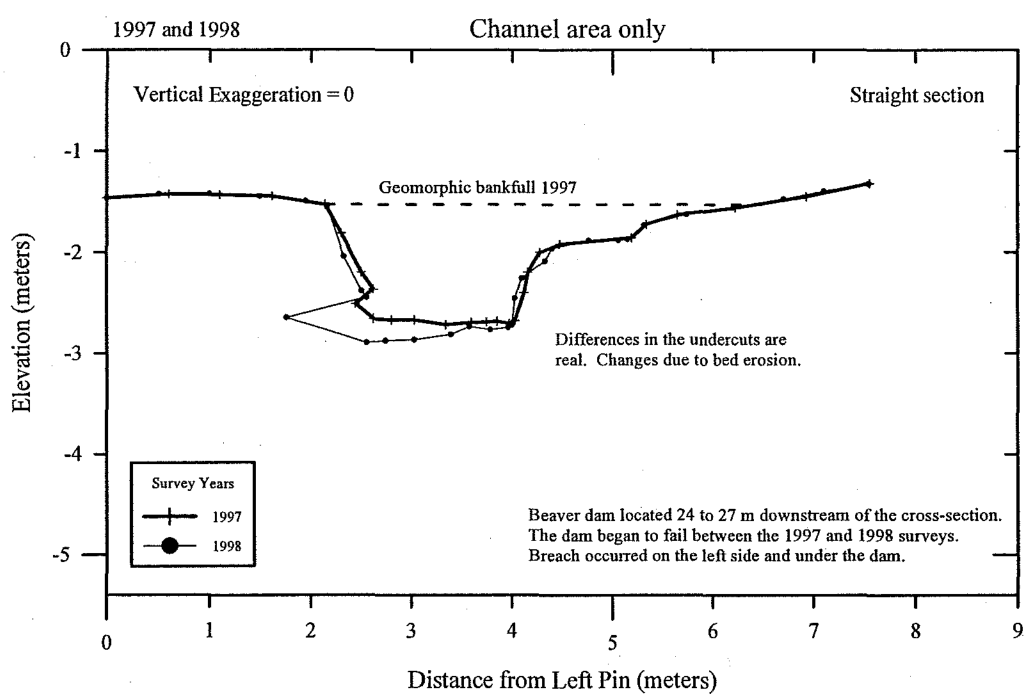
Price Creek cross-section 26
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998





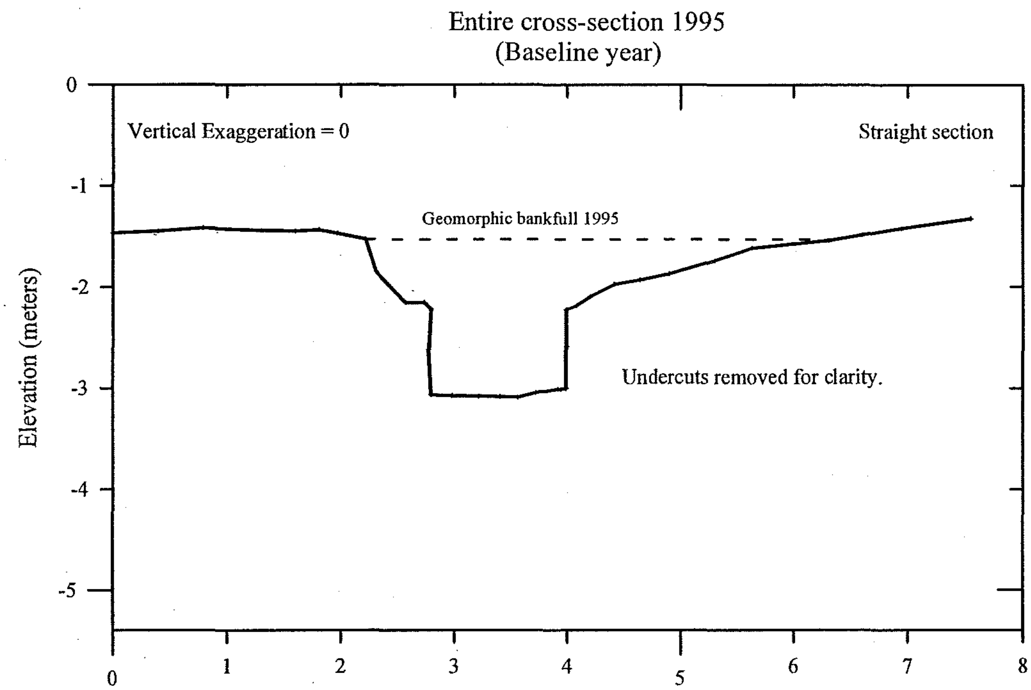
Price Creek cross-section 26 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

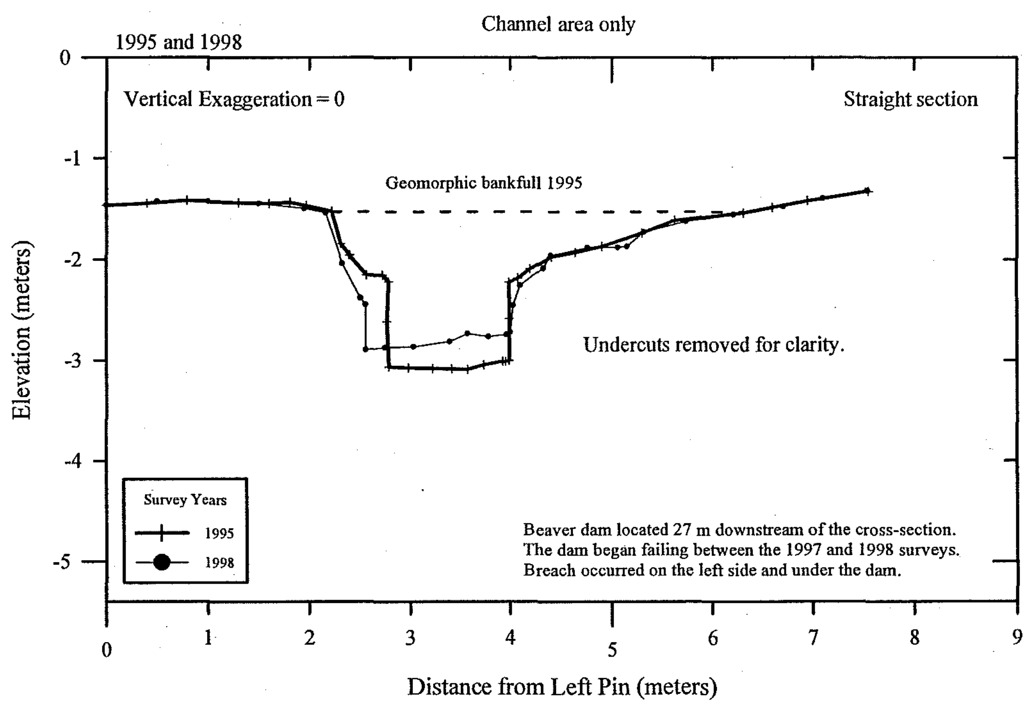




Price Creek cross-section 26 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

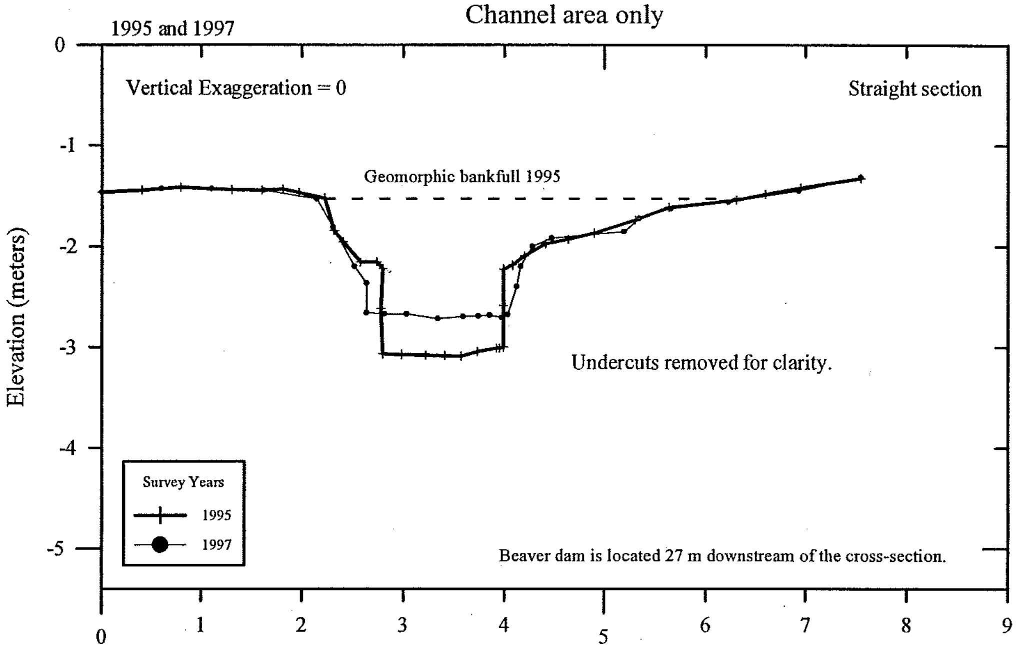
Undercuts removed for clarity.

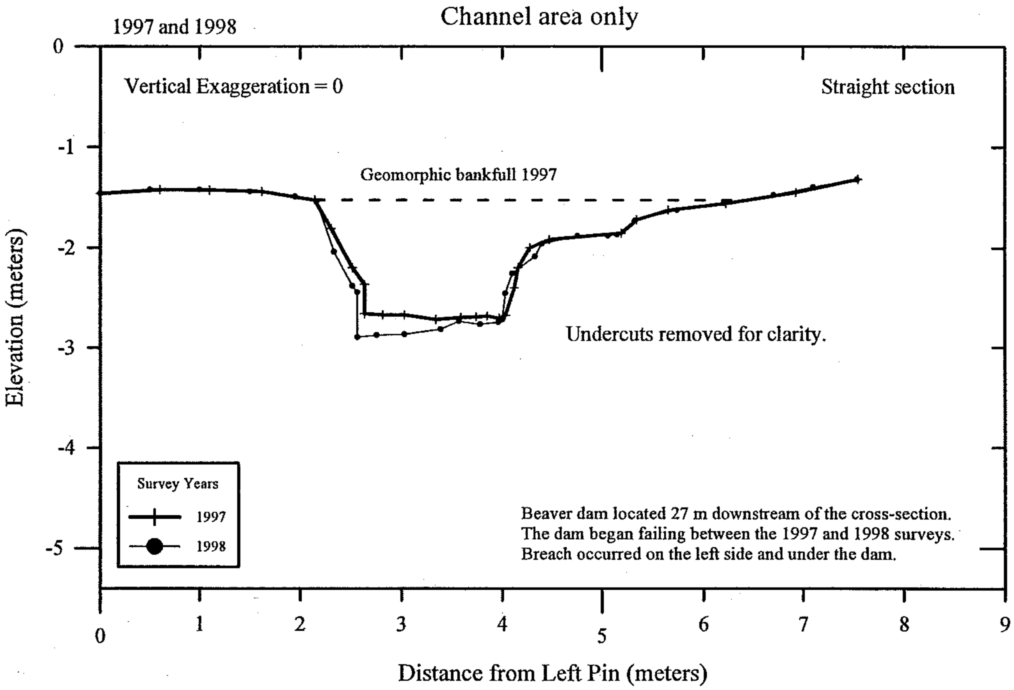




Price Creek cross-section 26 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

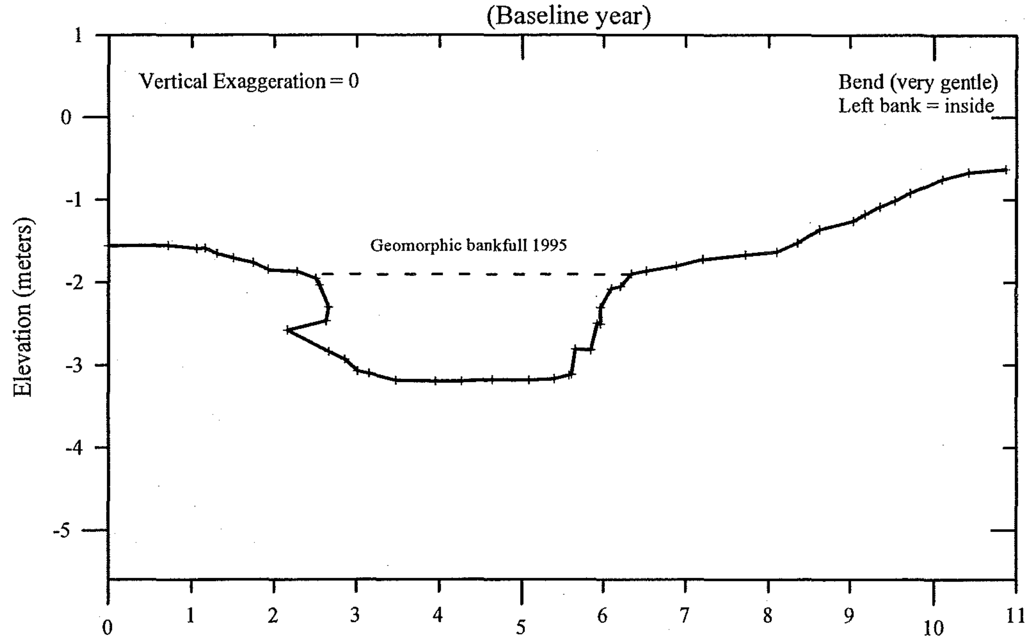
Undercuts removed for clarity.



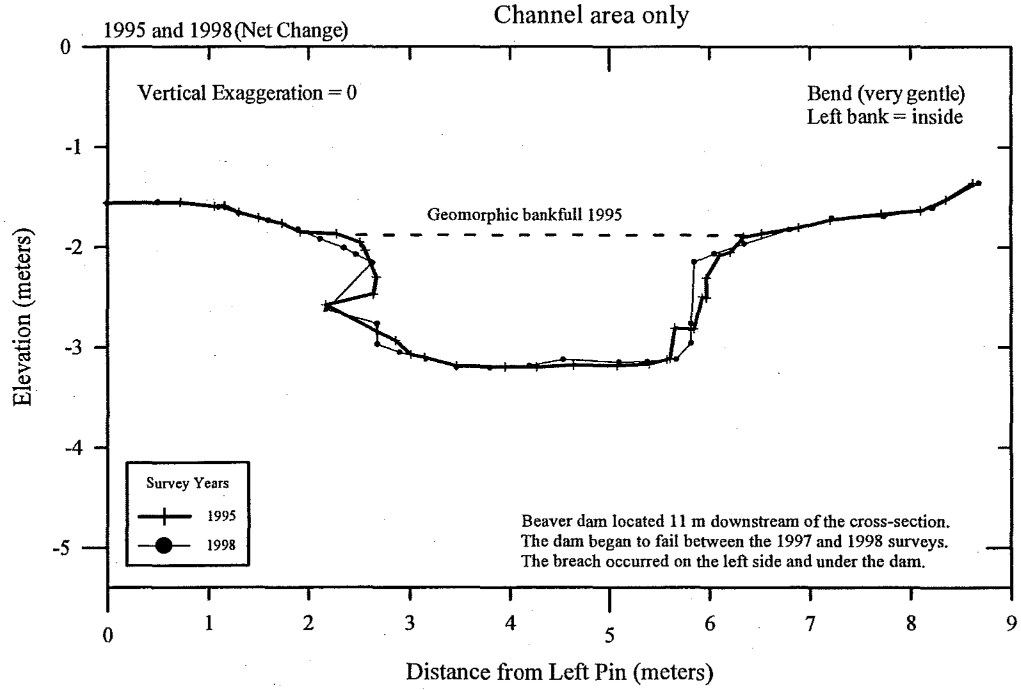


Price Creek cross-section 27
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

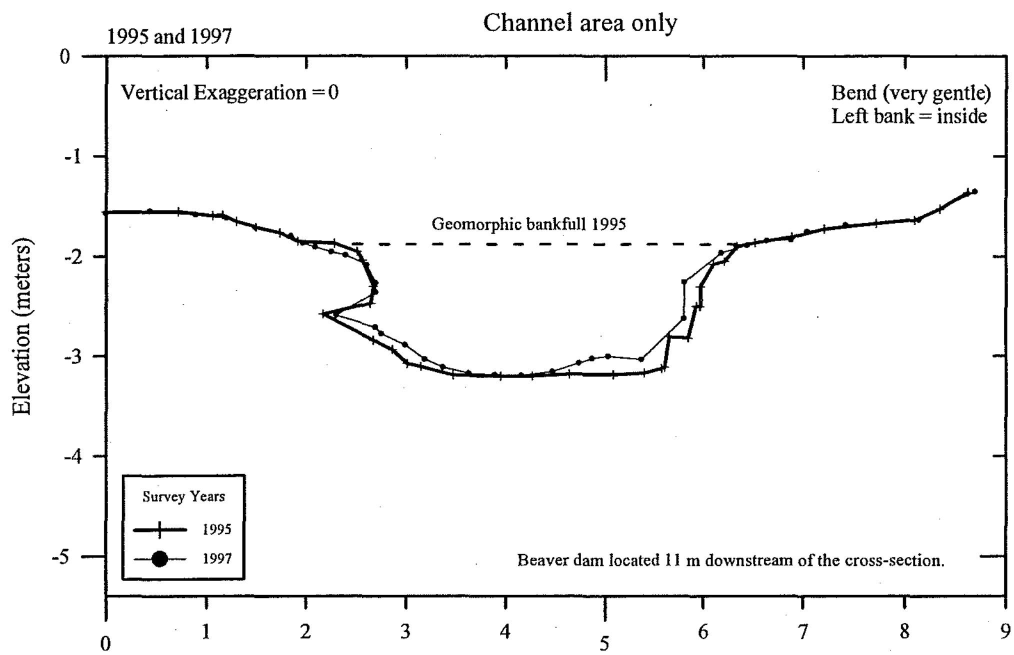
Entire cross-section 1995
(Baseline year)

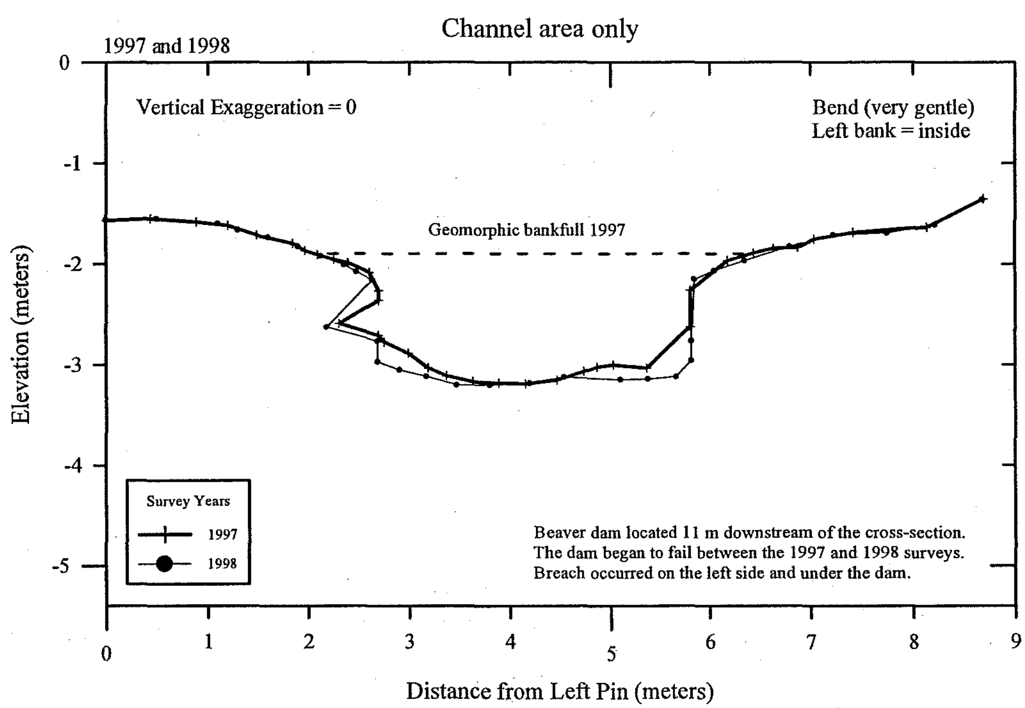


Channel area only



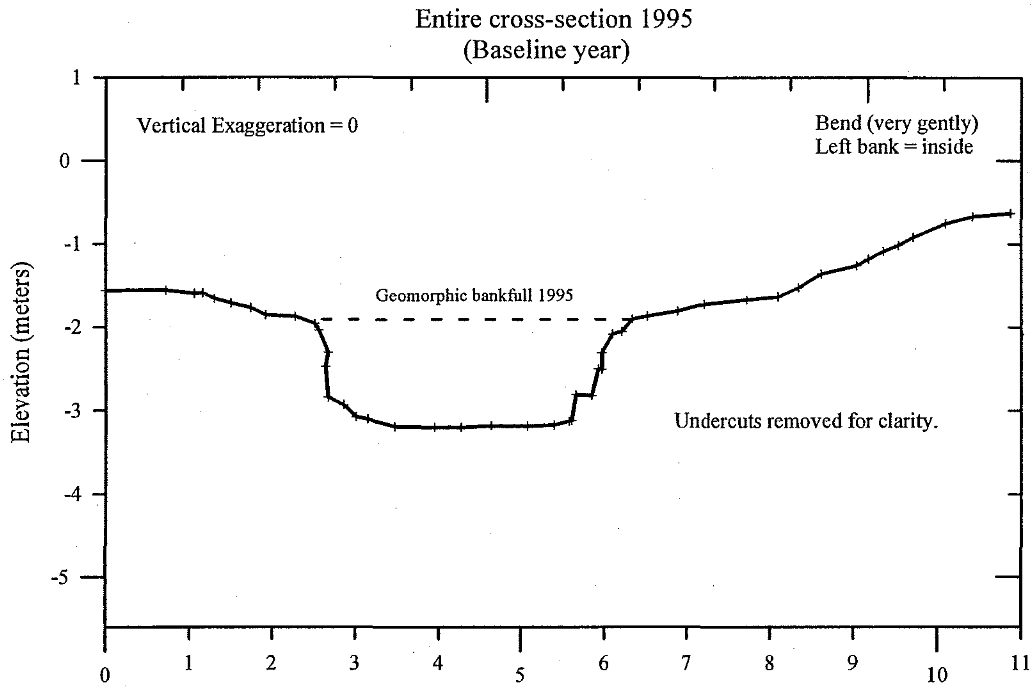
Price Creek cross-section 27 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

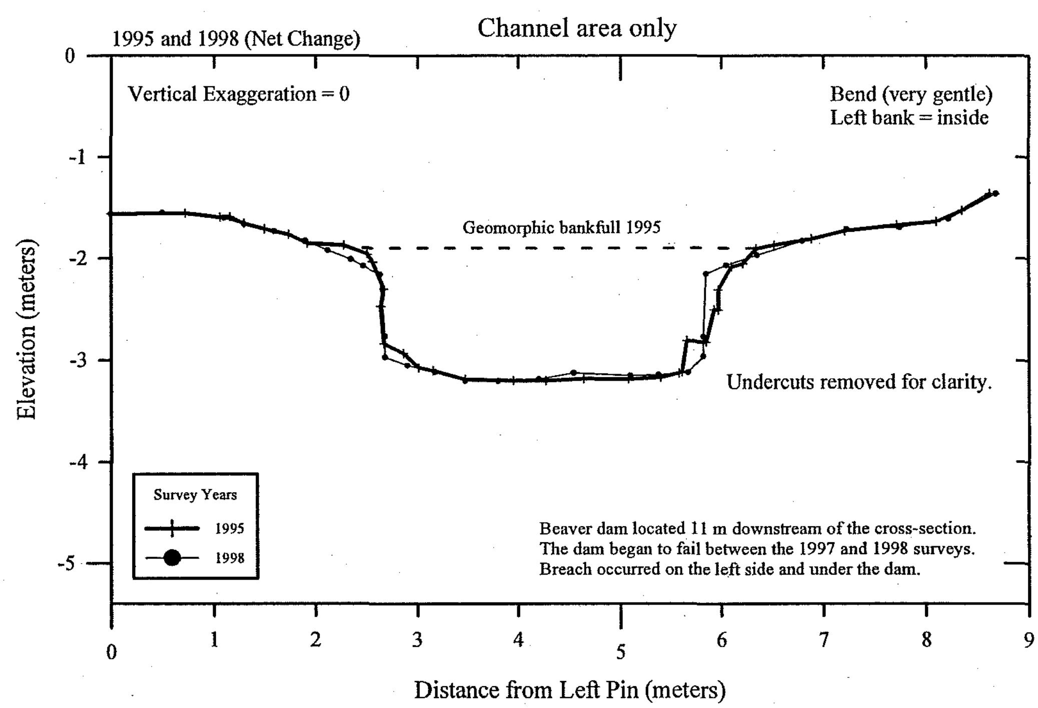




Price Creek cross-section 27 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

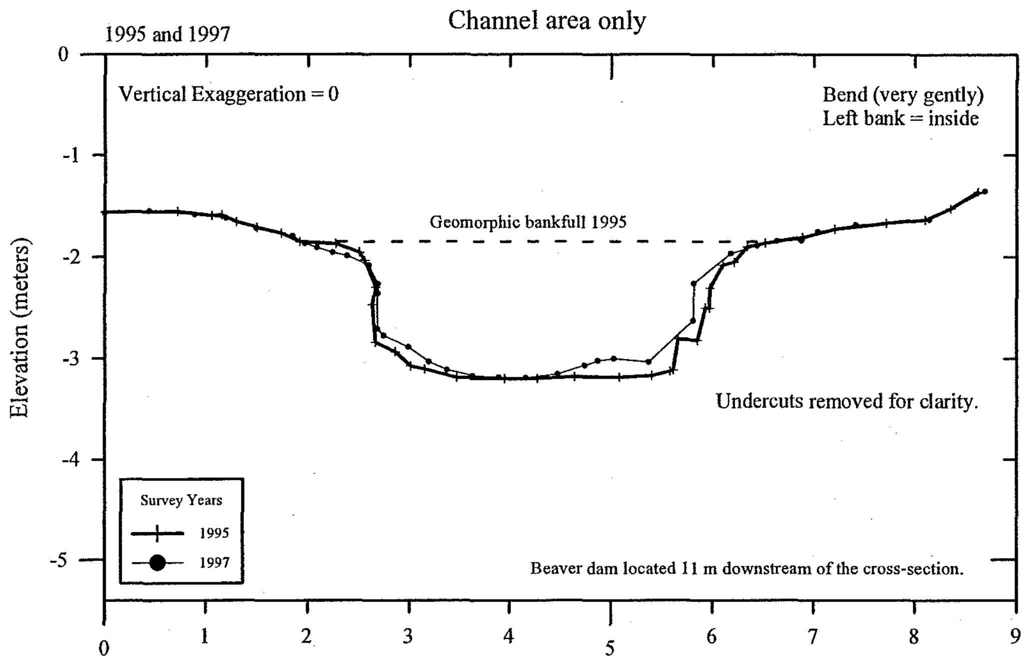
Undercuts removed for clarity.

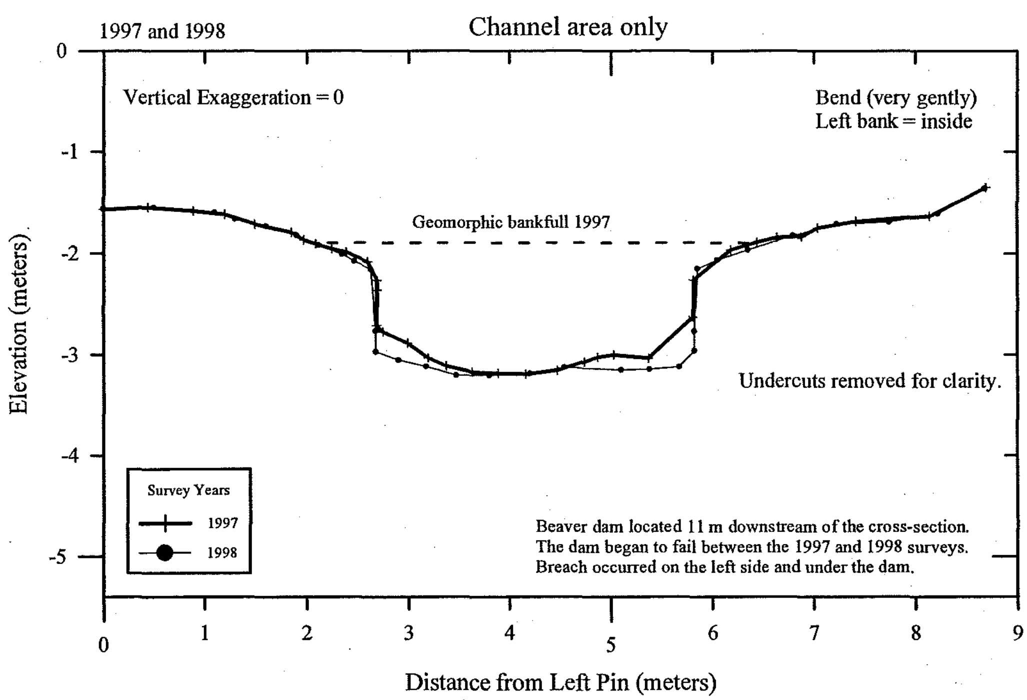




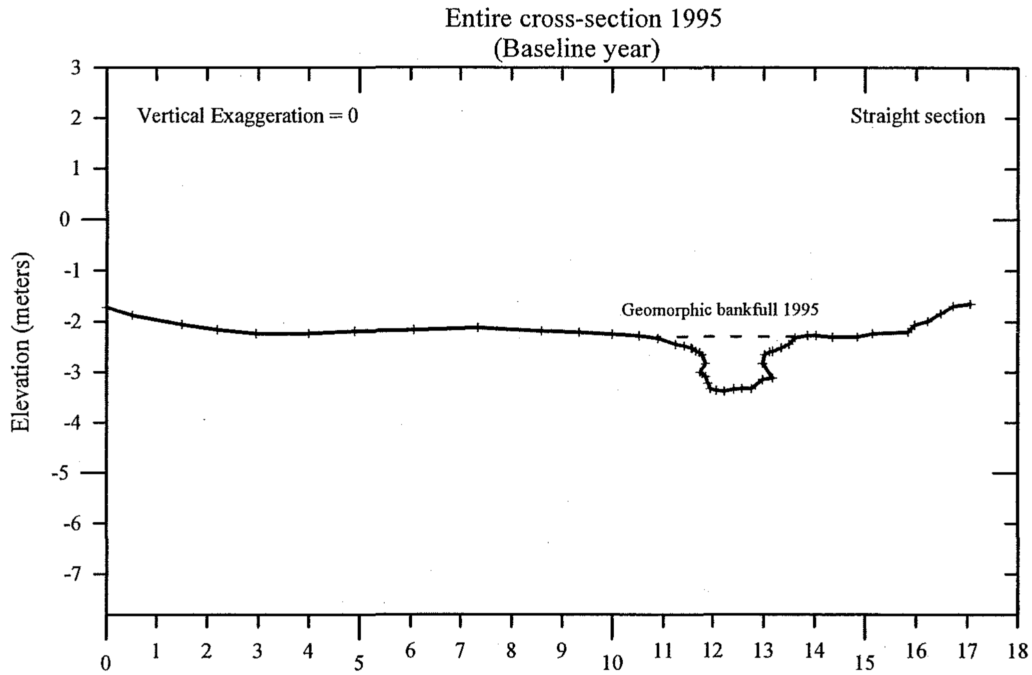
Price Creek cross-section 27 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

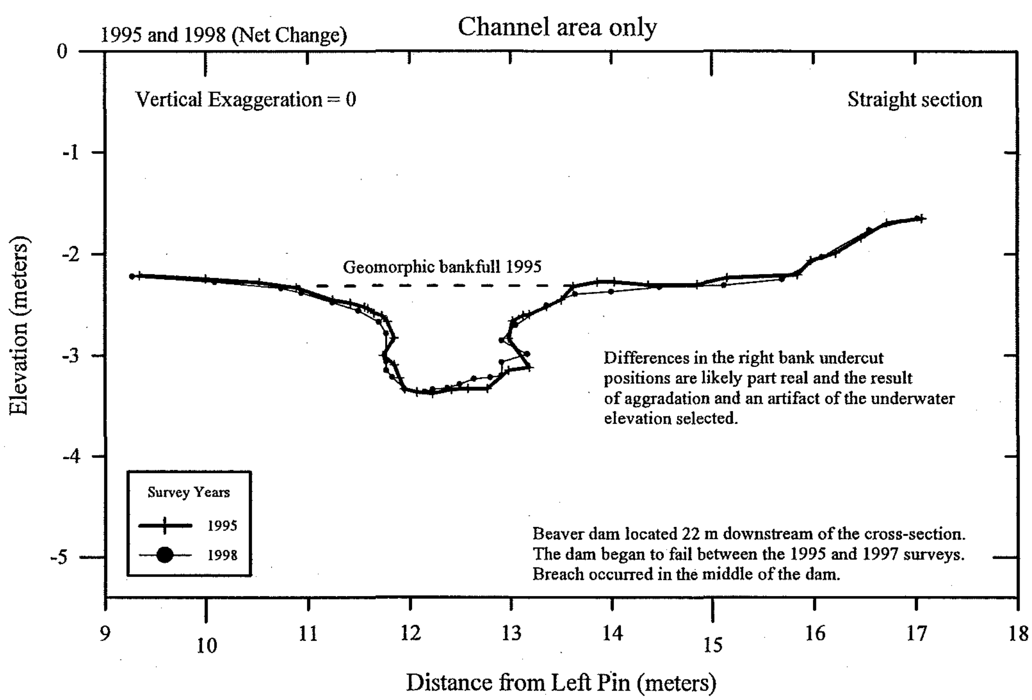
Undercuts removed for clarity.



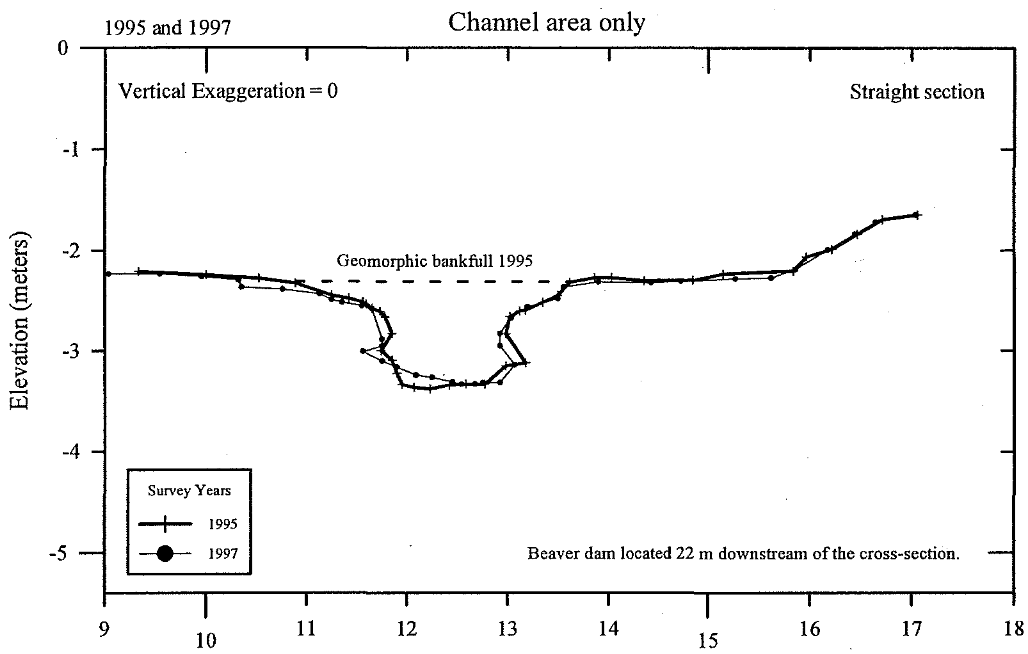


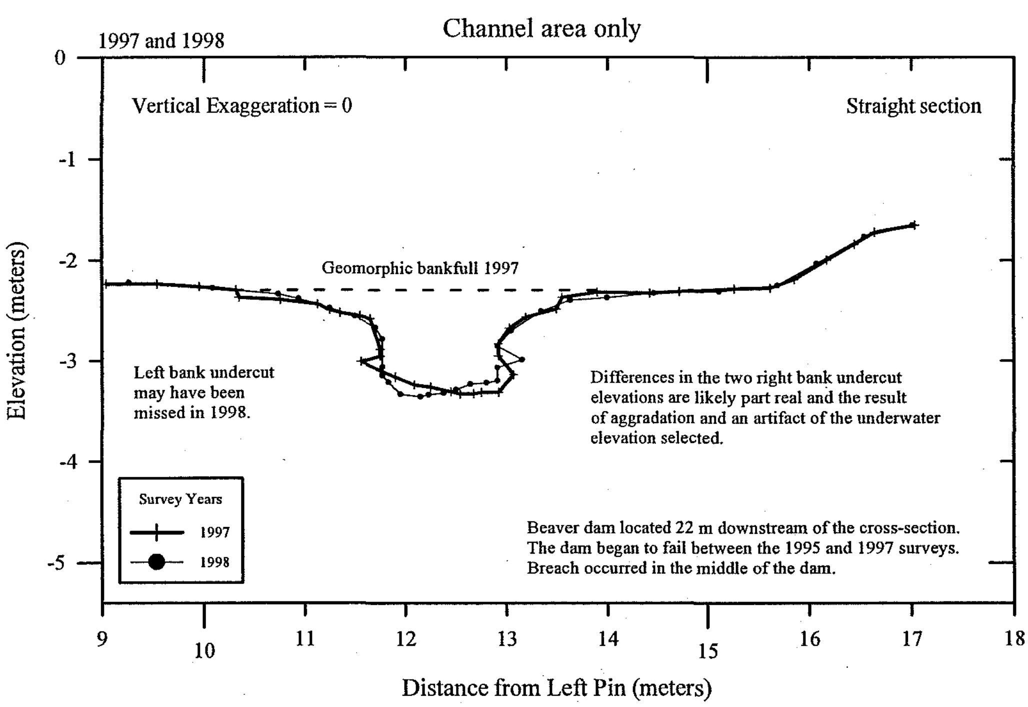
Price Creek cross-section 28
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998





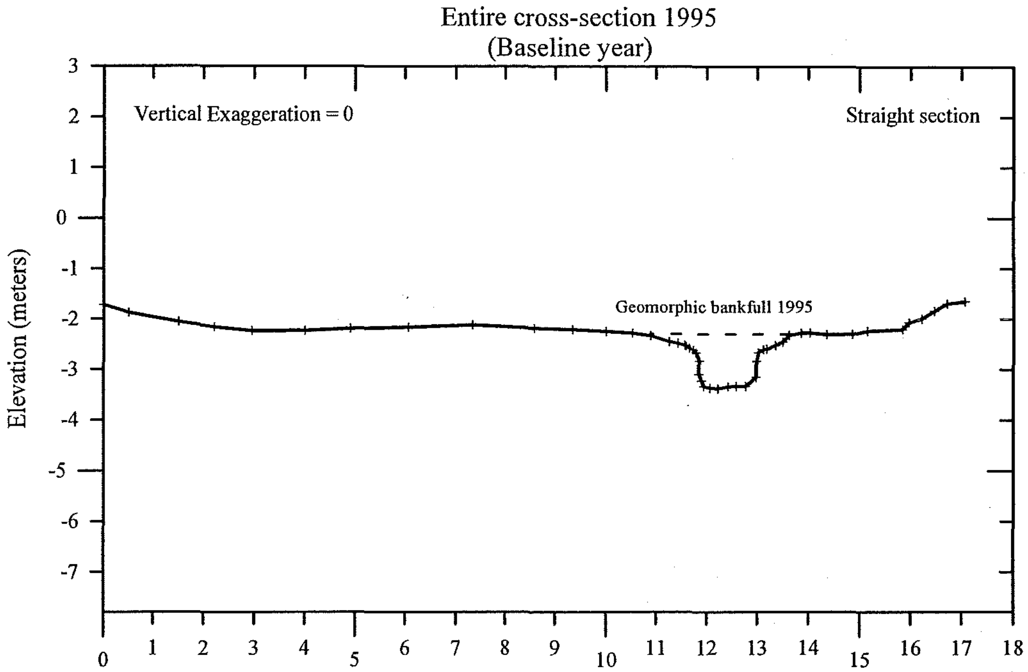
Price Creek cross-section 28 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

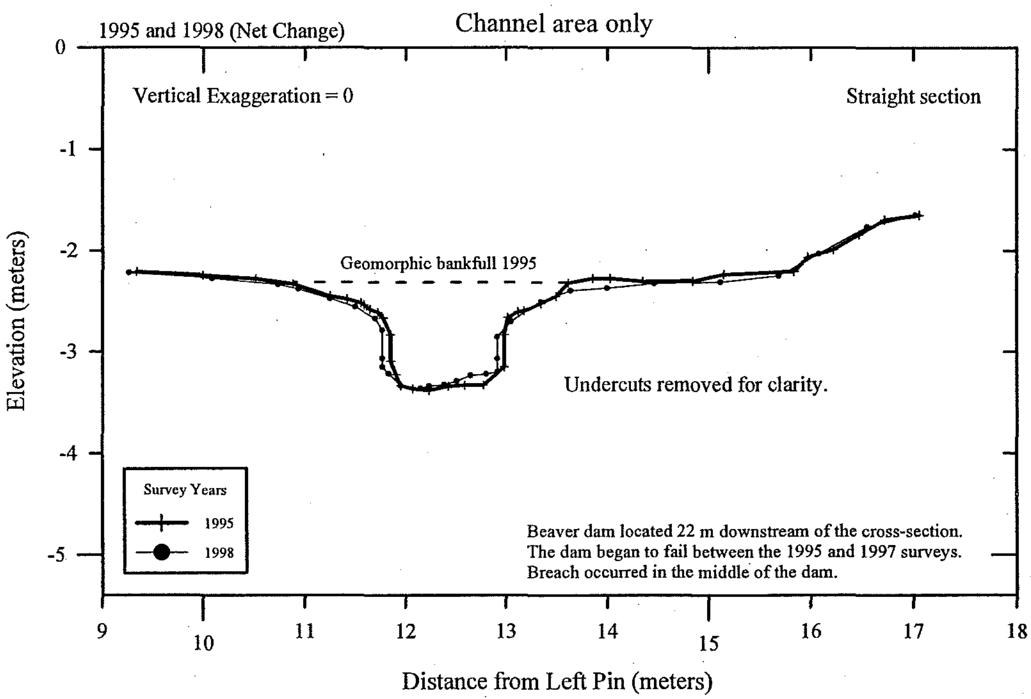




Price Creek cross-section 28 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

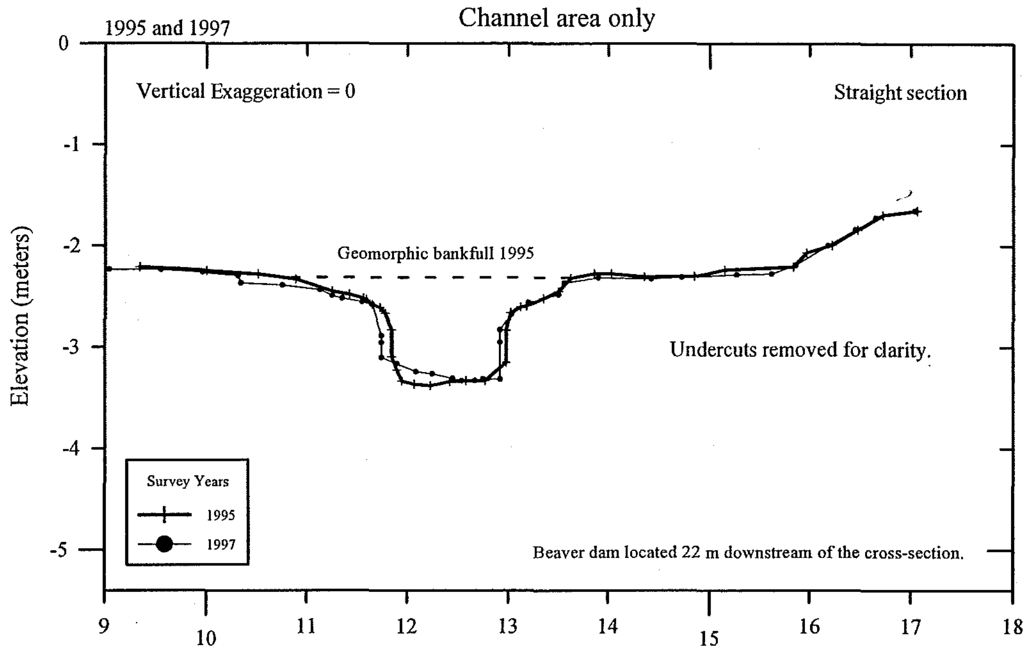
Undercuts removed for clarity.

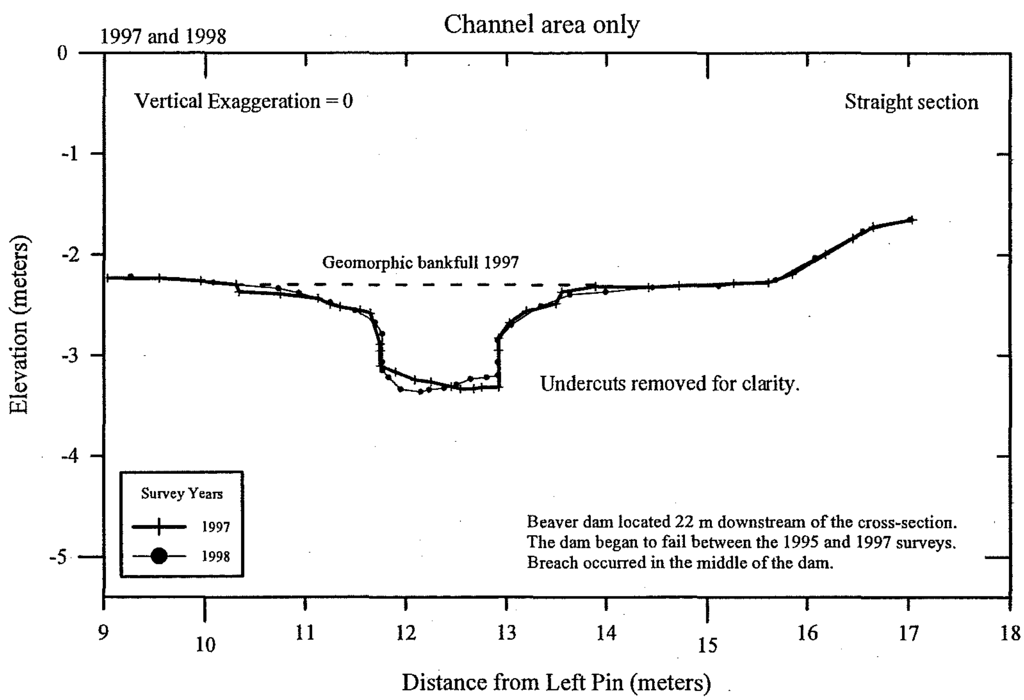




Price Creek cross-section 28 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

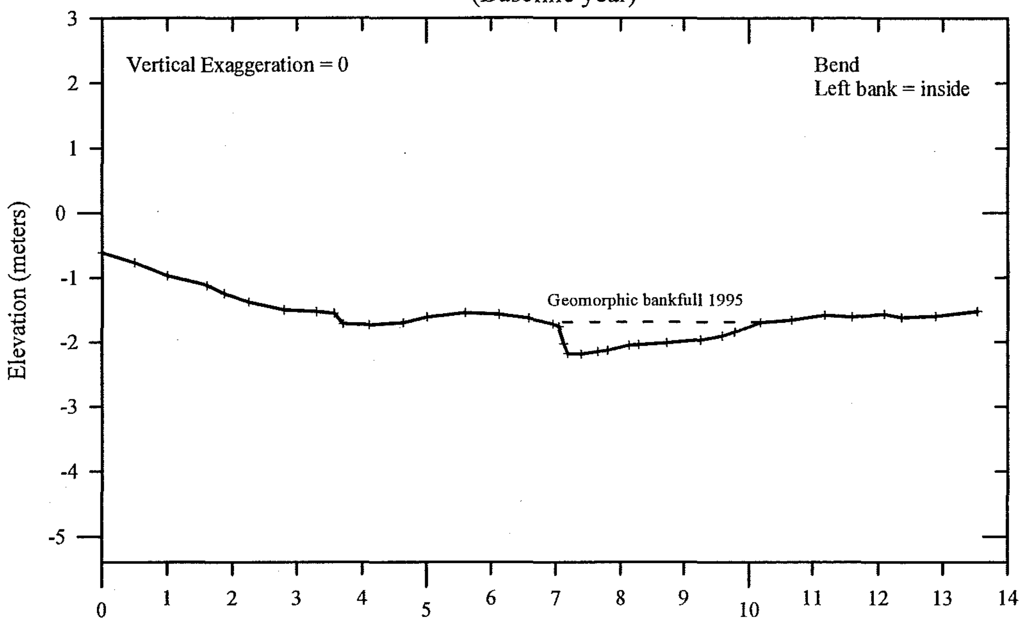
Undercuts removed for clarity.



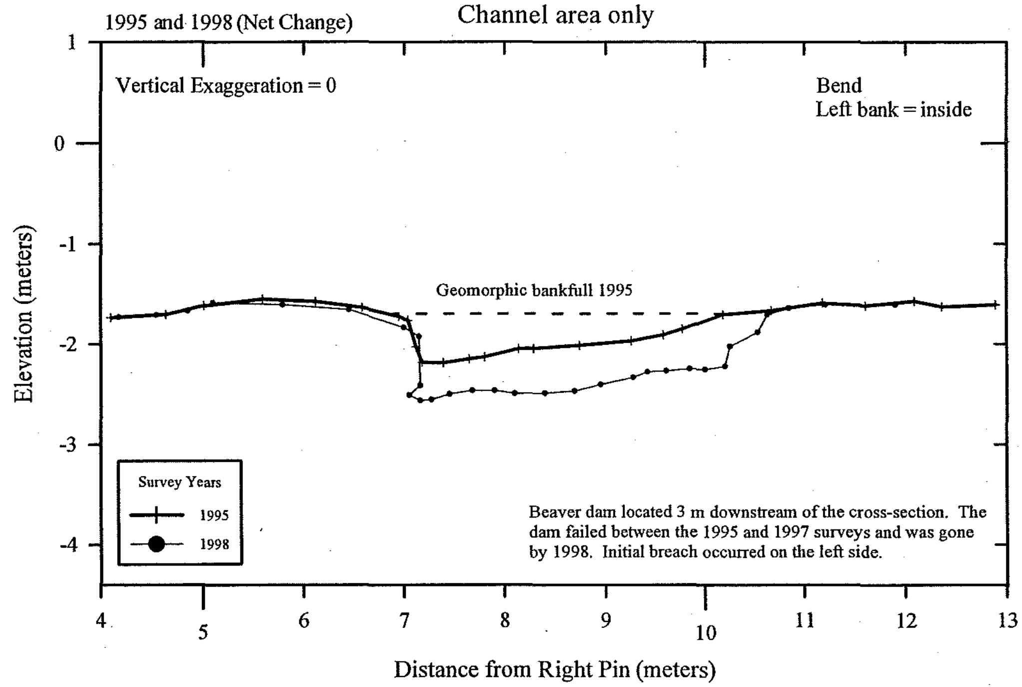


Price Creek cross-section 29
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

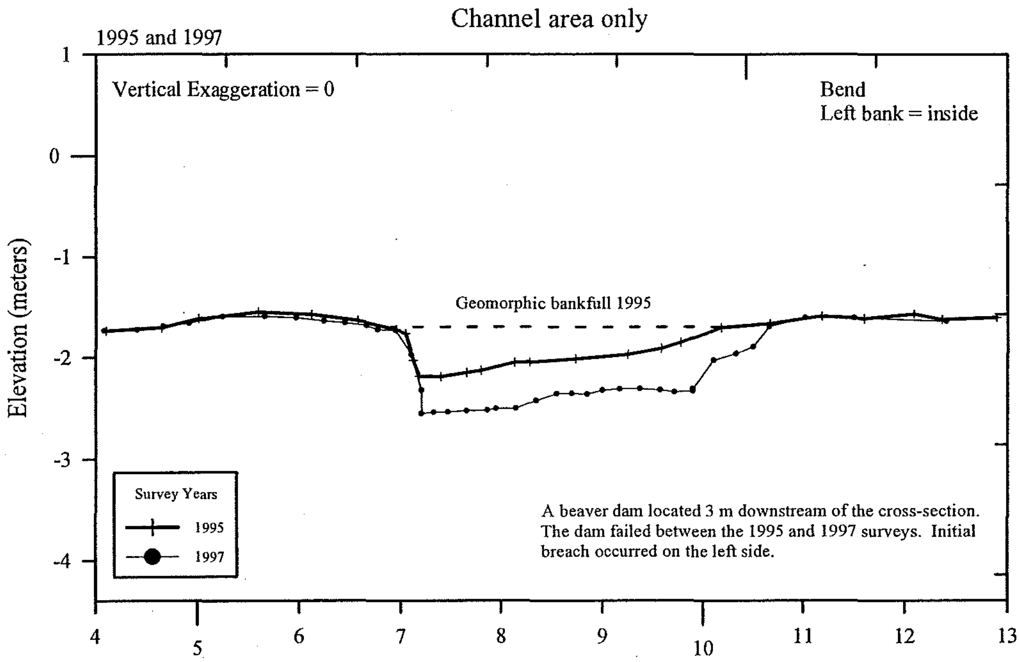
Entire cross-section 1995
(Baseline year)

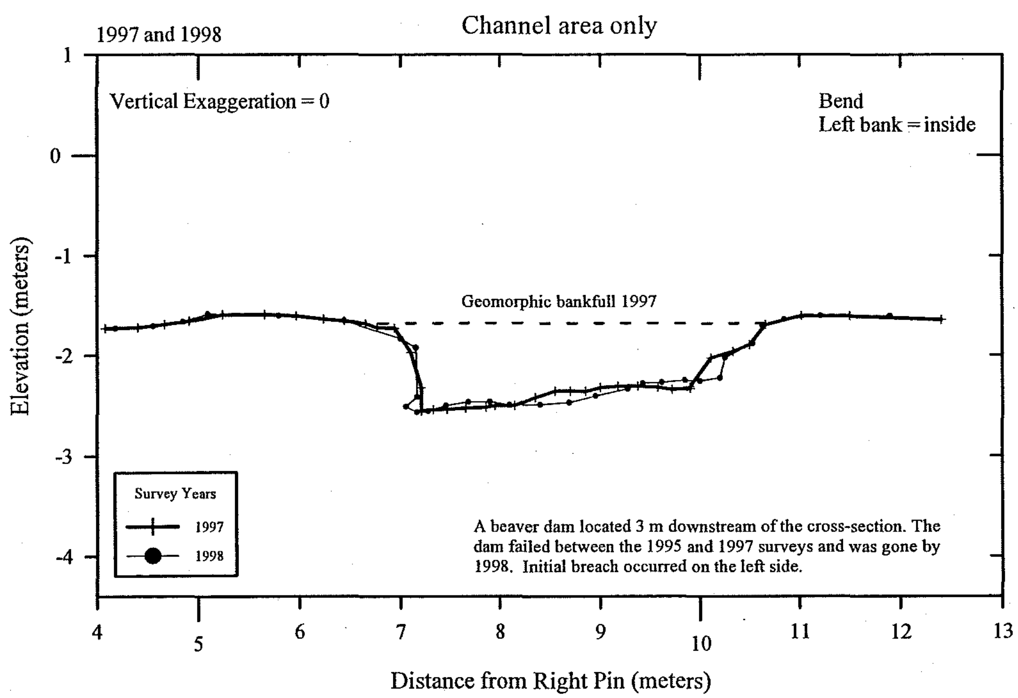


1995 and 1998 (Net Change) Channel area only



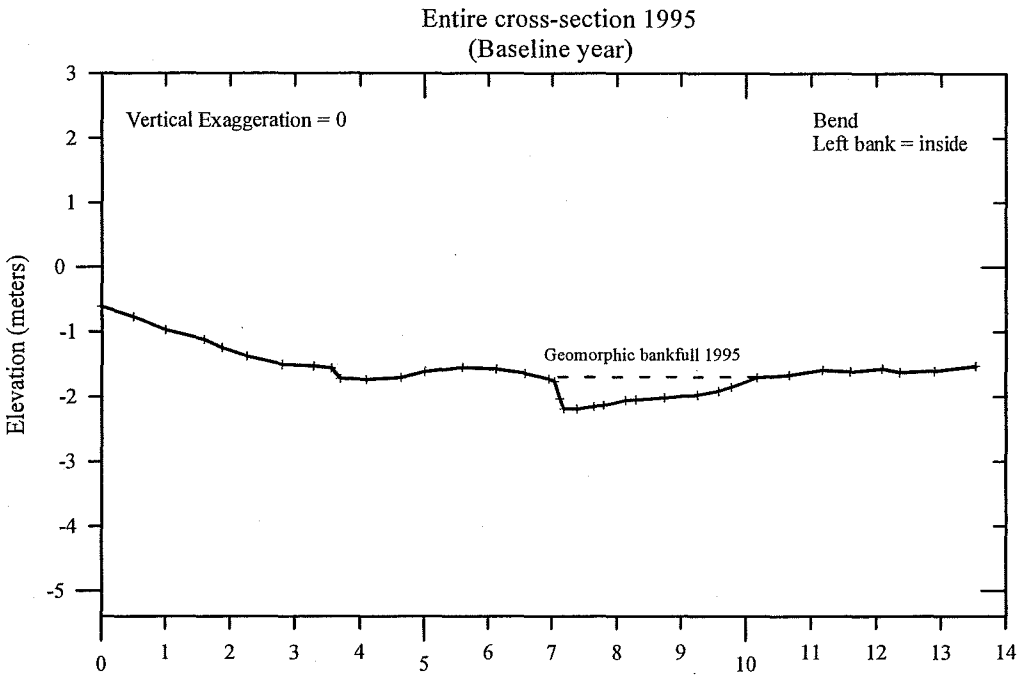
Price Creek cross-section 29 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

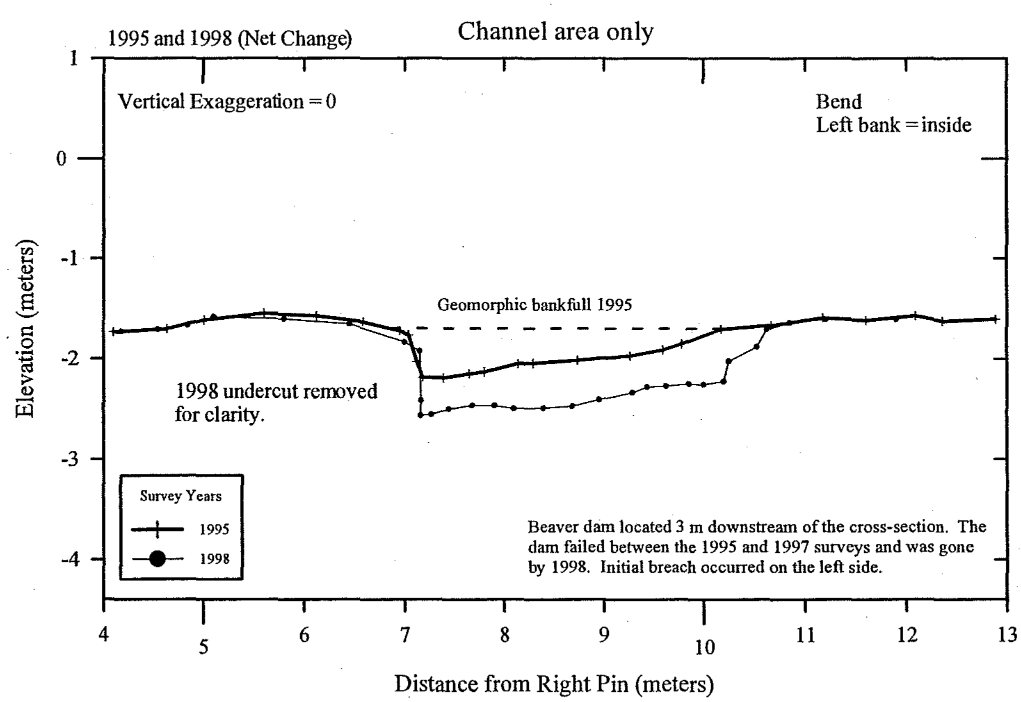




Price Creek cross-section 29 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

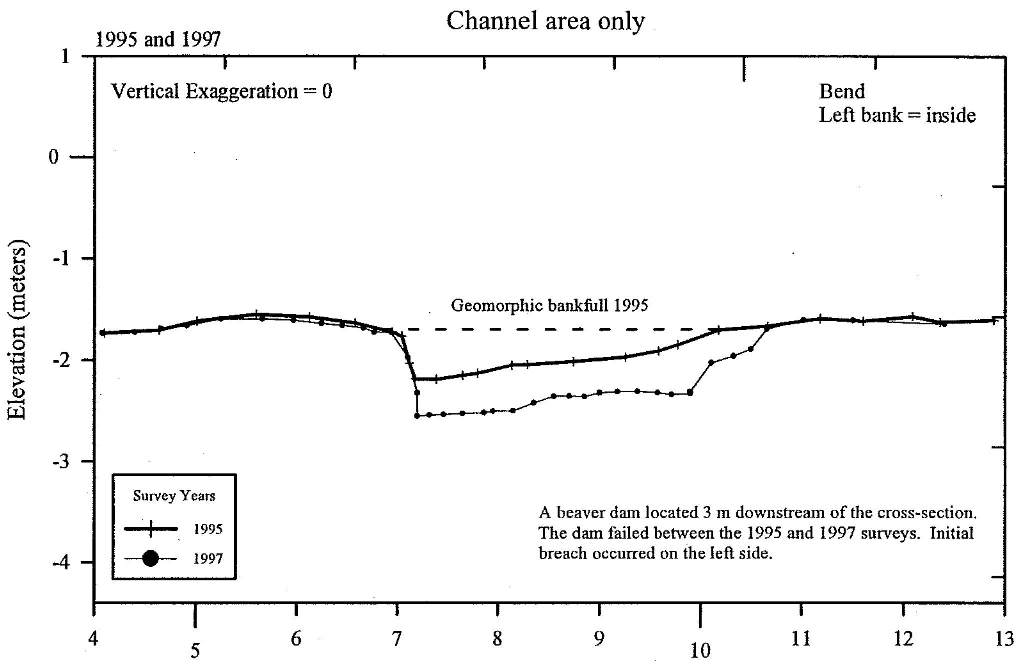
Undercuts removed for clarity.

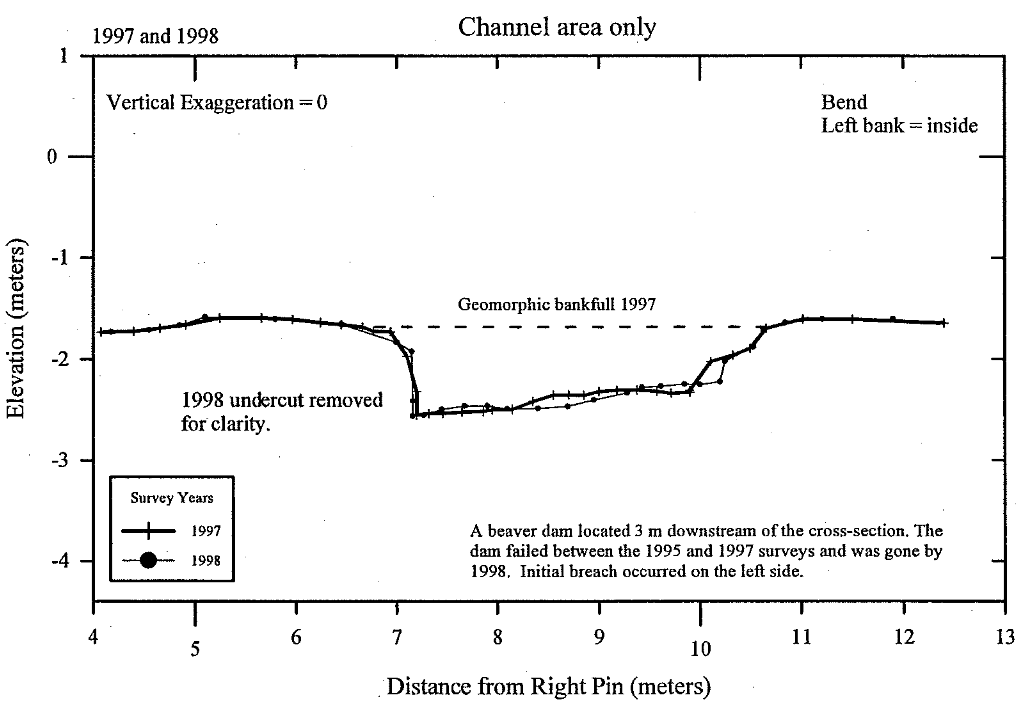




Price Creek cross-section 29 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

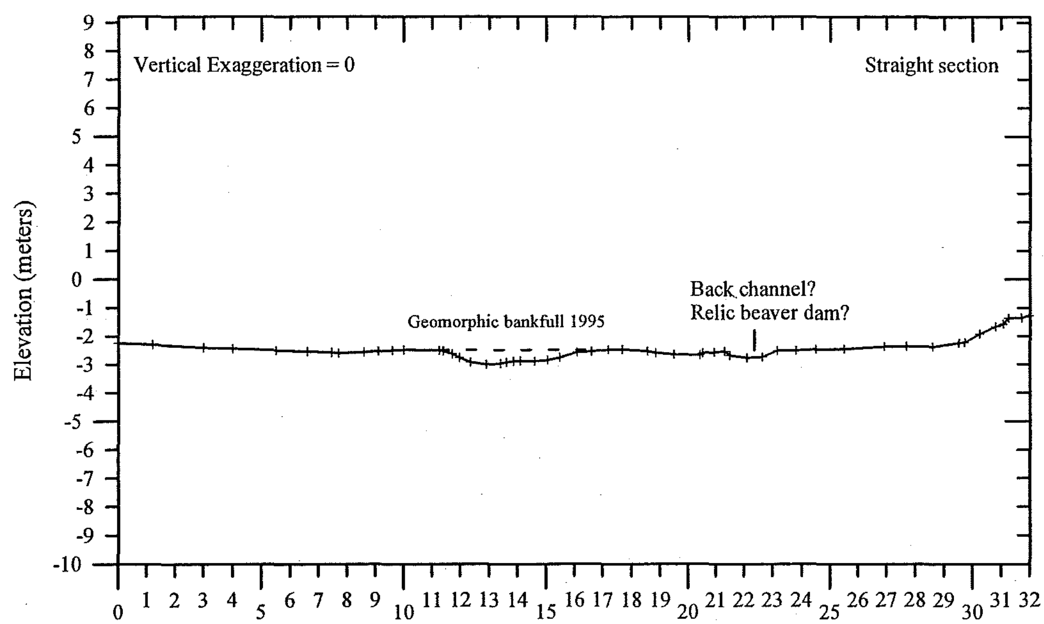
Undercuts removed for clarity.



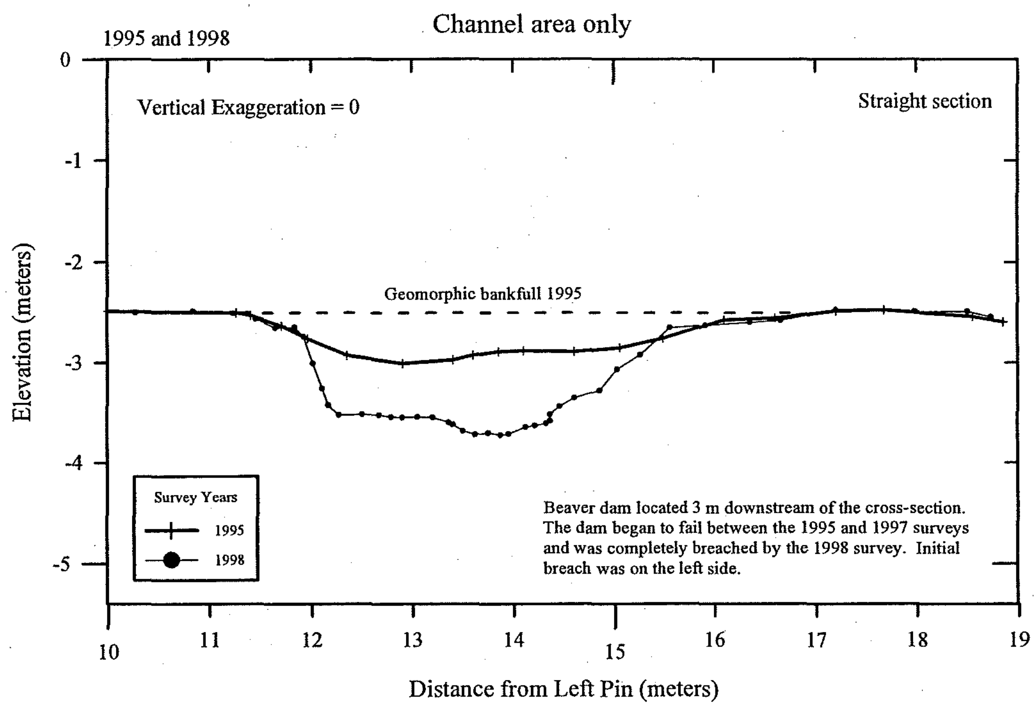


Price Creek cross-section 30
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998

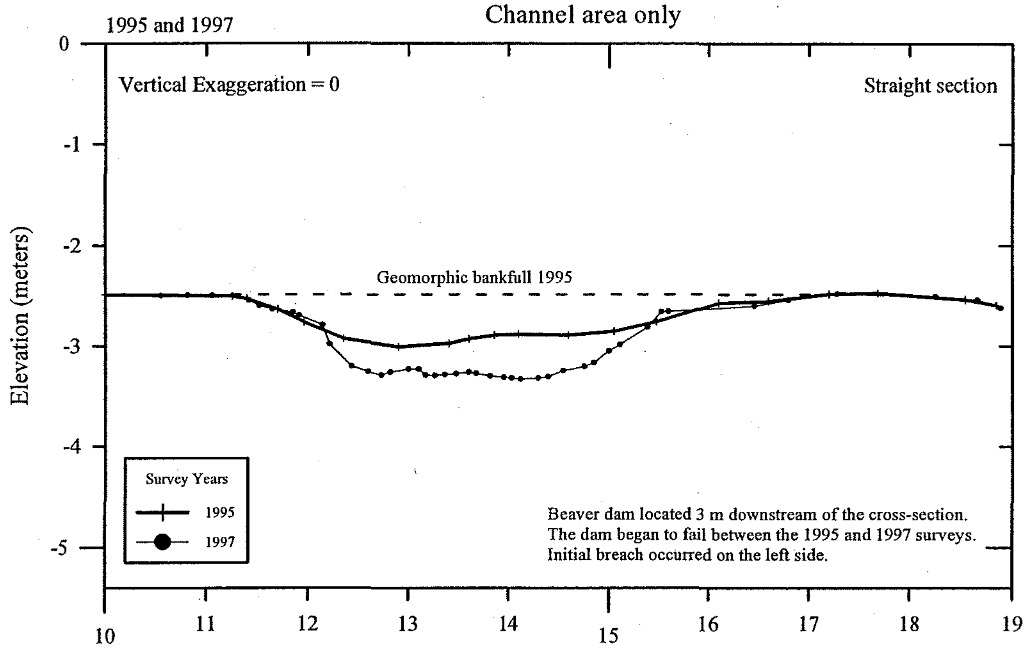
Entire cross-section 1995
(Baseline year)

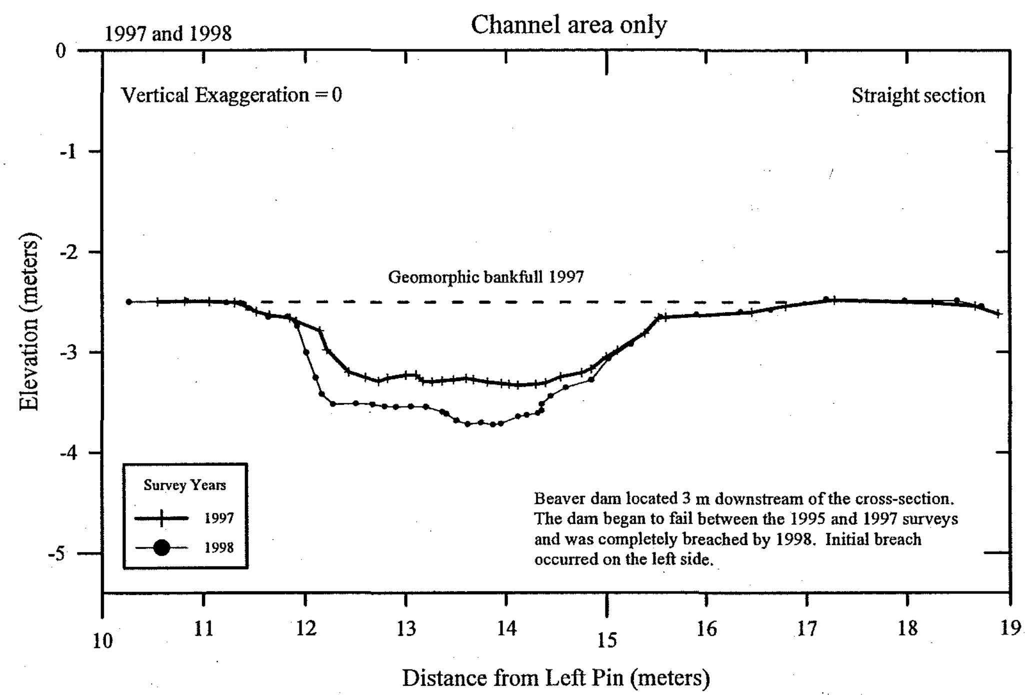


Channel area only

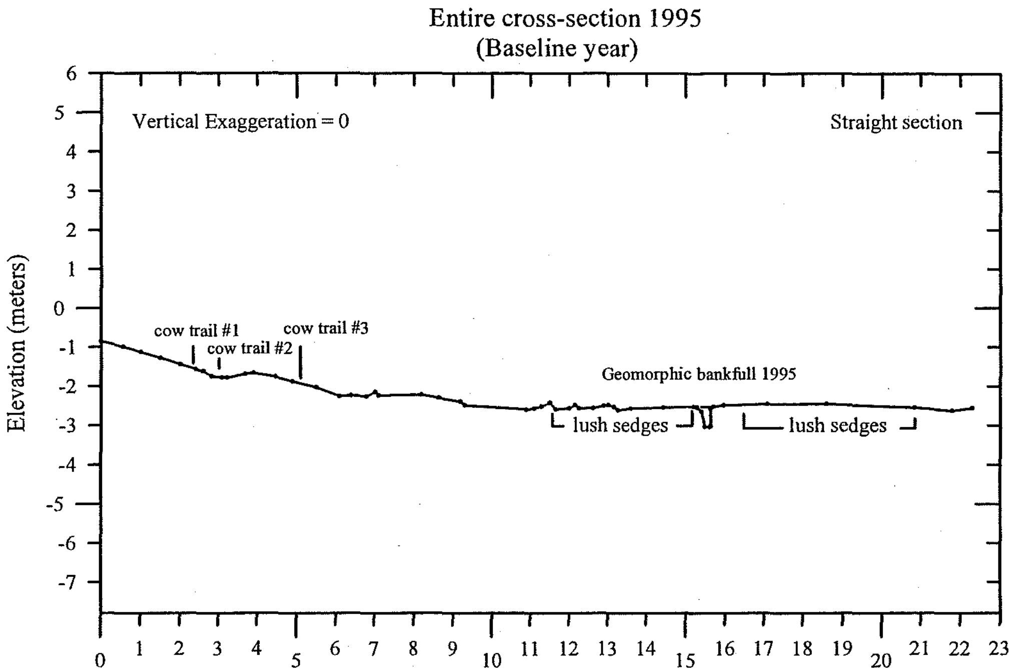


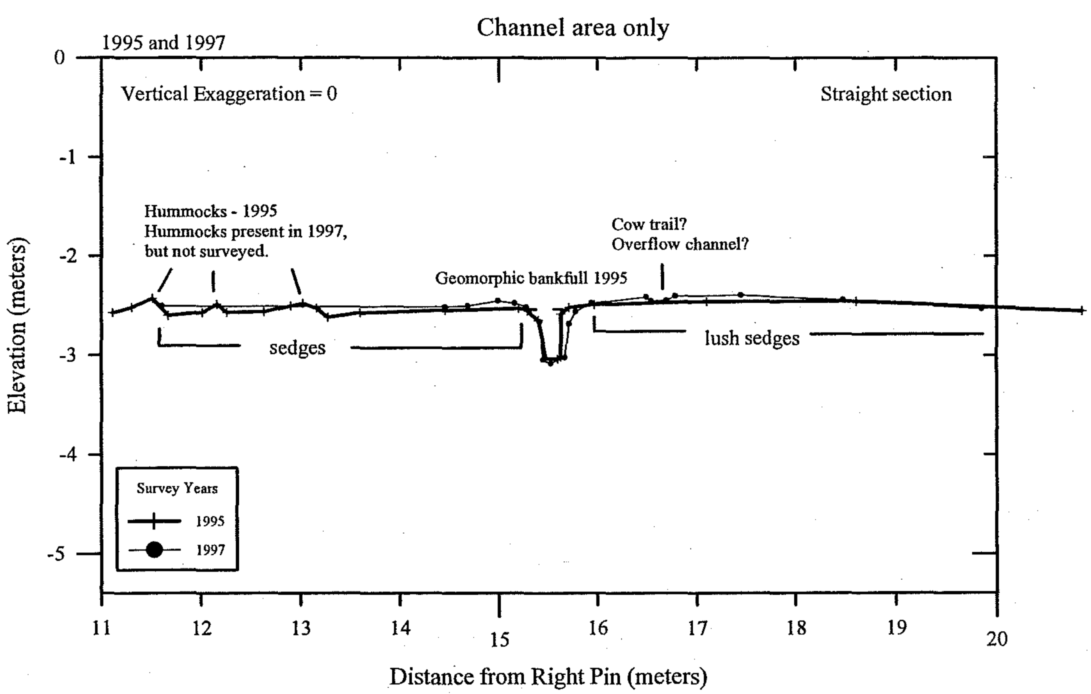
Price Creek cross-section 30 (continued)
New Cattle Exclosure/Beaver dam controlled
1995, 1997, and 1998



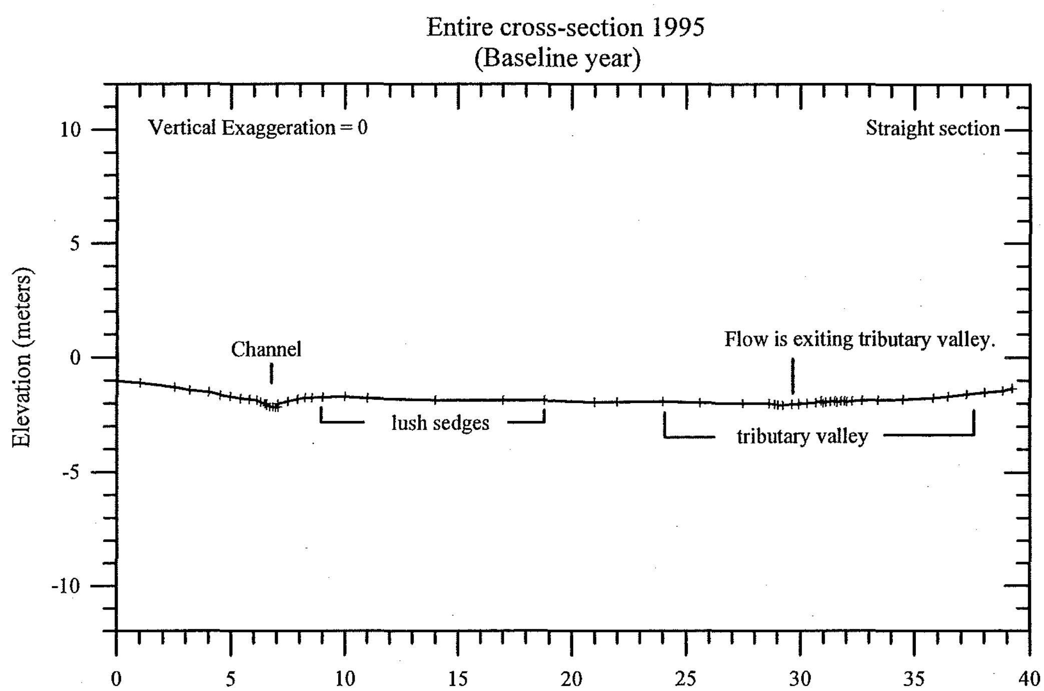


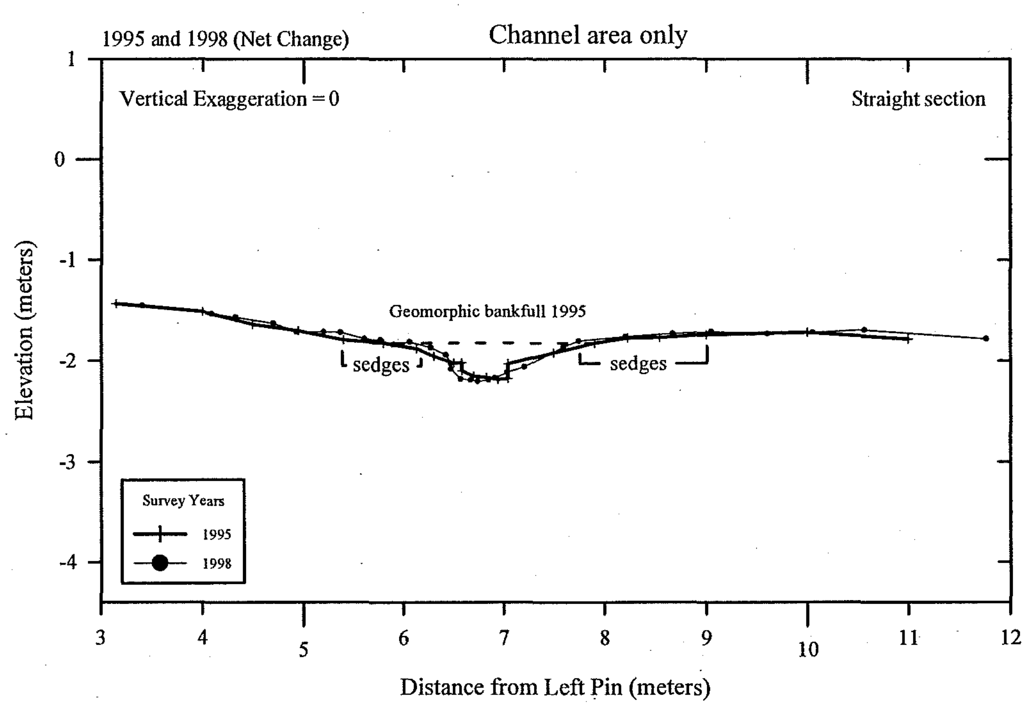
West Fork Price Creek cross-section 31
Riparian Guidelines
1995 and 1997



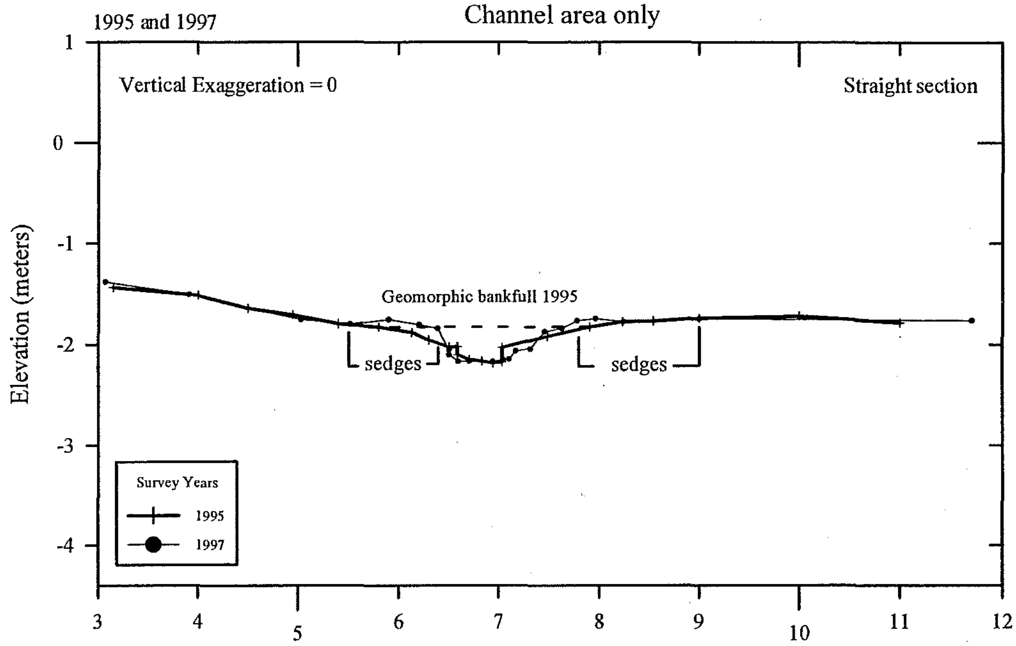


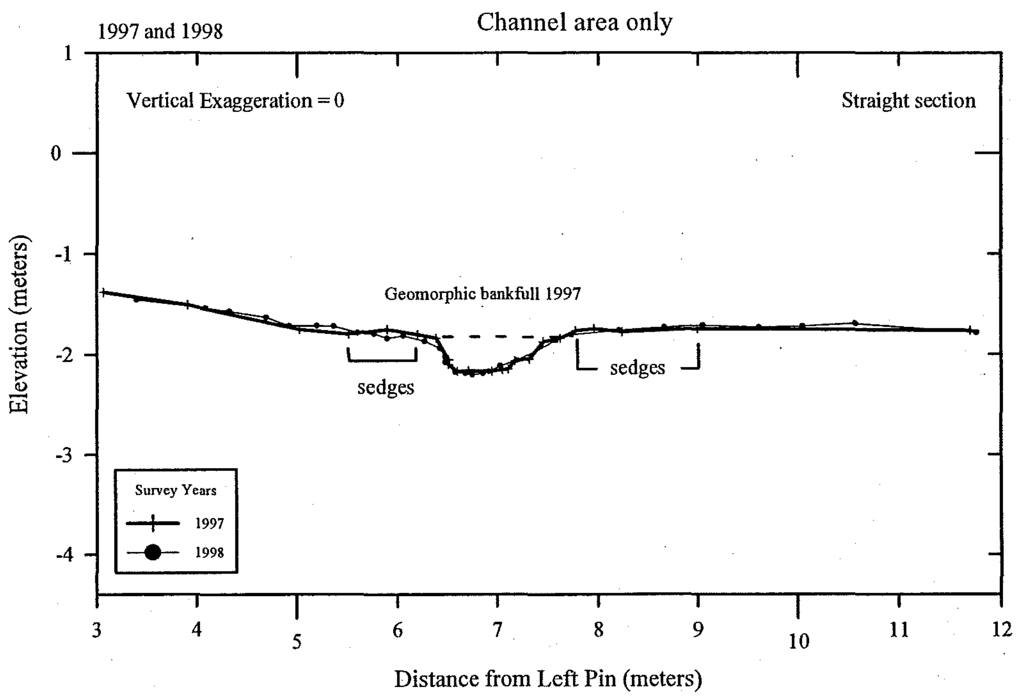
West Fork Price Creek cross-section 32
Riparian Guidelines
1995, 1997, and 1998



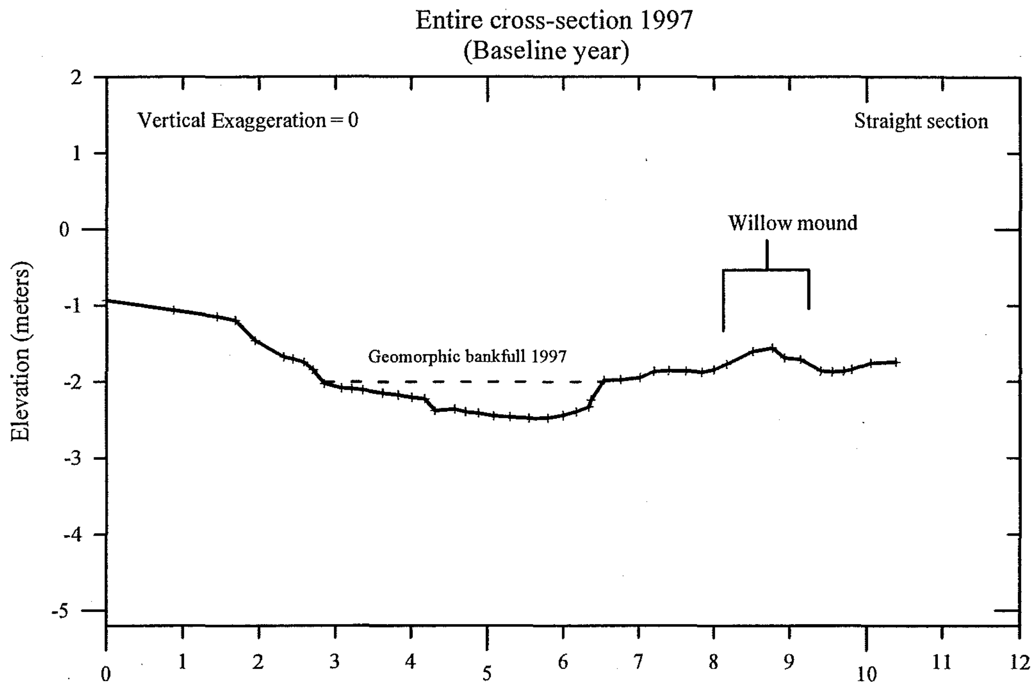


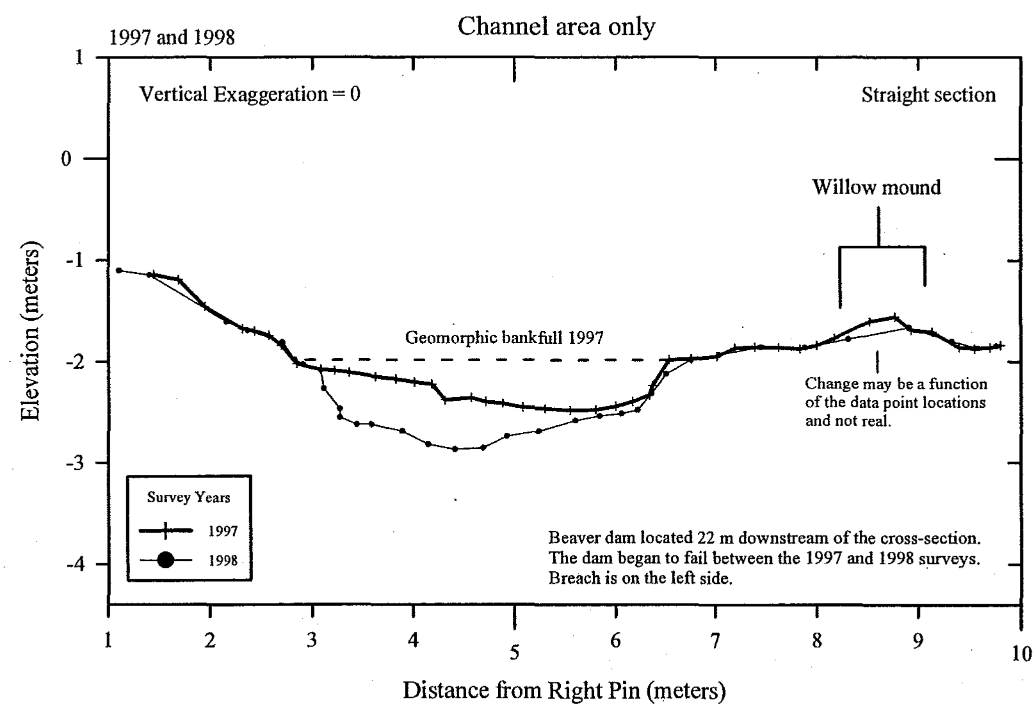
West Fork Price Creek cross-section 32 (continued)
Riparian Guidelines
1995, 1997, and 1998



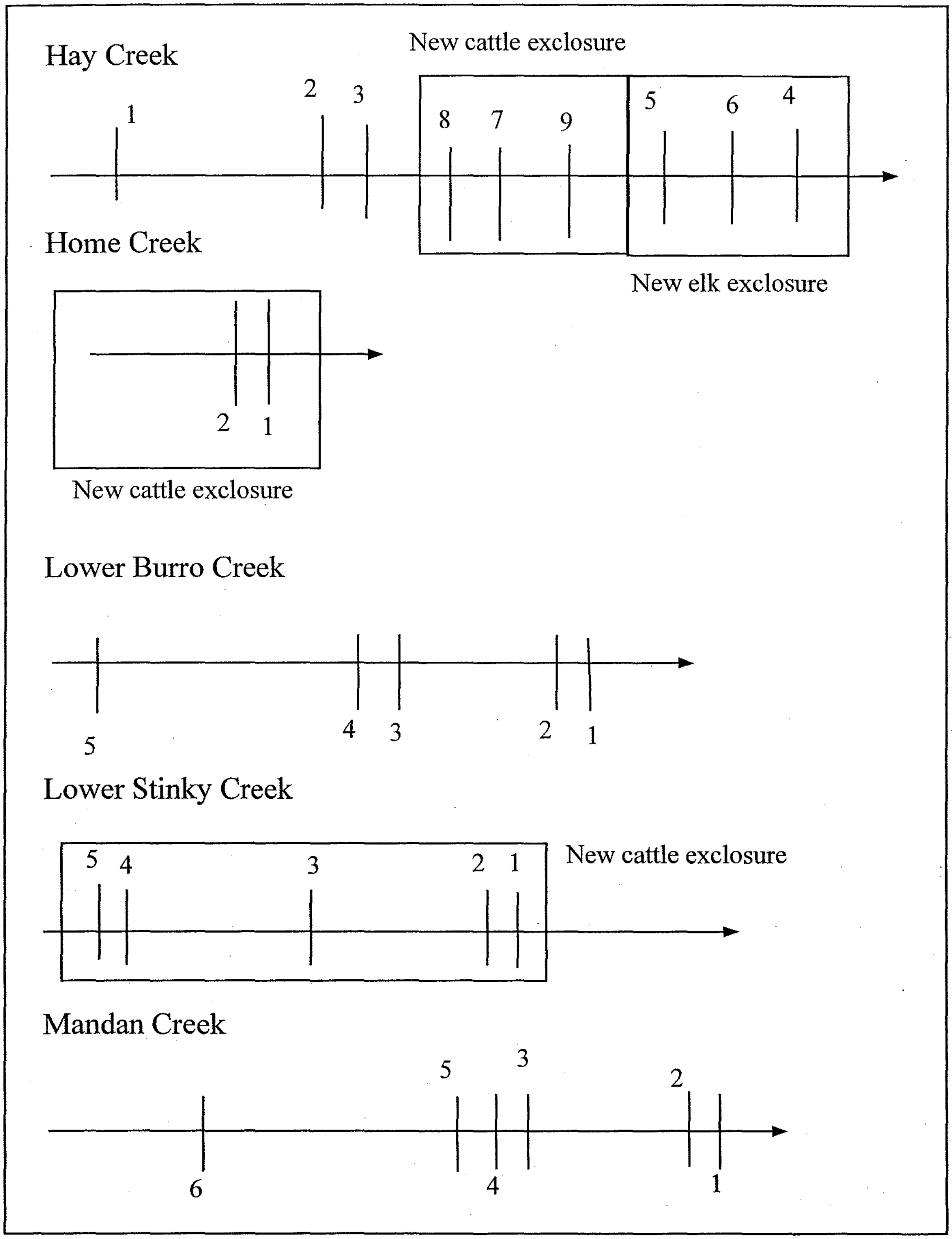


Price Creek cross-section 33
New Cattle Exclosure/Beaver dam controlled
1997 and 1998

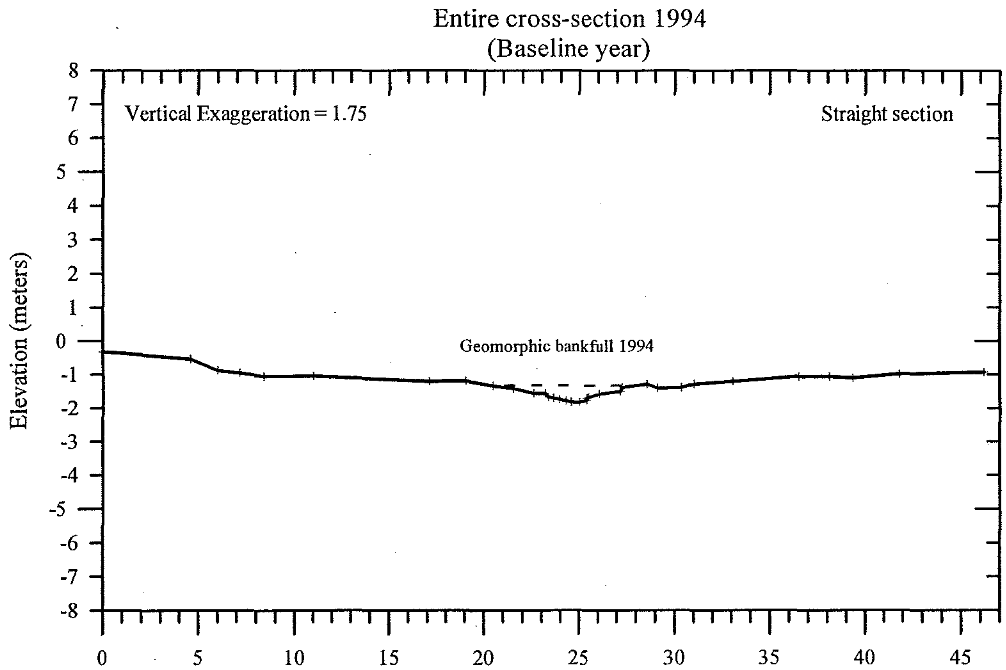


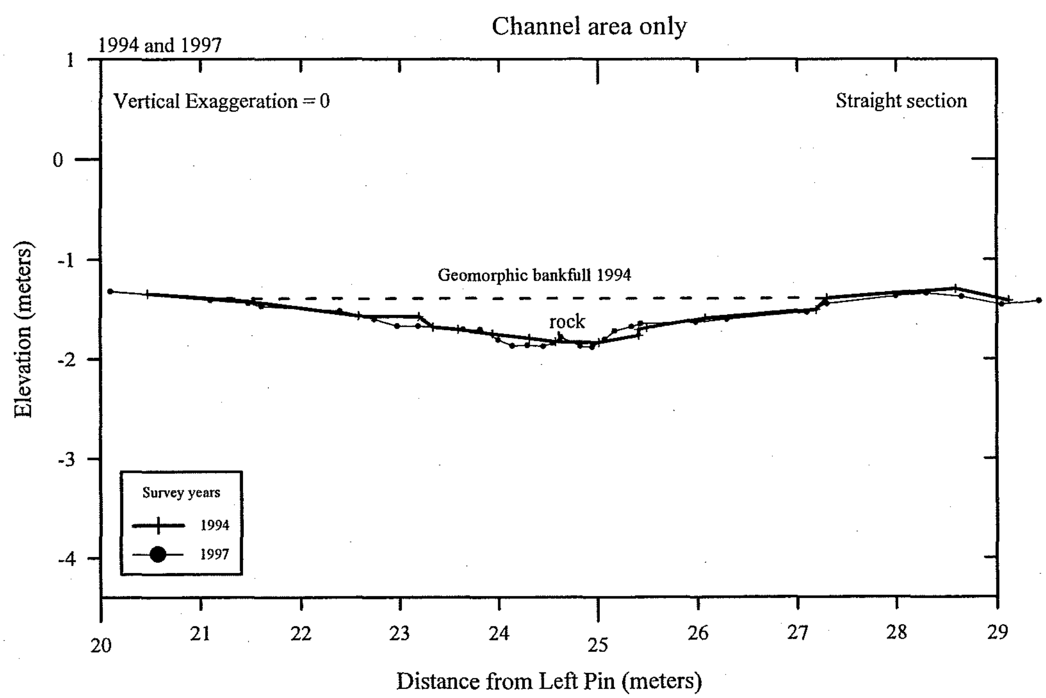


White Mountains suite, Arizona
Relative location of the cross-sections with respect to each other.

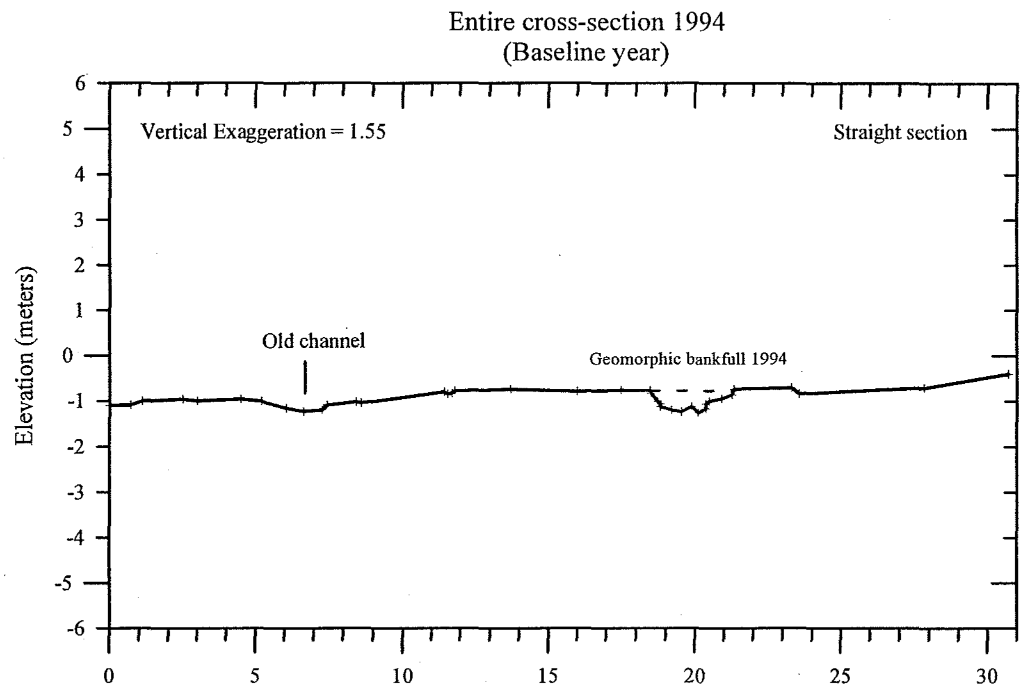


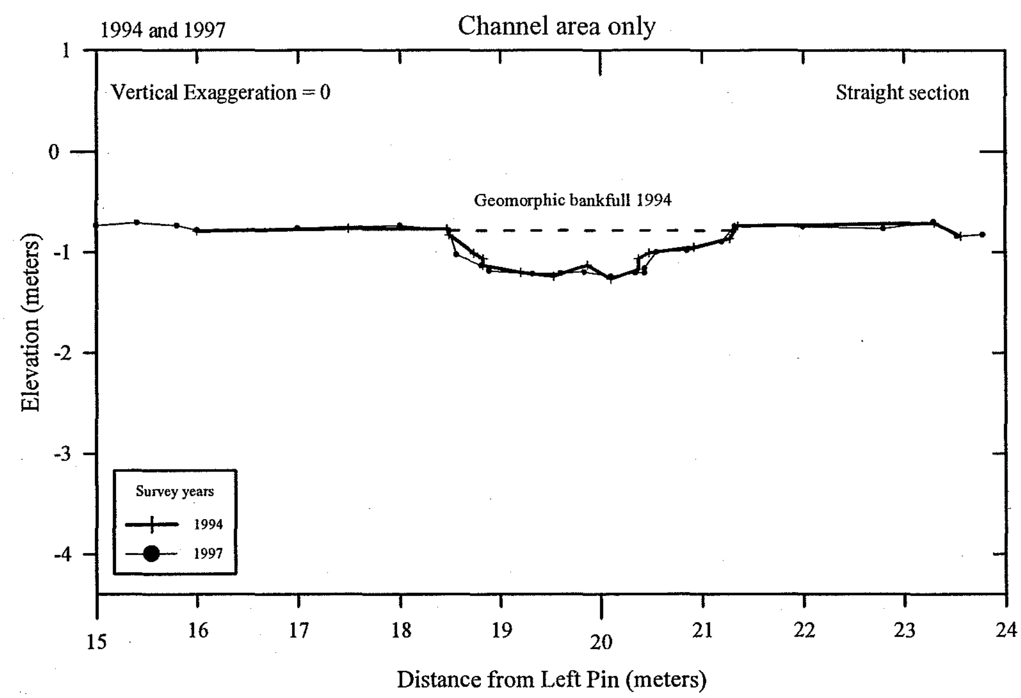
Hay Creek cross-section 1
Special Emphasis Management Area
1994 and 1997





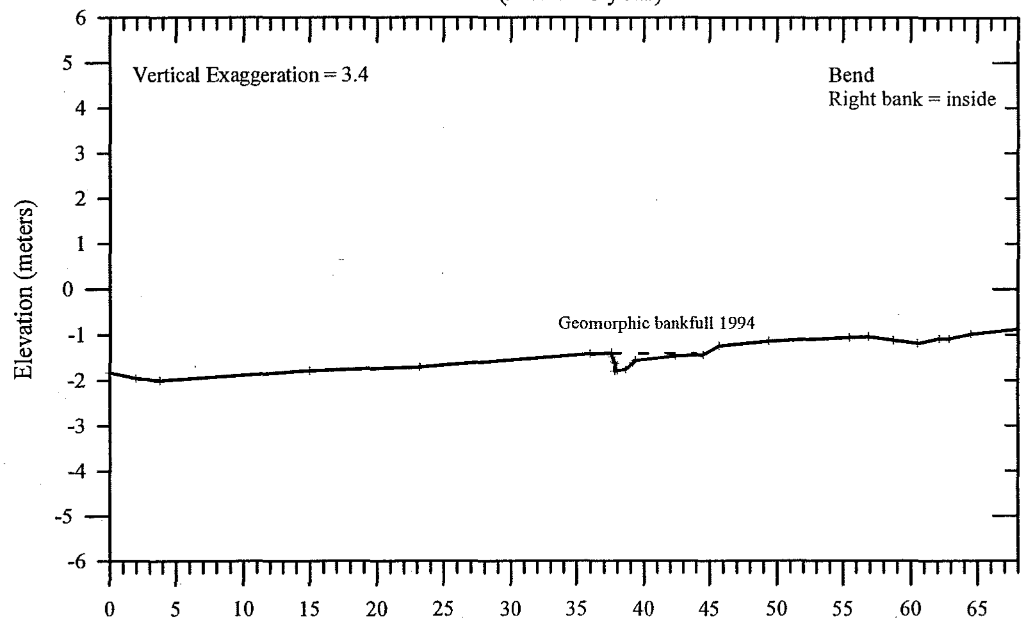
Hay Creek cross-section 2
Special Emphasis Management Area
1994 and 1997



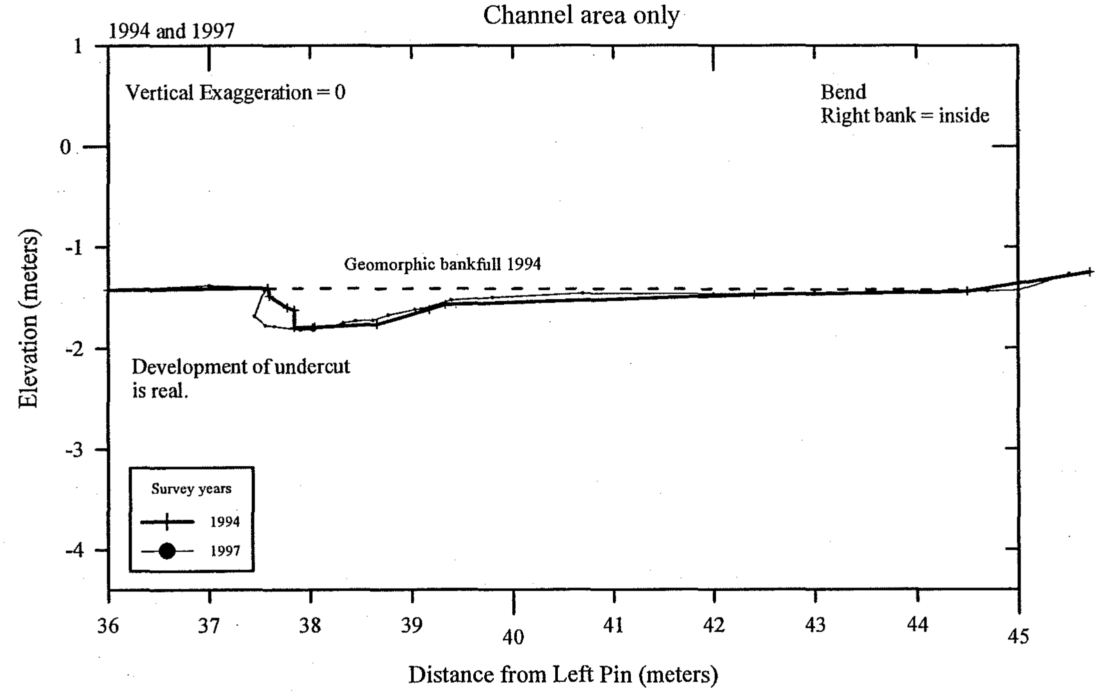


Hay Creek cross-section 3
Special Emphasis Management Area
1994 and 1997

Entire cross-section 1994
(Baseline year)



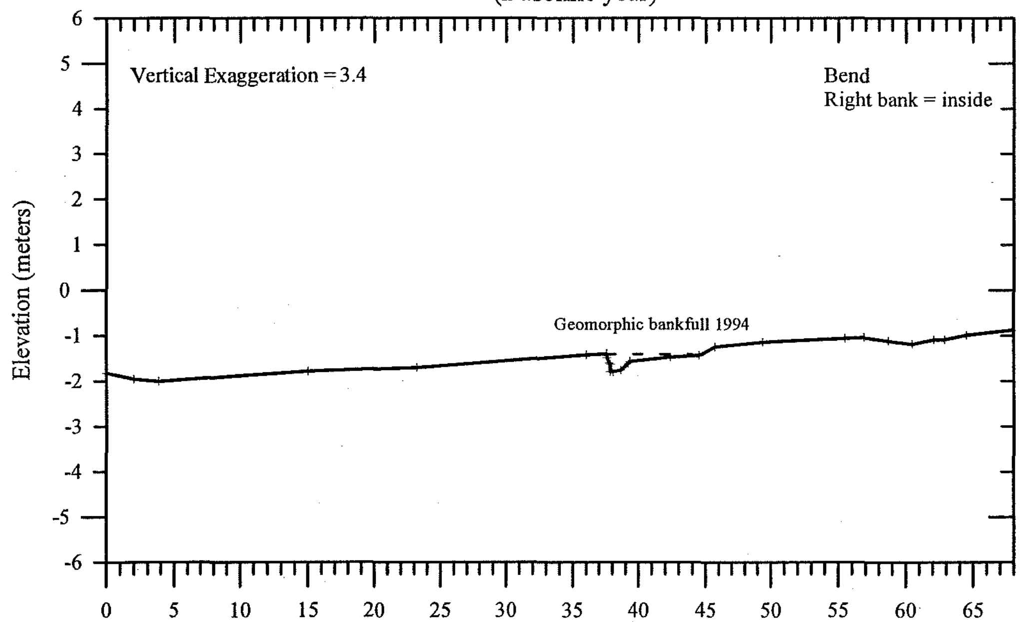
Channel area only



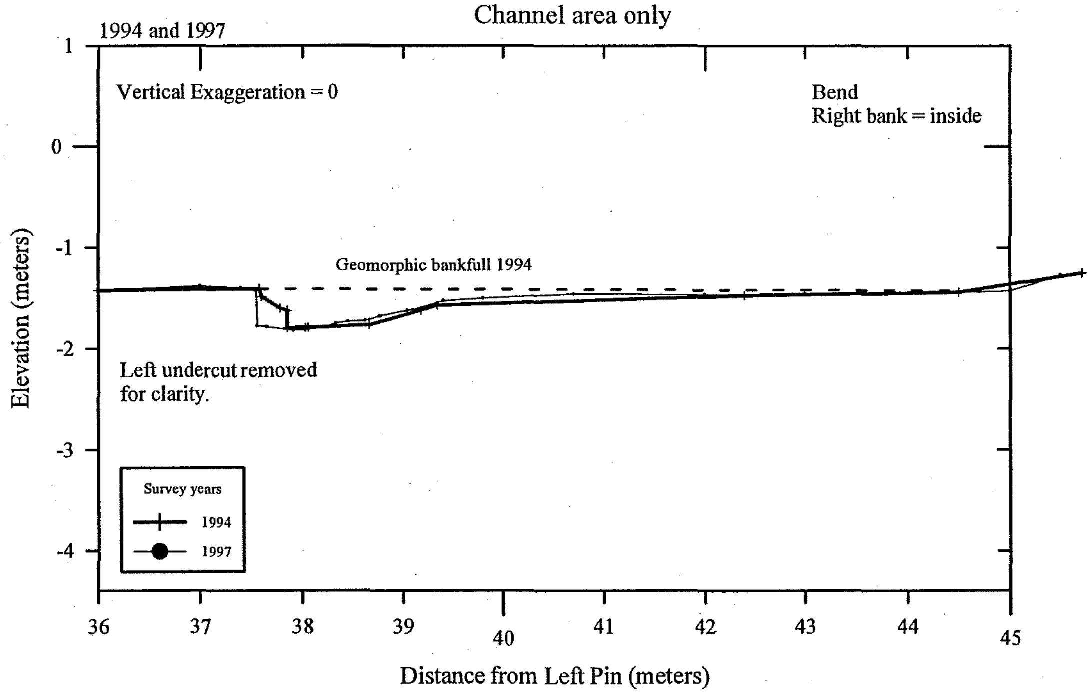
Hay Creek cross-section 3 (continued)
Special Emphasis Management Area
1994 and 1997

Undercut removed for clarity.

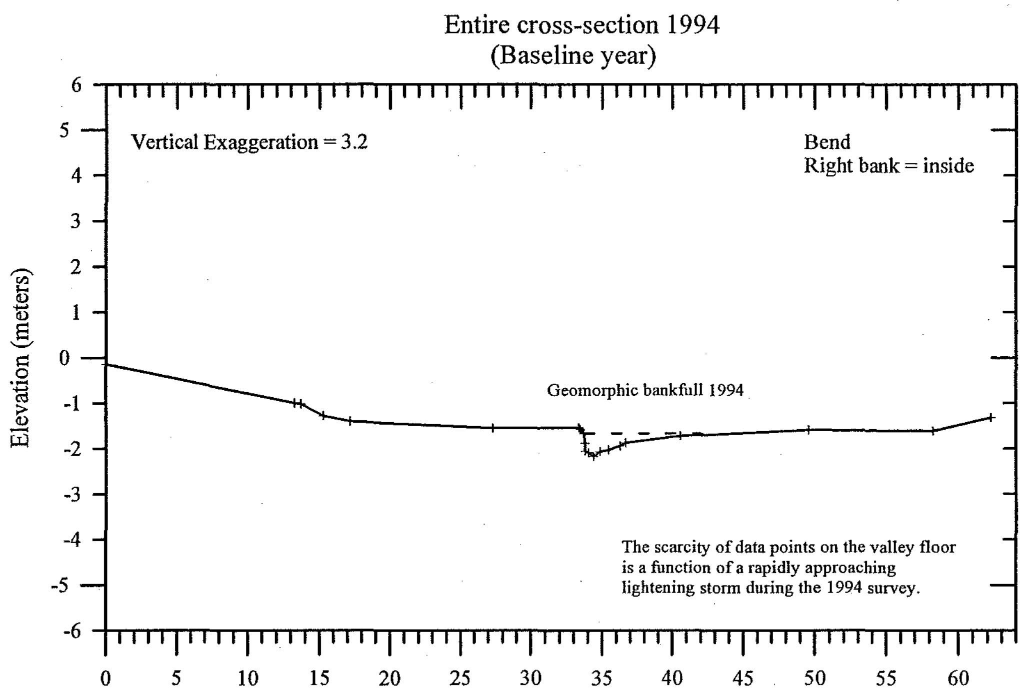
Entire cross-section 1994
(Baseline year)

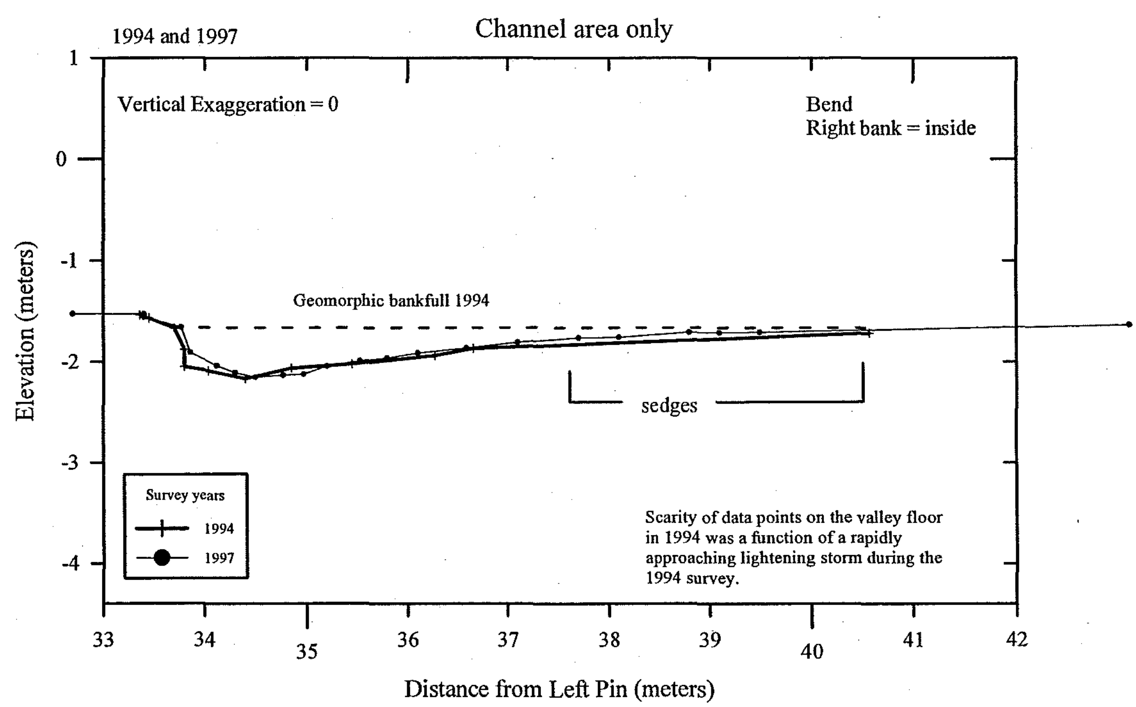


Channel area only



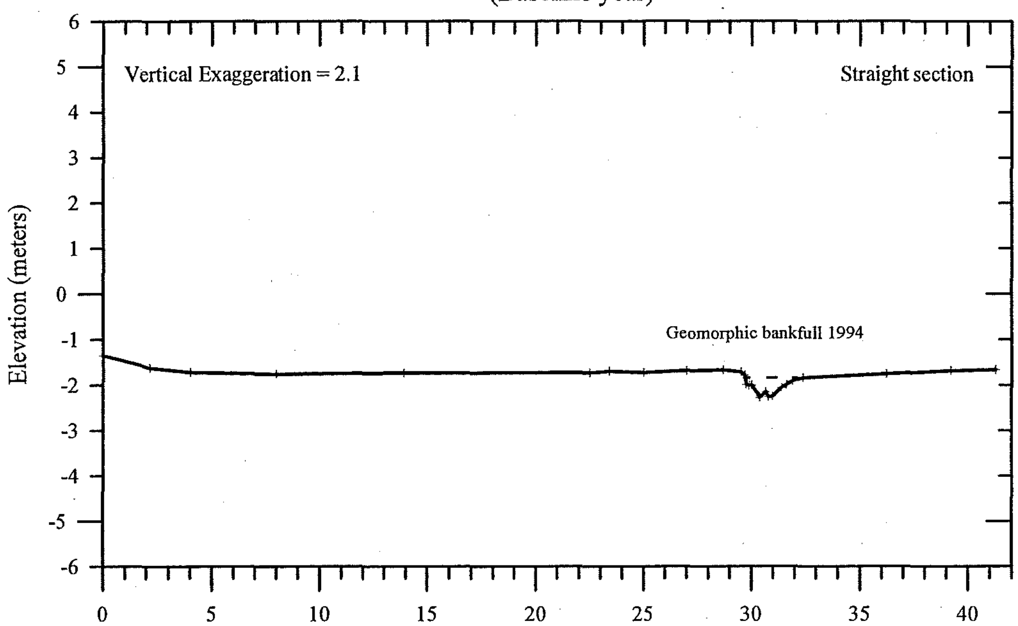
Hay Creek cross-section 4
New Elk Exclosure
1994 and 1997



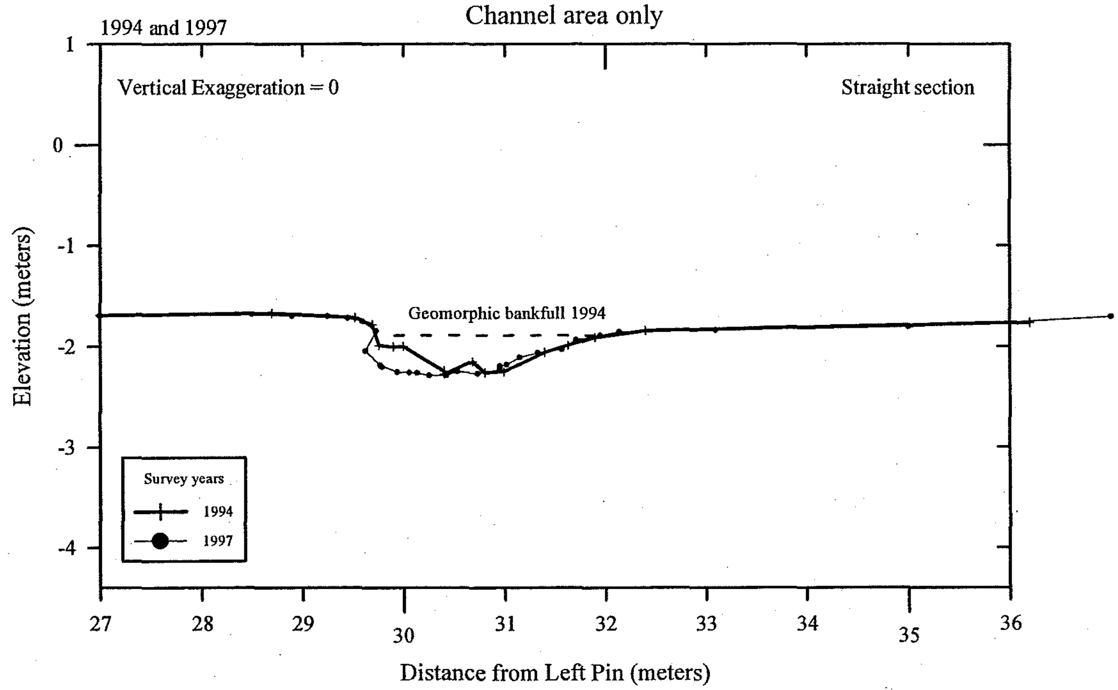


Hay Creek cross-section 5
New Elk Exclosure
1994 and 1997

Entire cross-section 1994
(Baseline year)

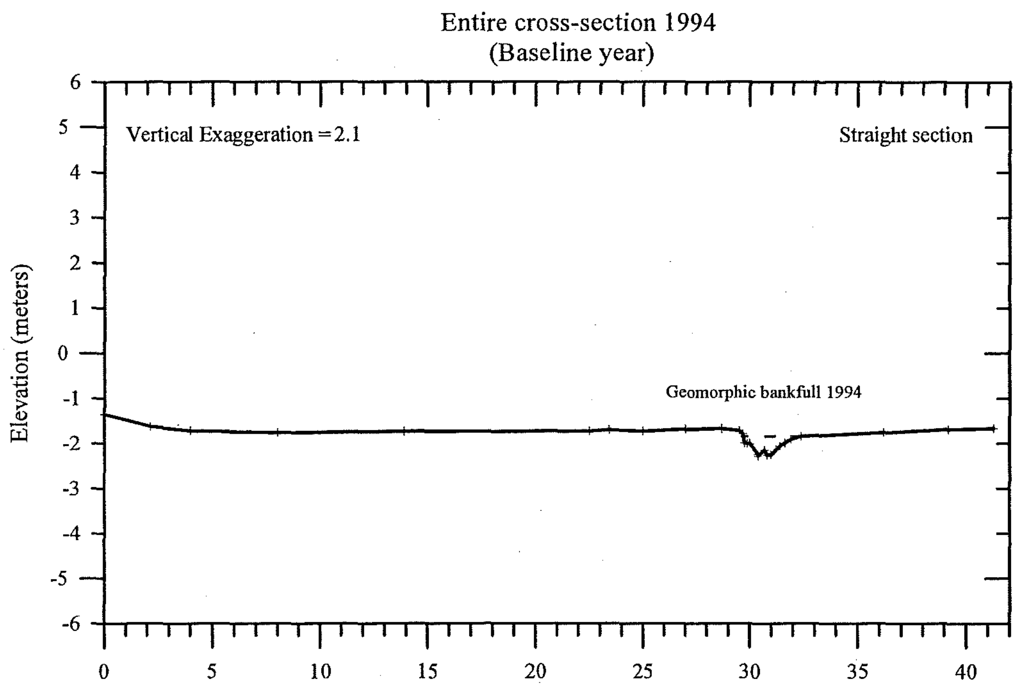


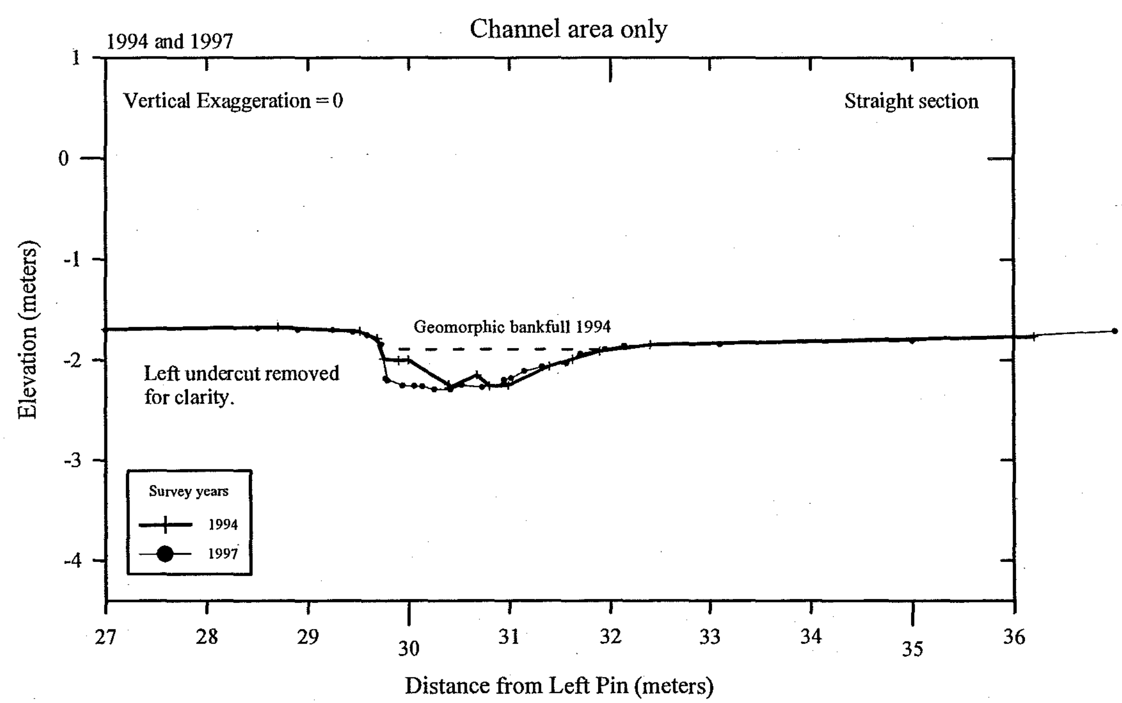
Channel area only



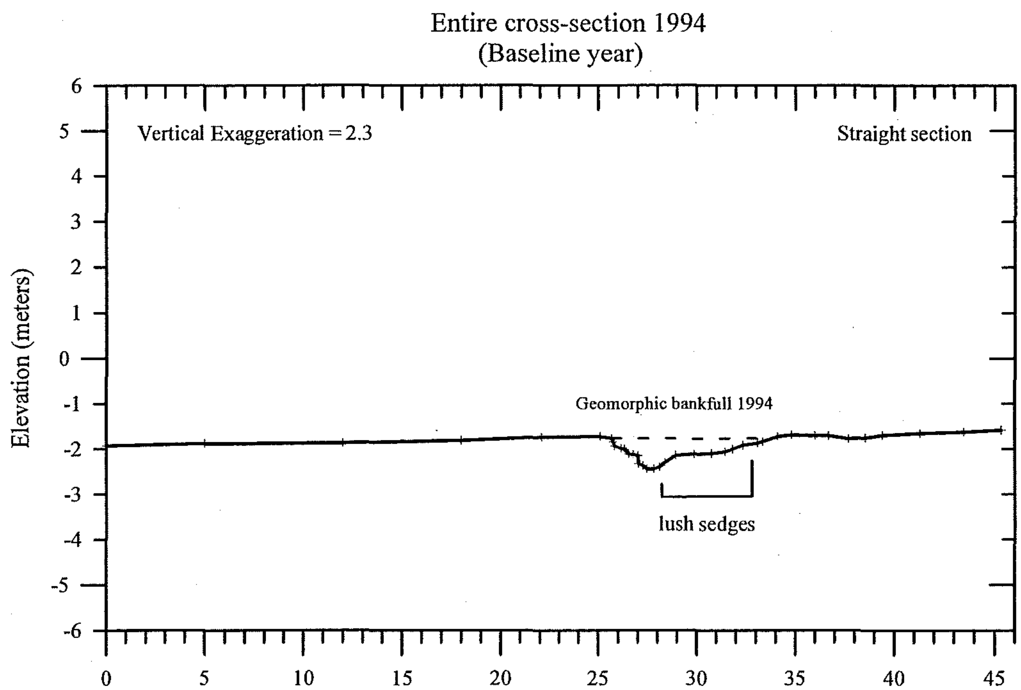
Hay Creek cross-section 5 (continued)
New Elk Exclosure
1994 and 1997

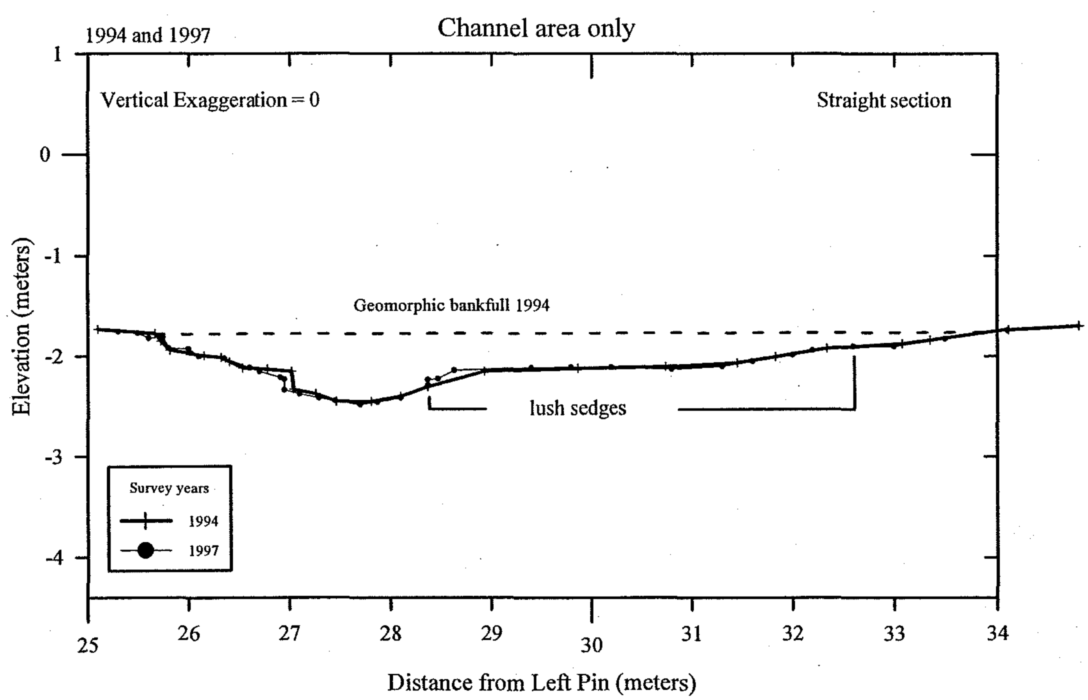
Undercut removed for clarity





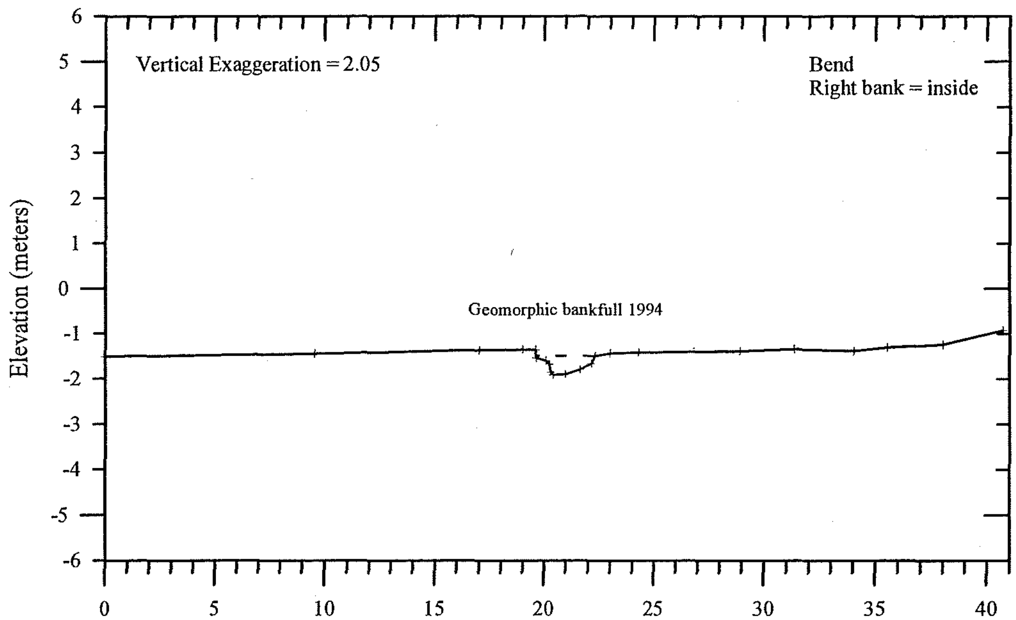
Hay Creek cross-section 6
New Elk Exclosure
1994 and 1997



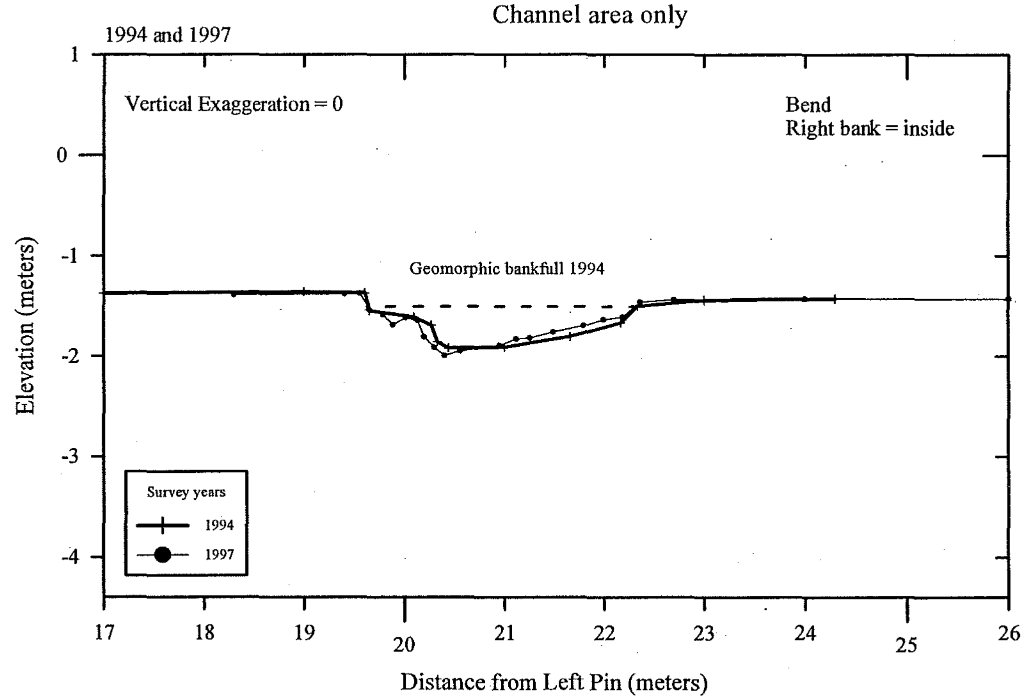


Hay Creek cross-section 7
New Cattle Exclosure
1994 and 1997

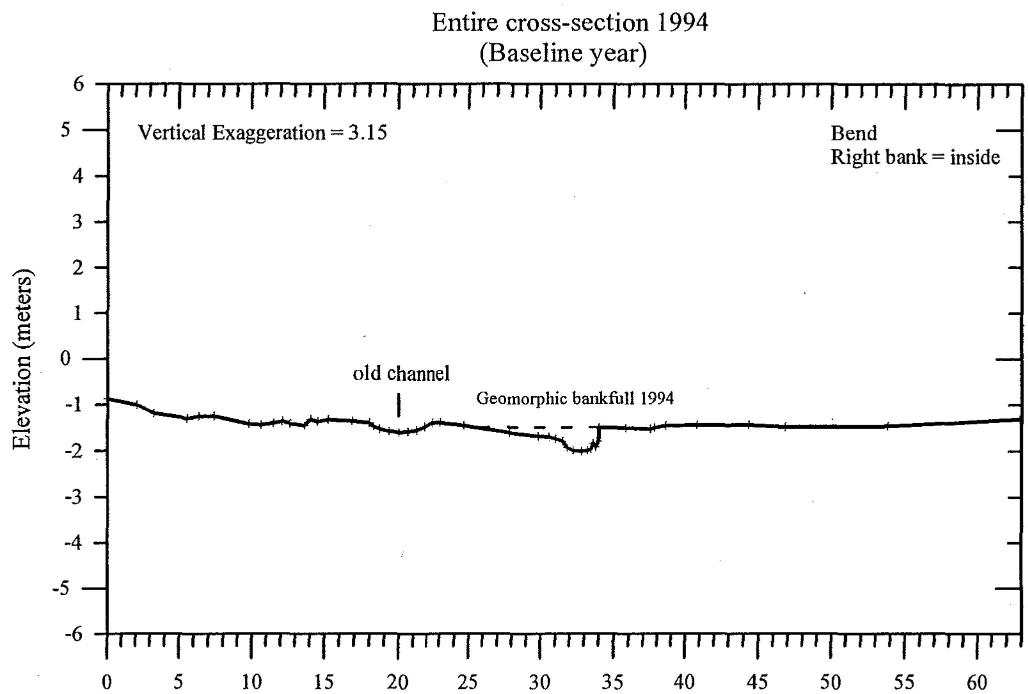
Entire cross-section 1994
(Baseline year)

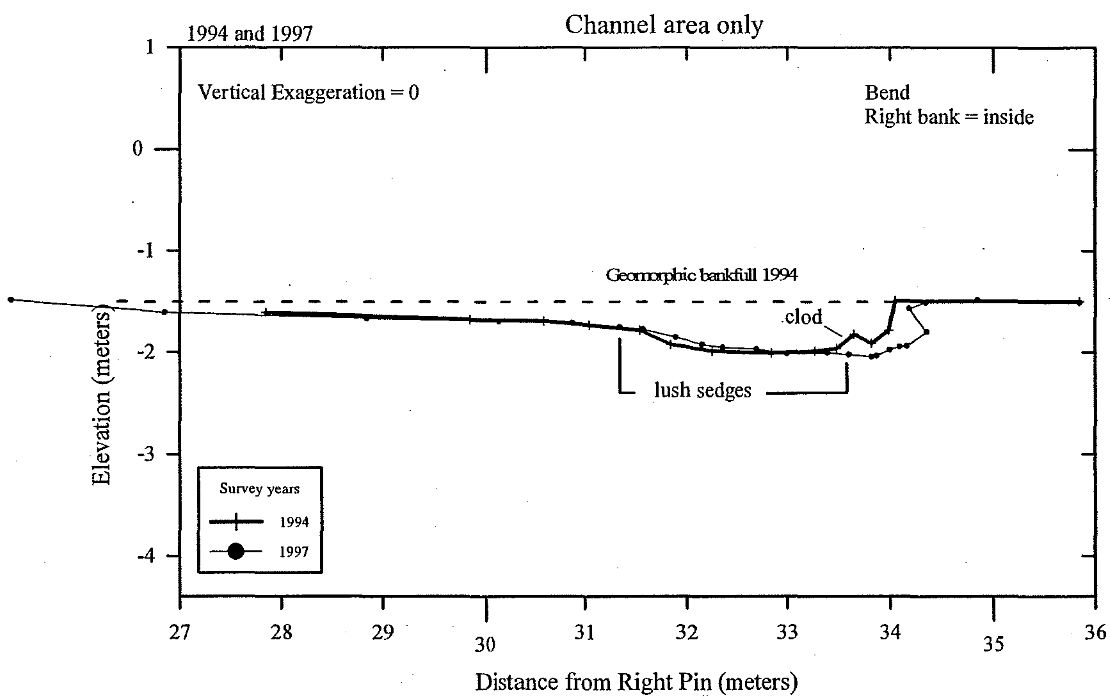


Channel area only



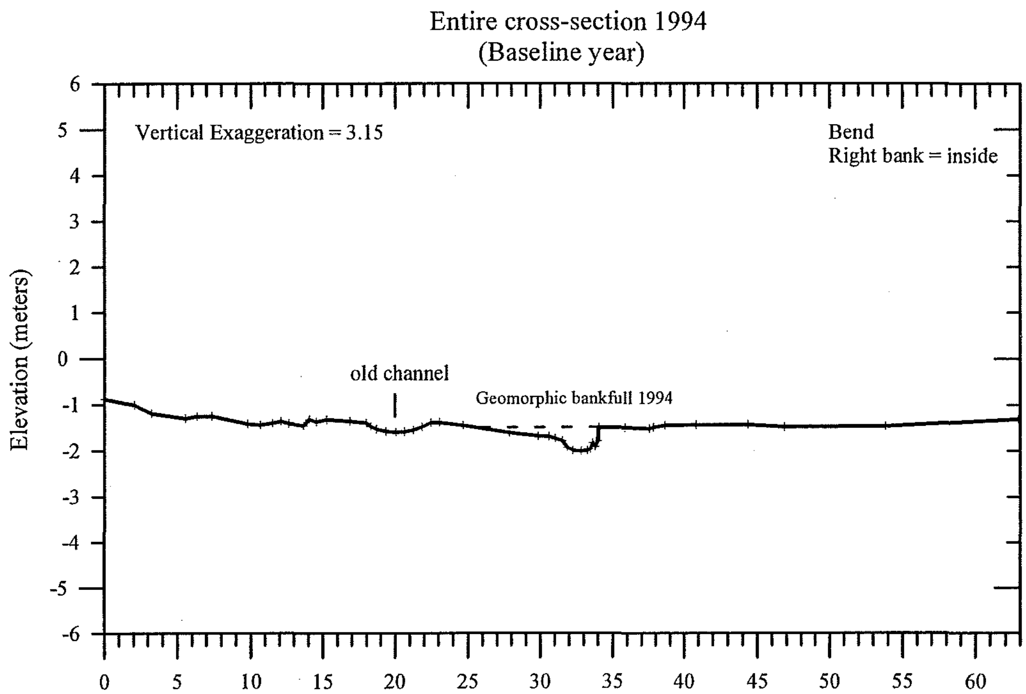
Hay Creek cross-section 8
New Cattle Exclosure
1994 and 1997

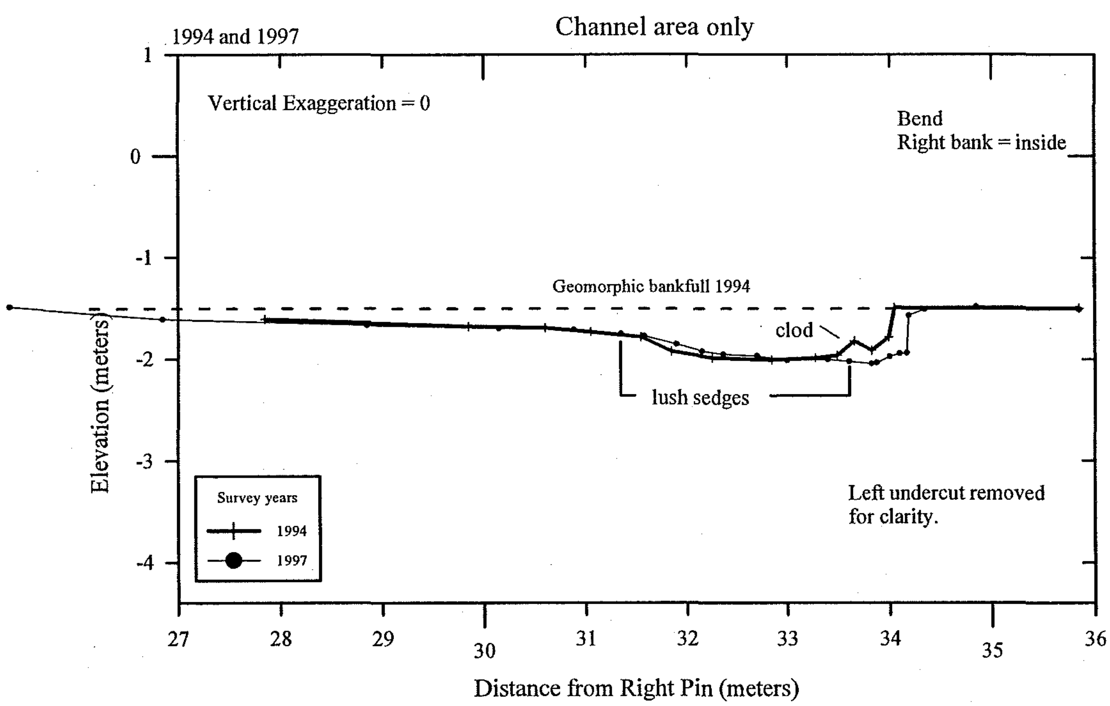




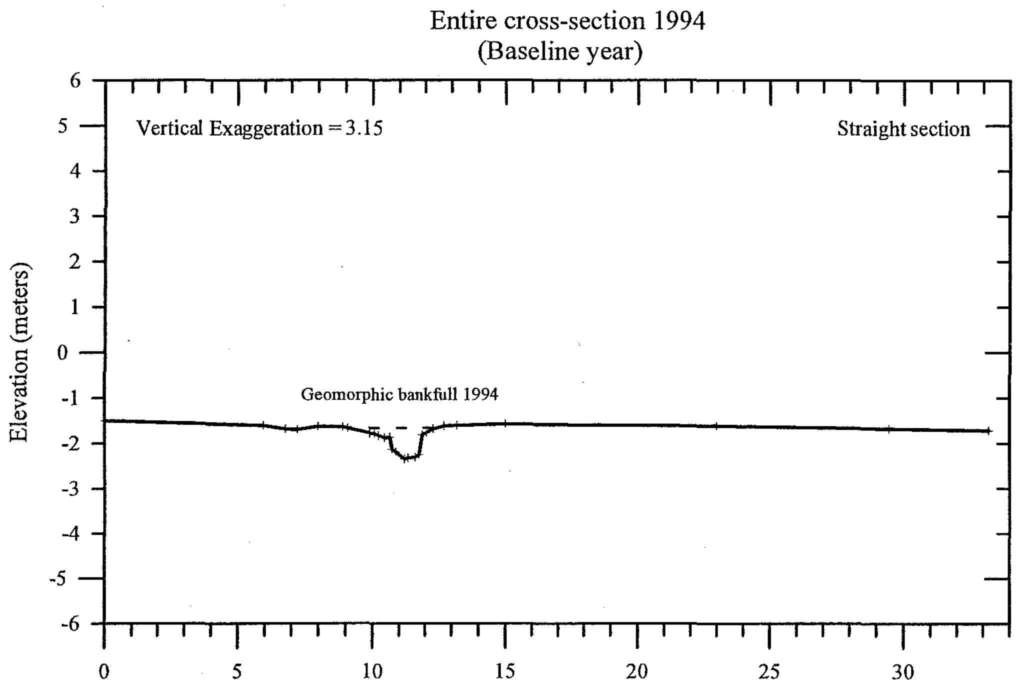
Hay Creek cross-section 8 (continued)
New Cattle Exclosure
1994 and 1997

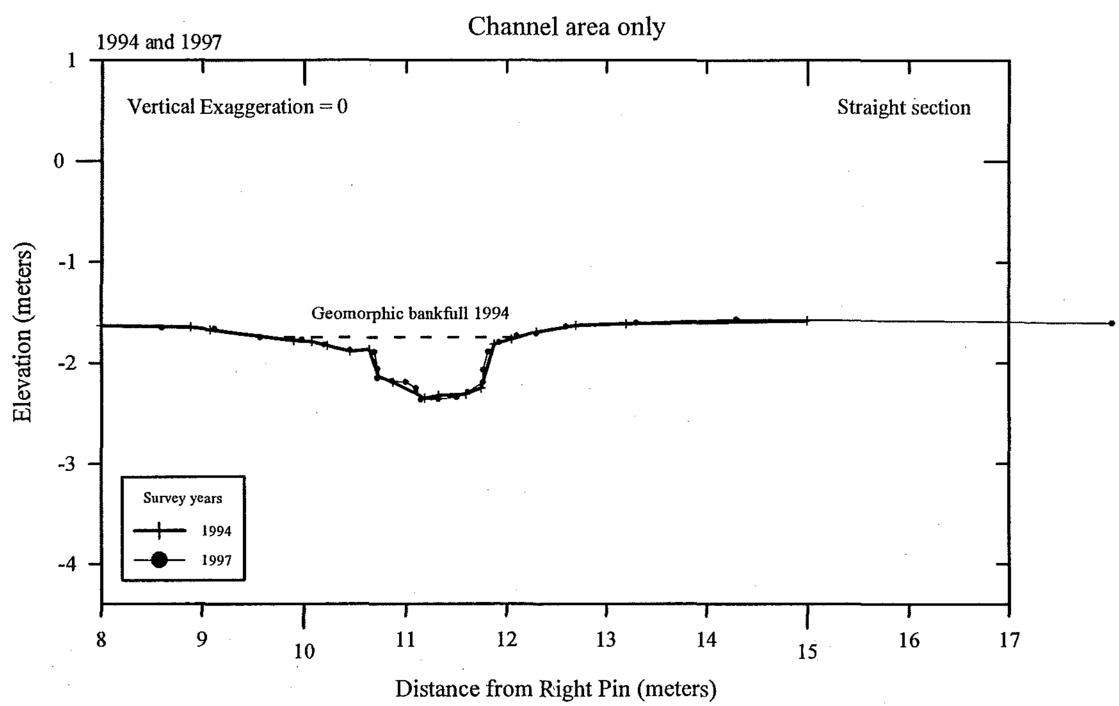
Undercut removed for clarity.



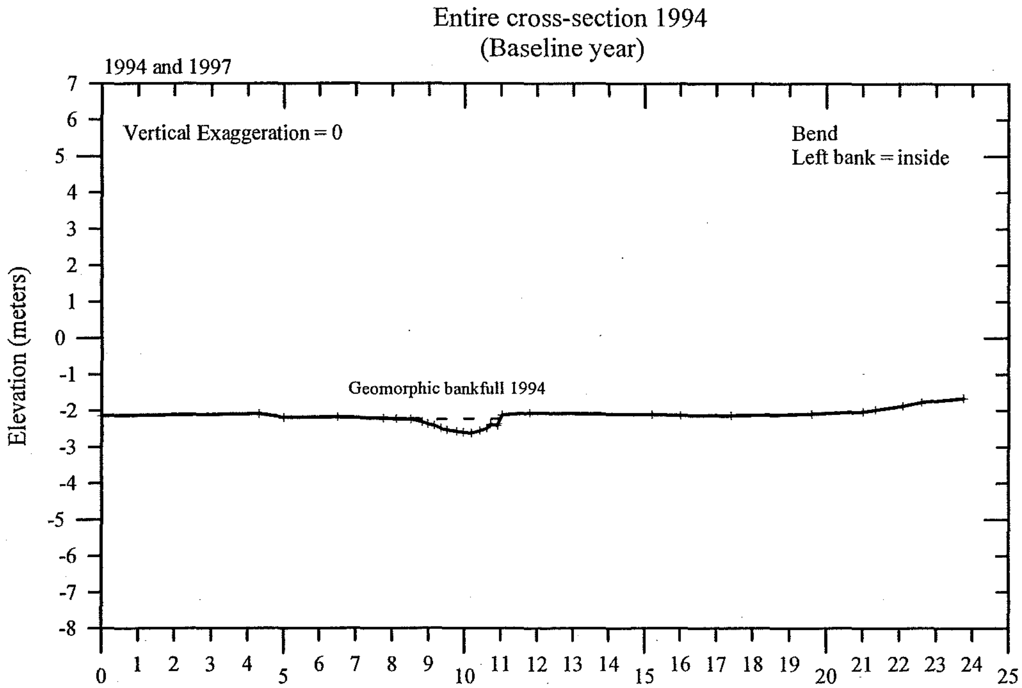


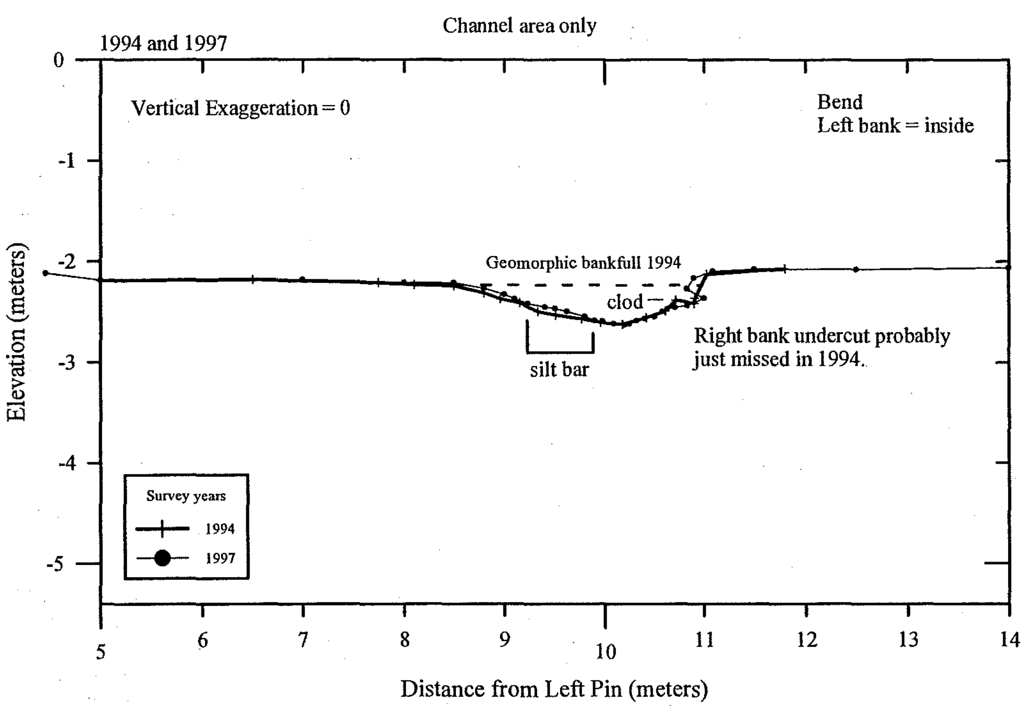
Hay Creek cross-section 9
New Cattle Exclosure
1994 and 1997





Home Creek cross-section 1
New Cattle Exclosure
1994 and 1997

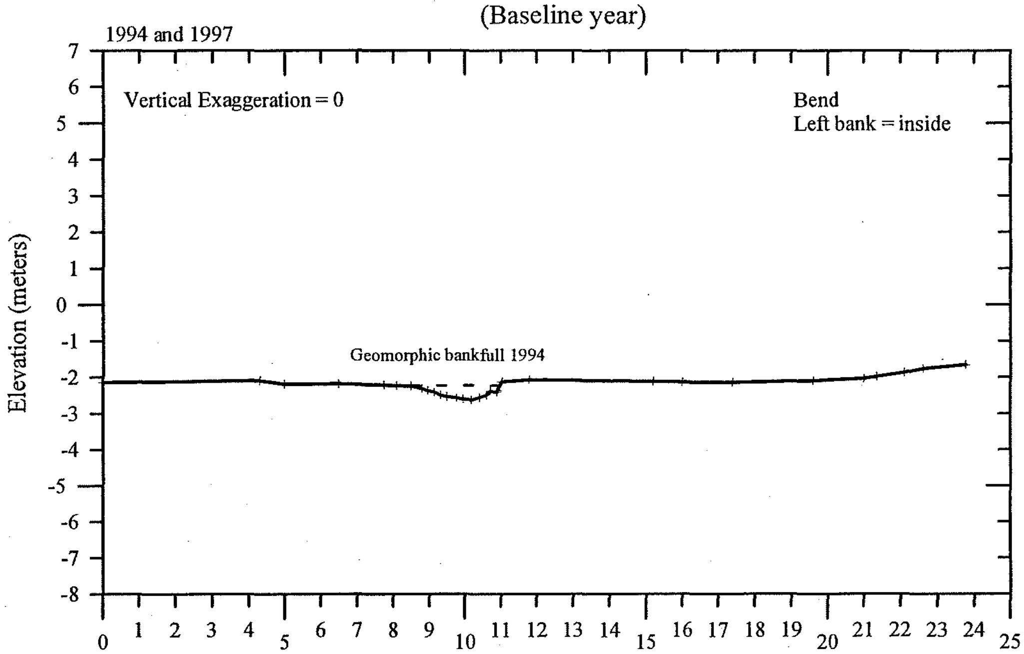




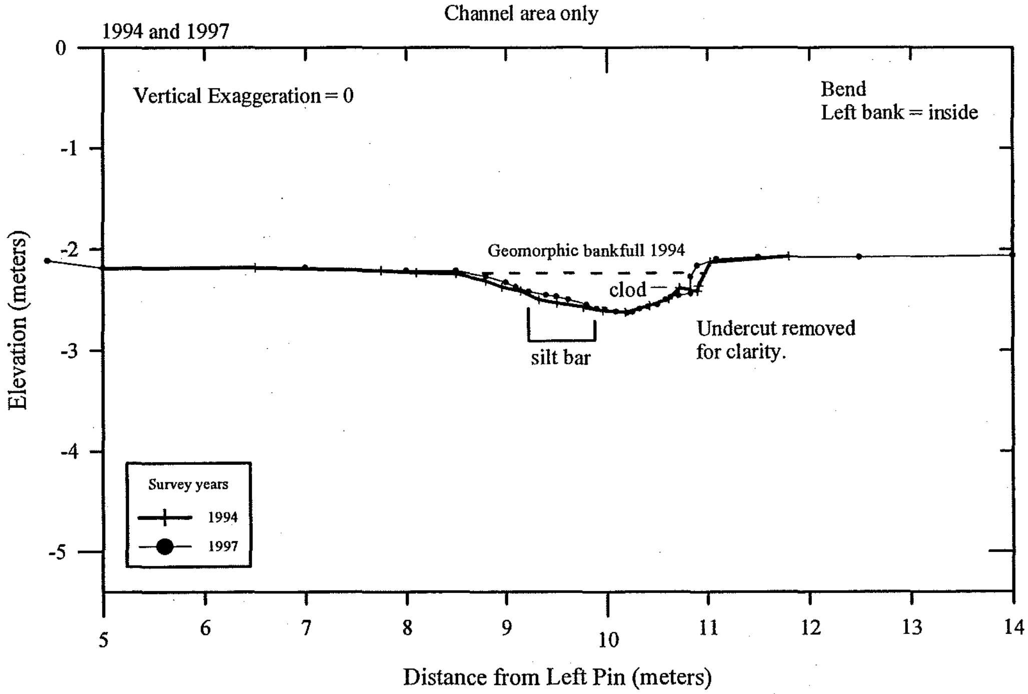
Home Creek cross-section 1 (continued)
New Cattle Exclosure
1994 and 1997

Undercut removed for clarity.

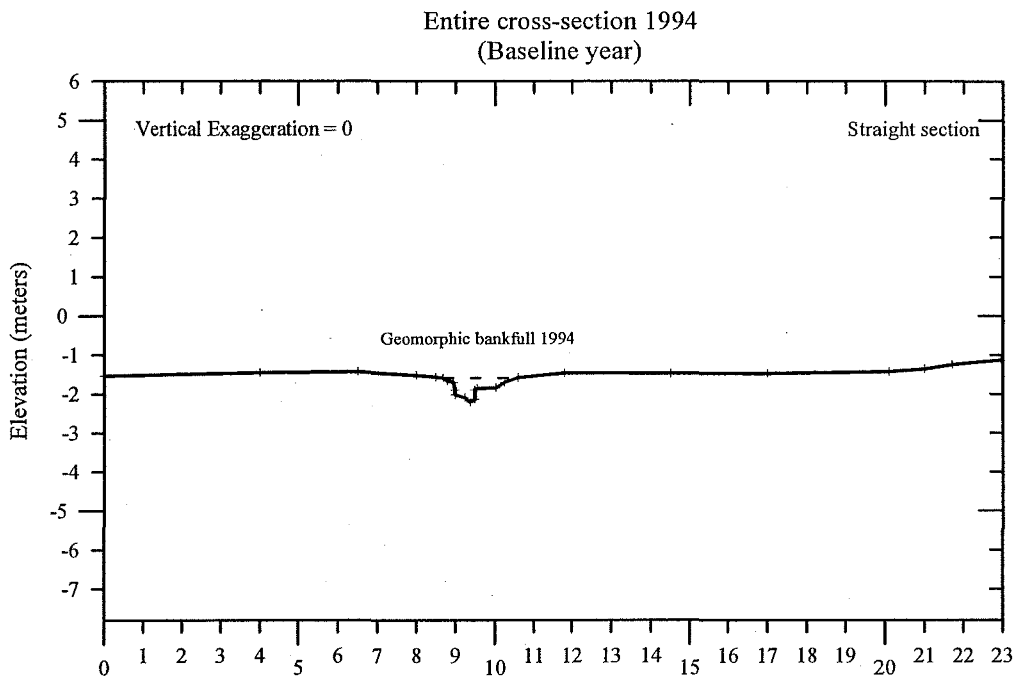
Entire cross-section 1994
(Baseline year)

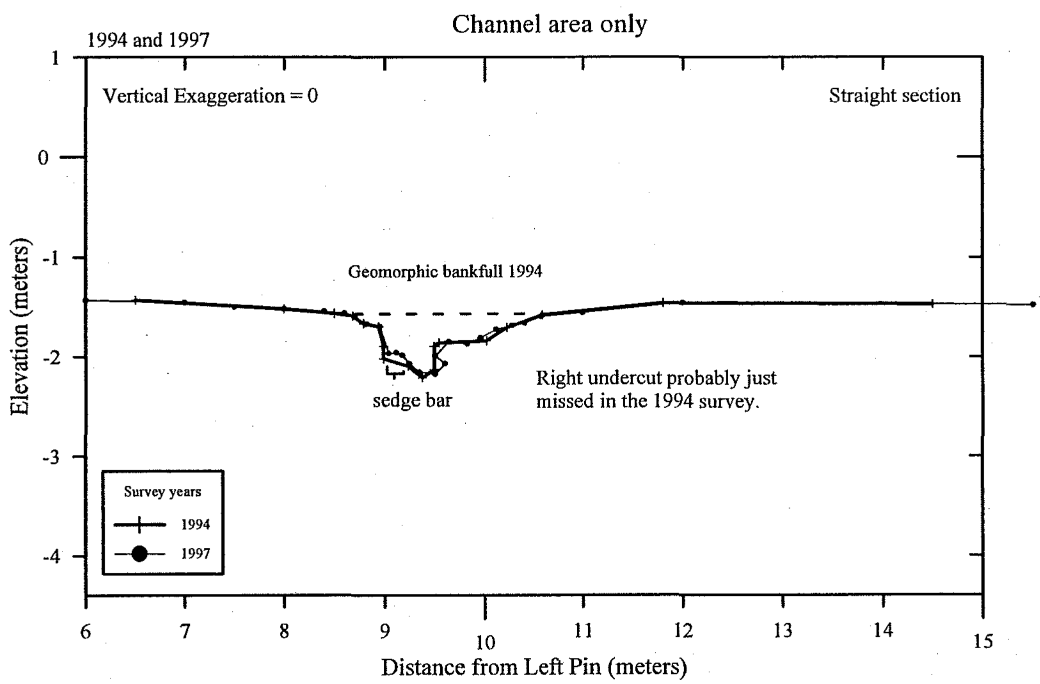


Channel area only



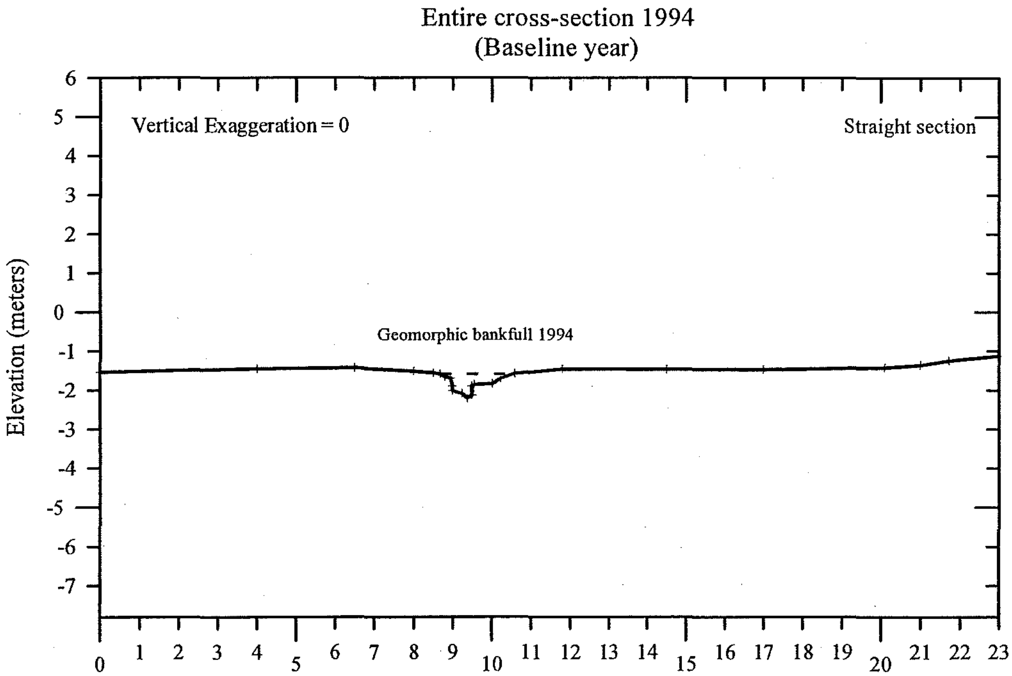
Home Creek cross-section 2
New Cattle Exclosure
1994 and 1997

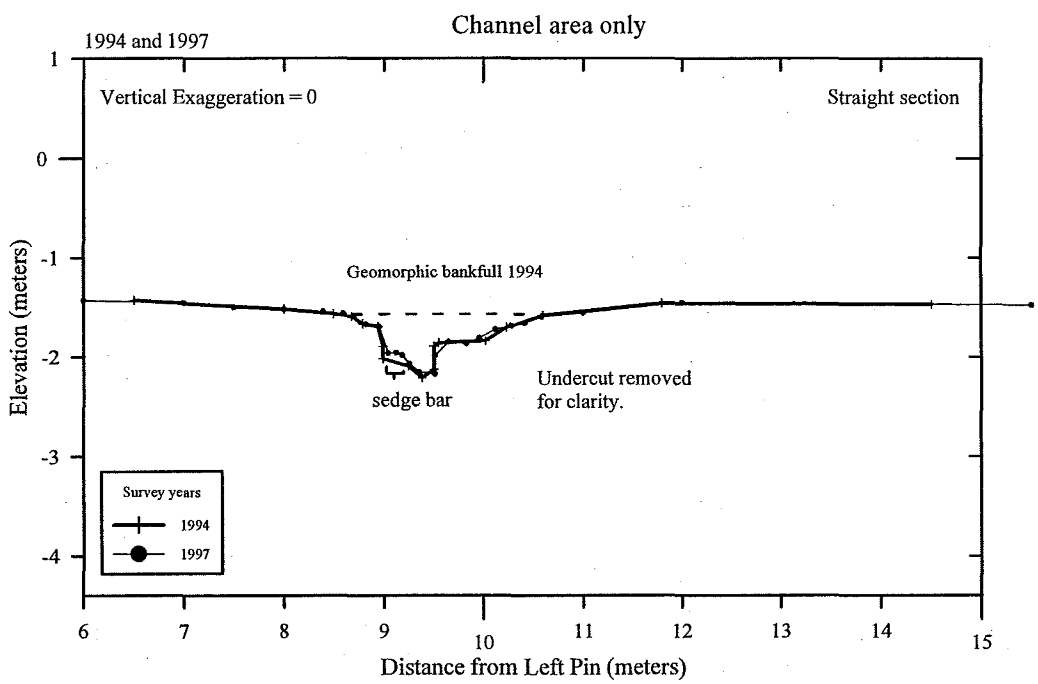




Home Creek cross-section 2 (continued)
New Cattle Exclosure
1994 and 1997

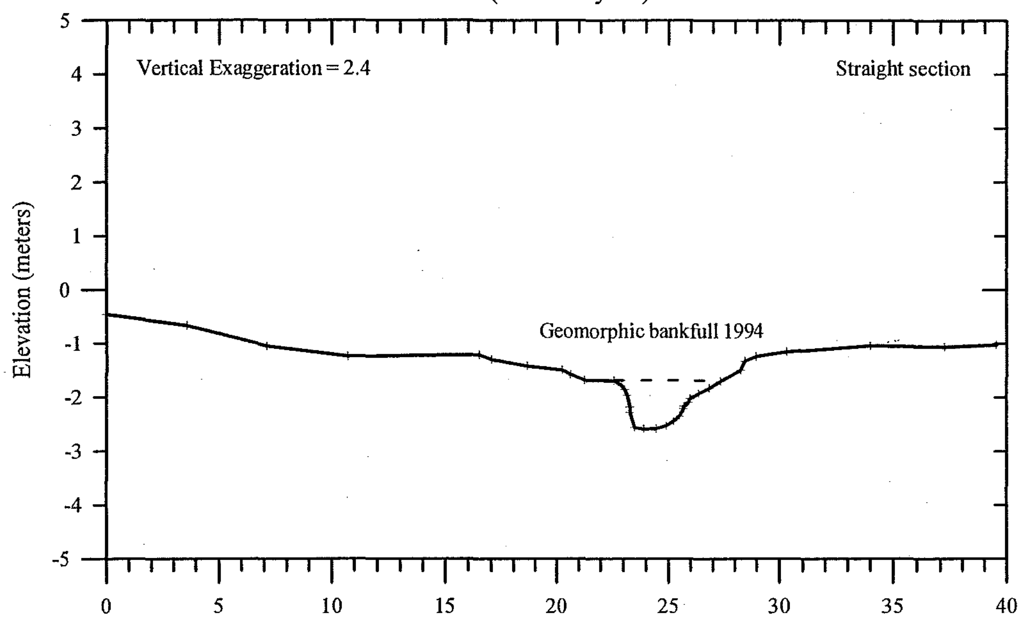
Undercut removed for clarity.



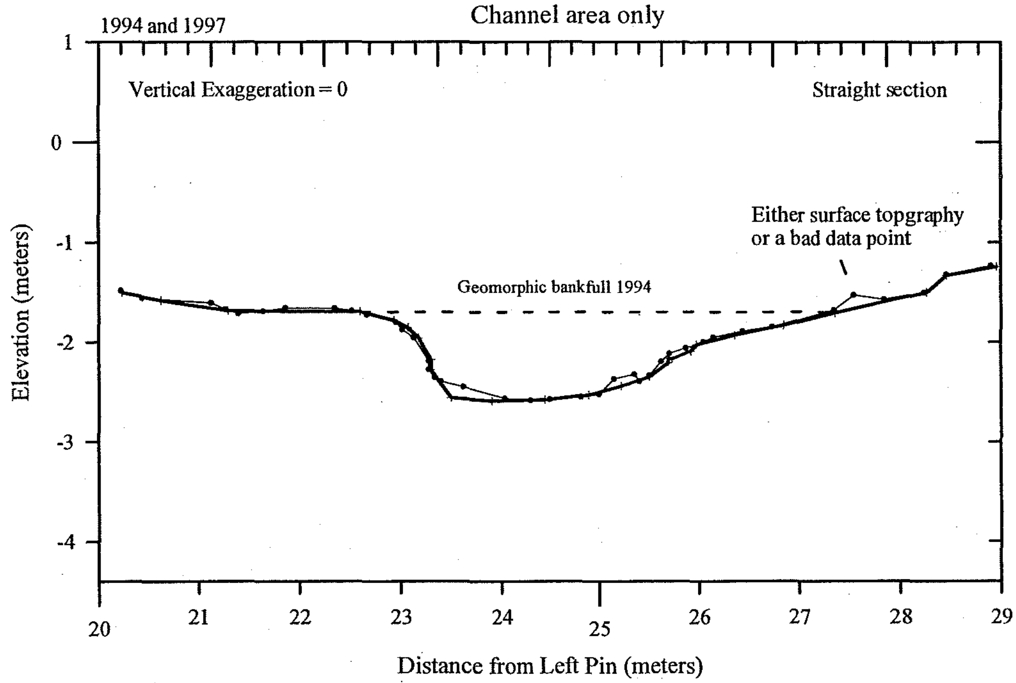


Lower Burro Creek cross-section 1
Special Emphasis Management Area
1994 and 1997

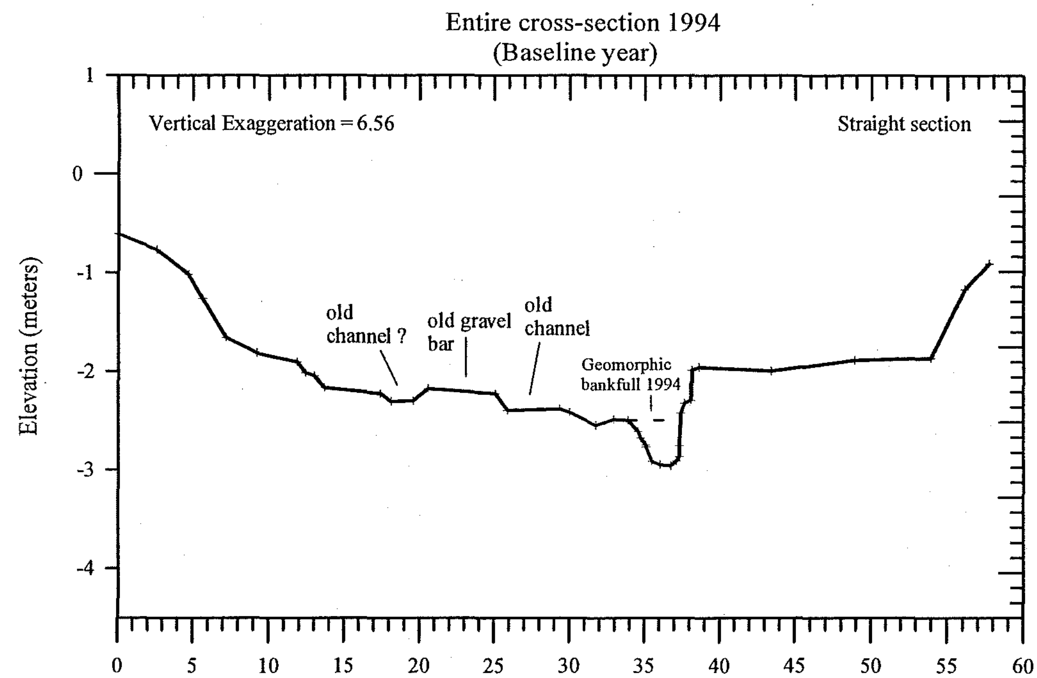
Entire cross-section 1994
(Baseline year)

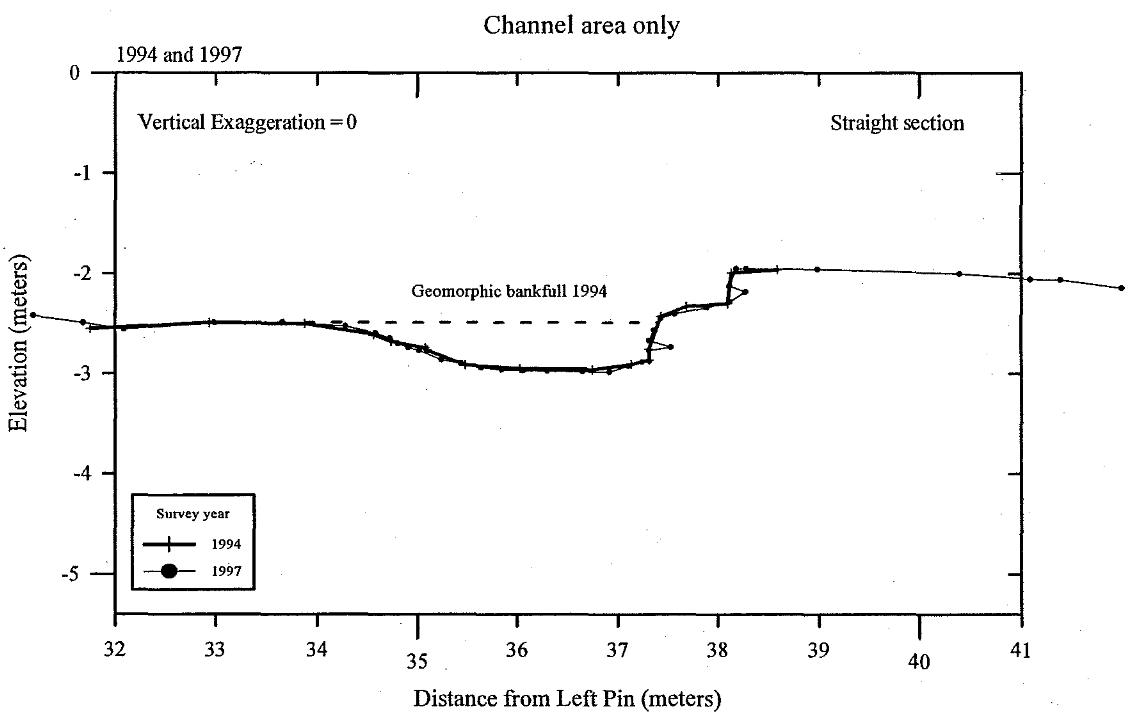


Channel area only



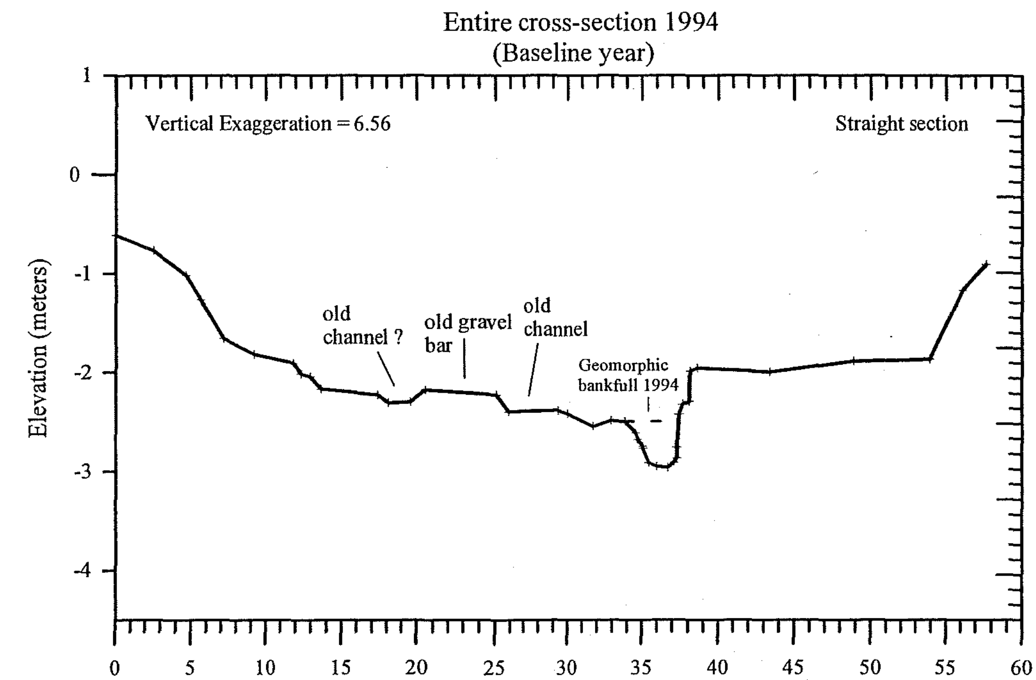
Lower Burro Creek cross-section 2
Special Emphasis Management Area
1994 and 1997

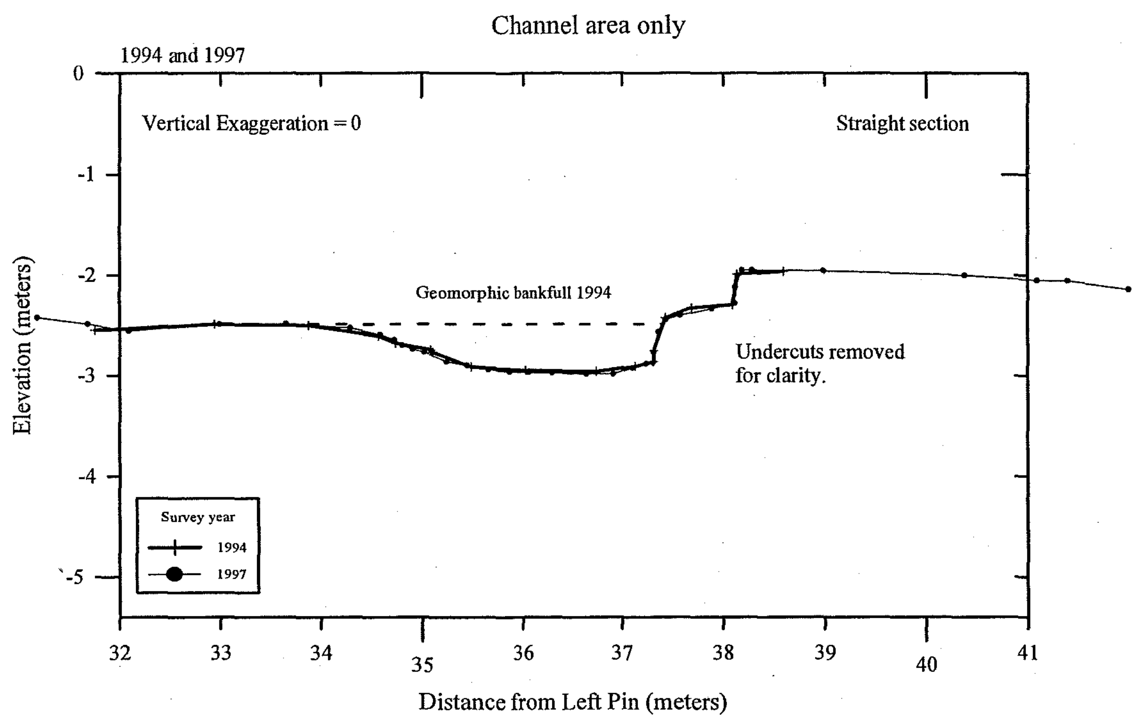




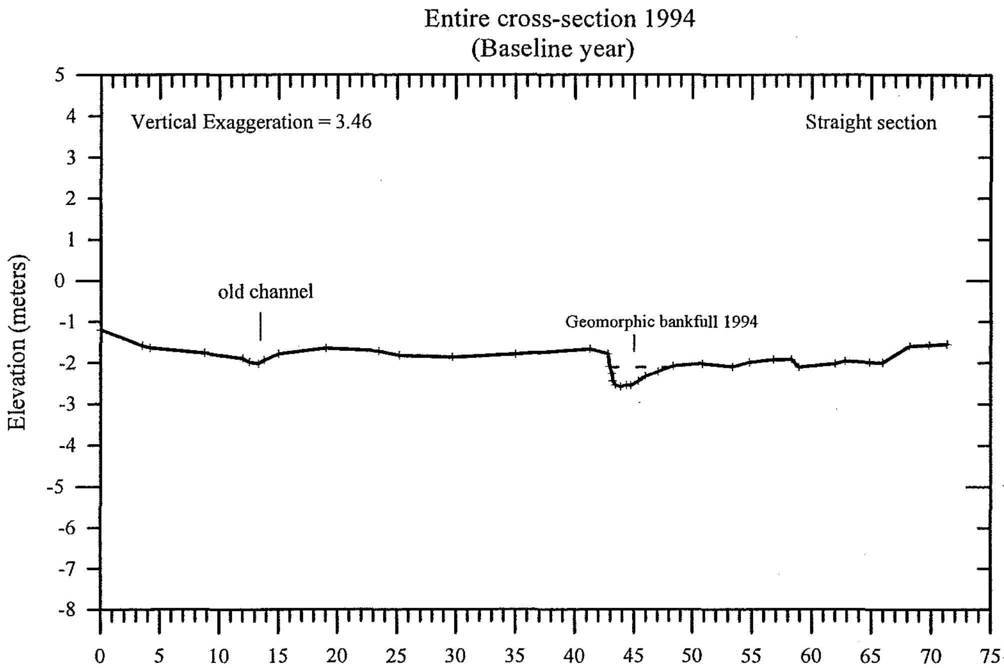
Lower Burro Creek cross-section 2 (continued)
Special Emphasis Management Area
1994 and 1997

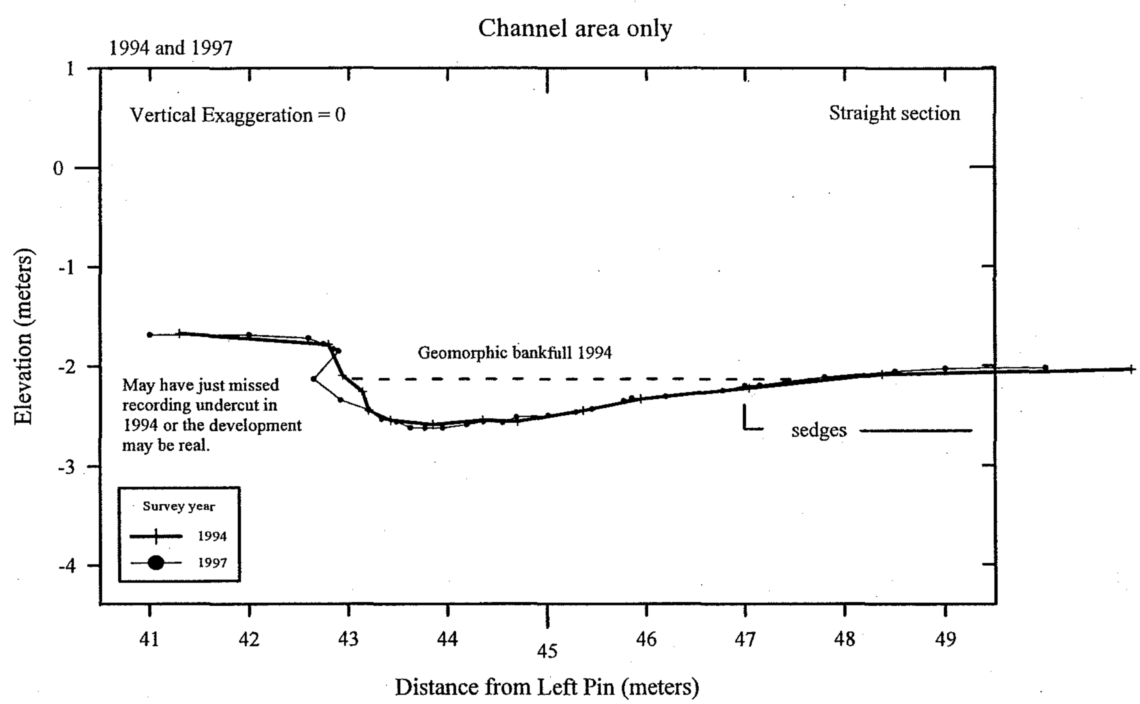
Undercuts removed for clarity.





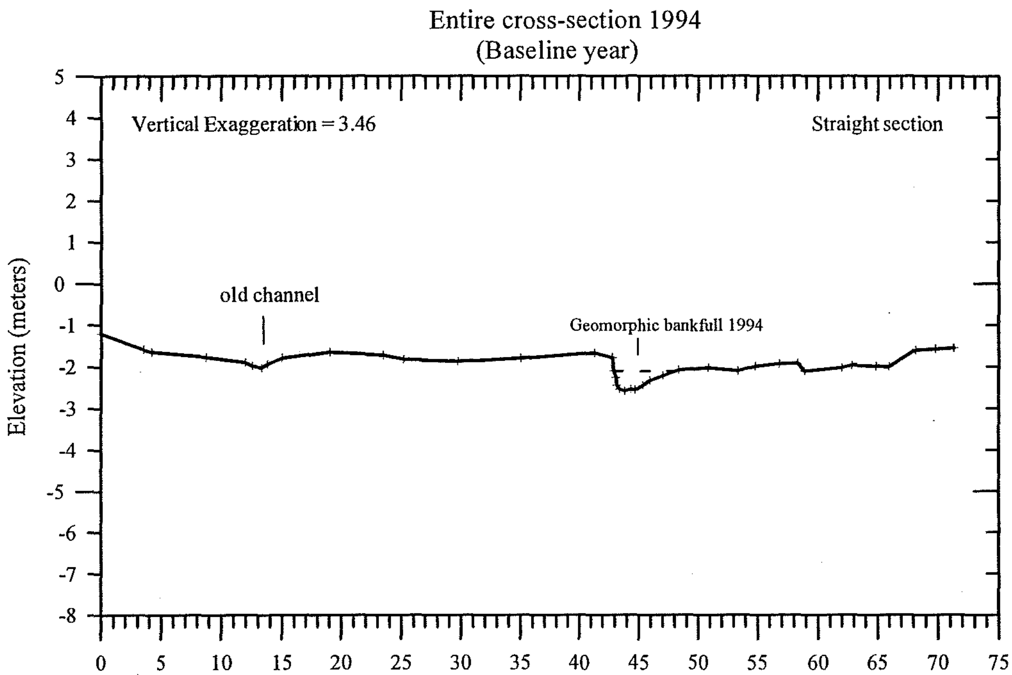
Lower Burro Creek cross-section 3
Special Emphasis Management Area
1994 and 1997

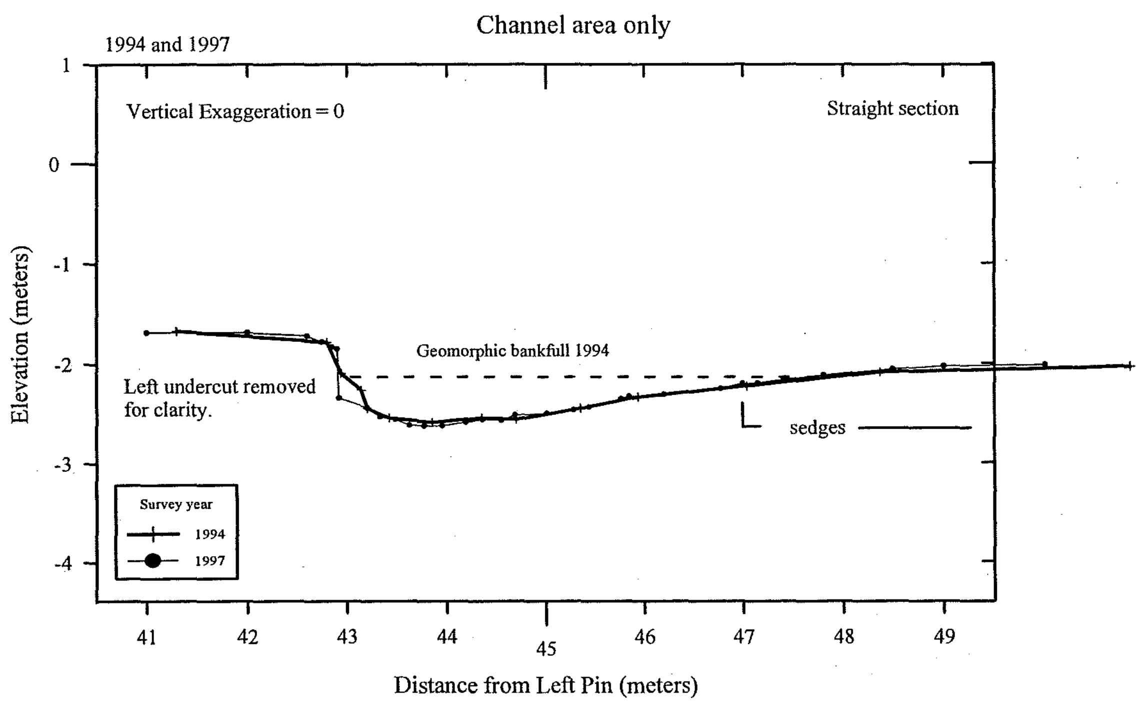




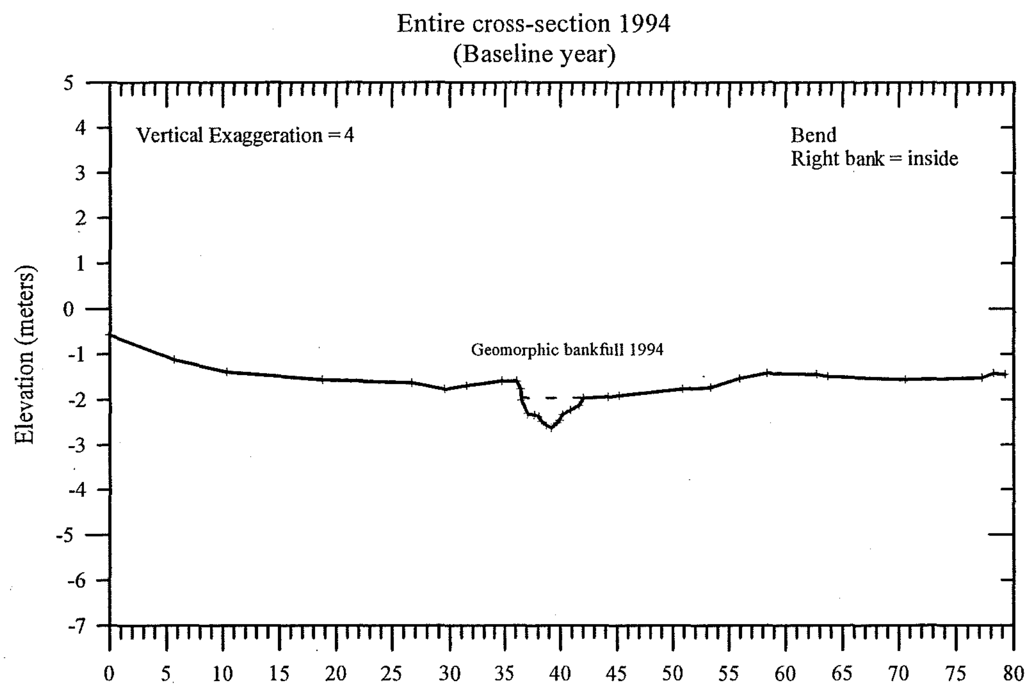
Lower Burro Creek cross-section 3 (continued)
Special Emphasis Management Area
1994 and 1997

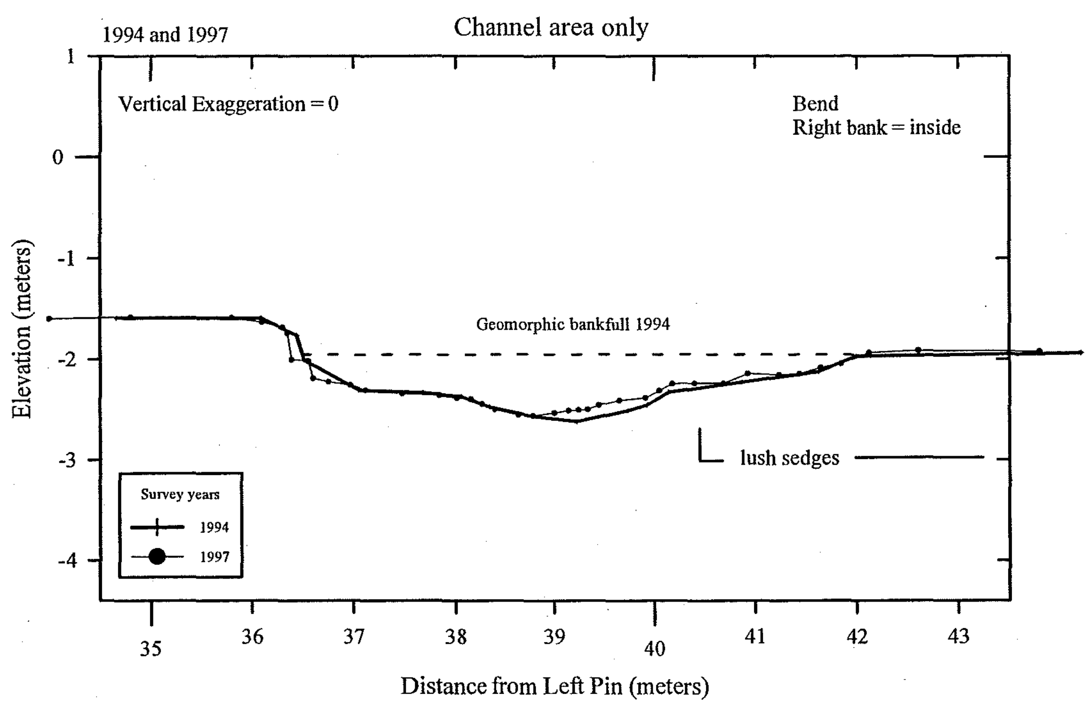
Undercut removed for clarity.



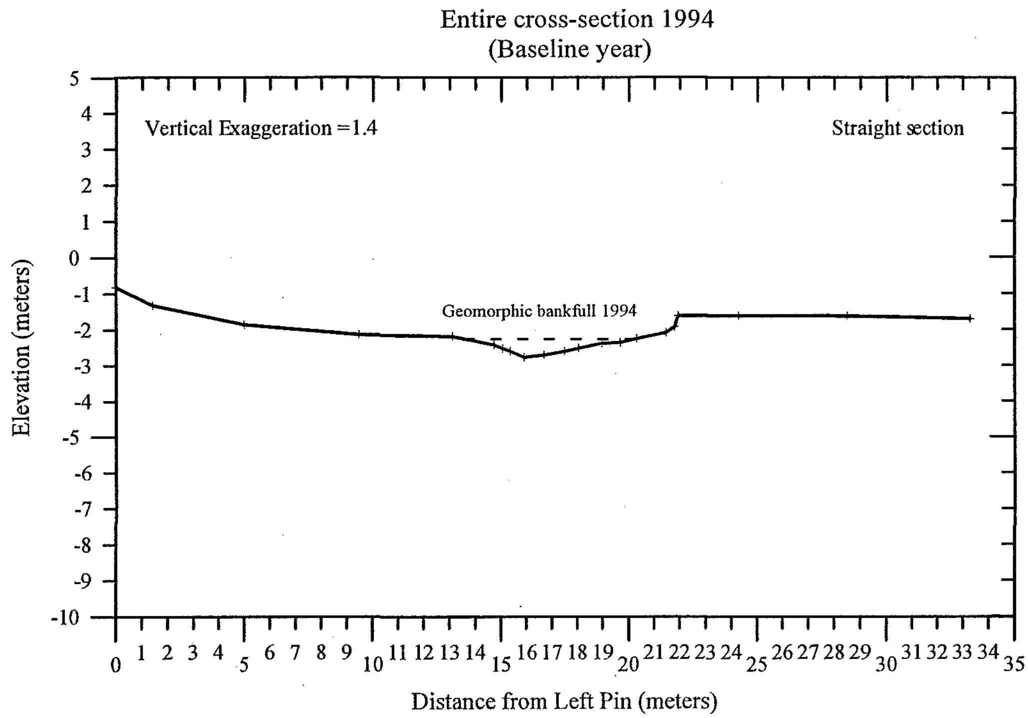


Lower Burro Creek cross-section 4
Special Emphasis Management Area
1994 and 1997



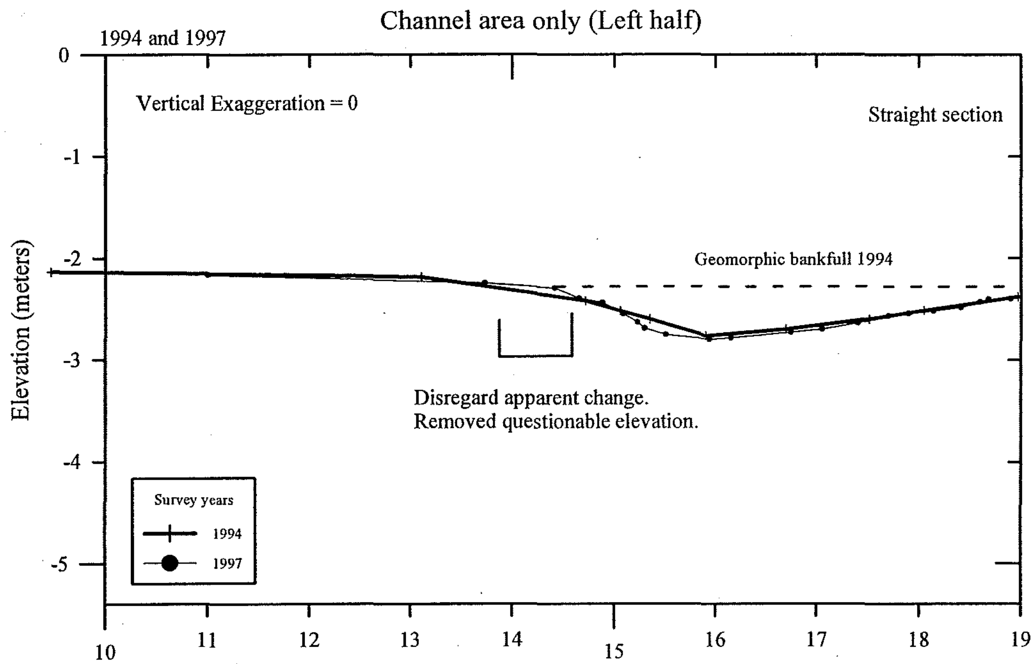


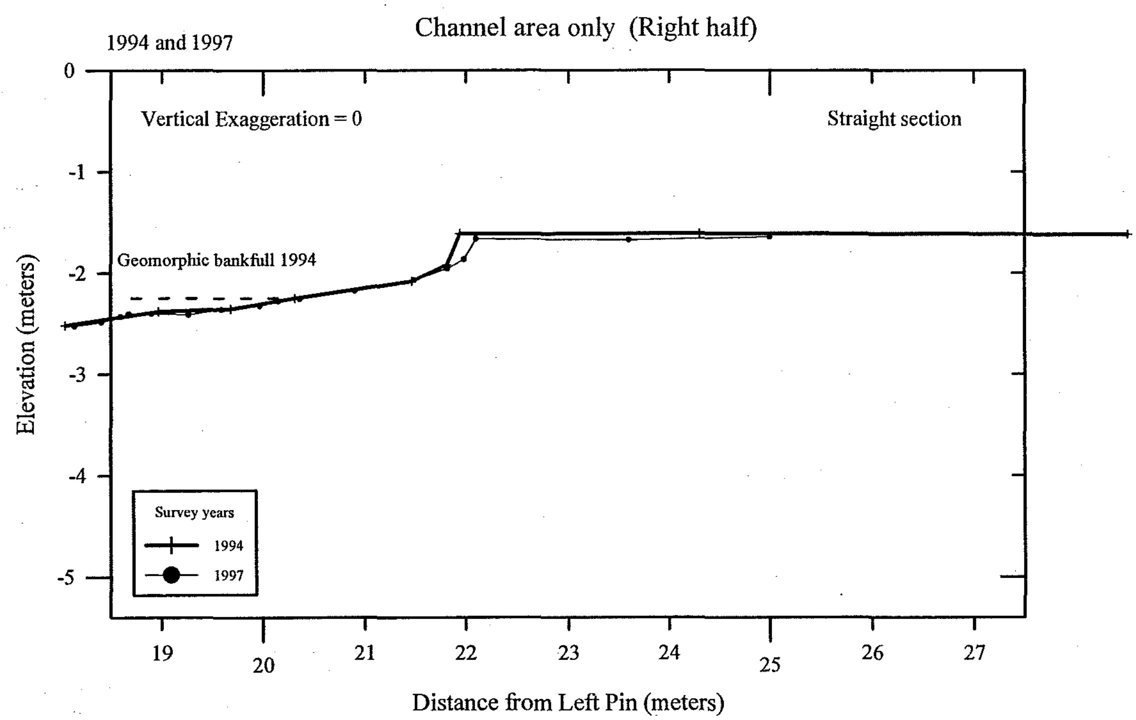
Lower Burro Creek cross-section 5
Special Emphasis Management Area
1994 and 1997



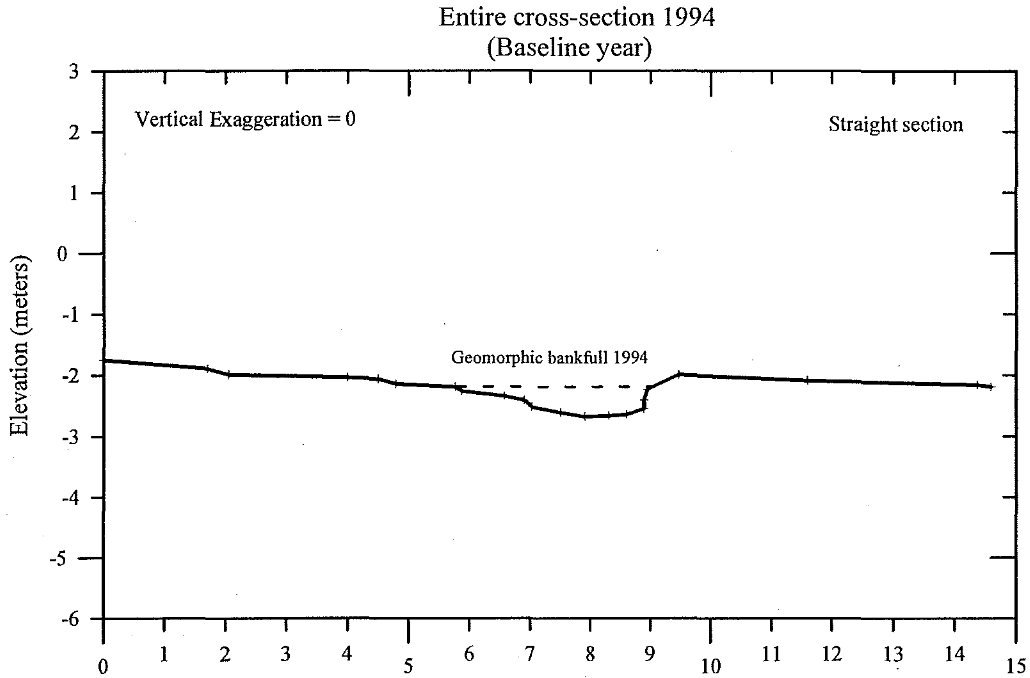
The length of the channel area for cross-section 5 required that it be split into two sections in order to maintain the same scale as the other channel area plots. See next page for the cross-ection 5 channel-area-plots.

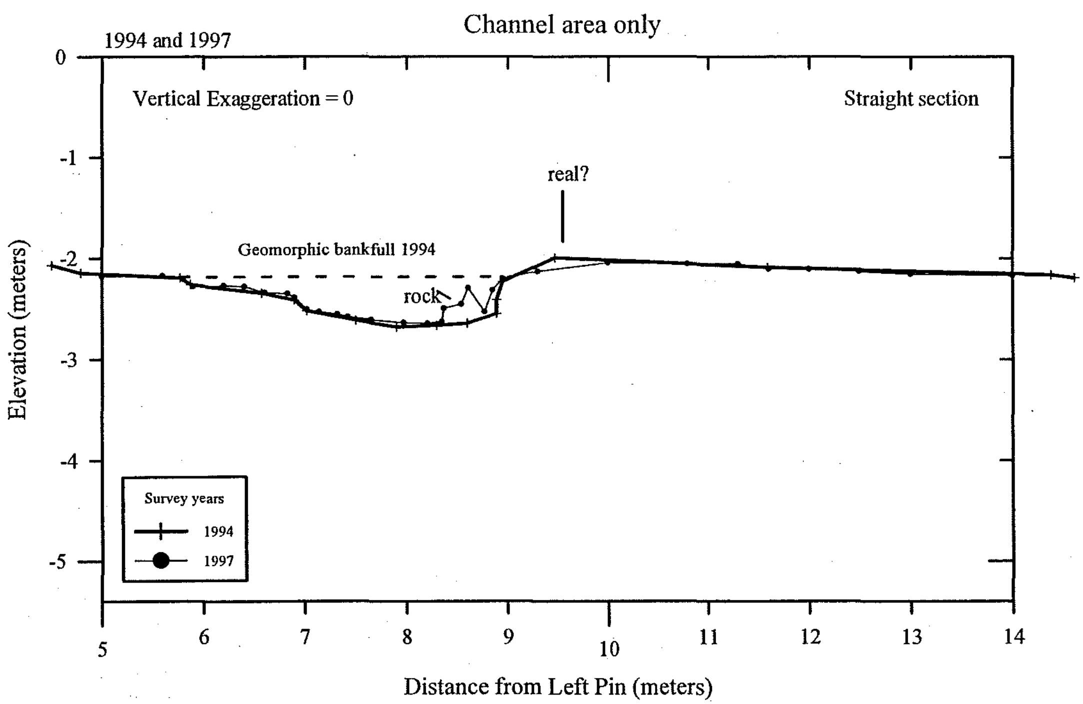
Lower Burro Creek cross-section 5 (continued)
Special Emphasis Management Area
1994 and 1997



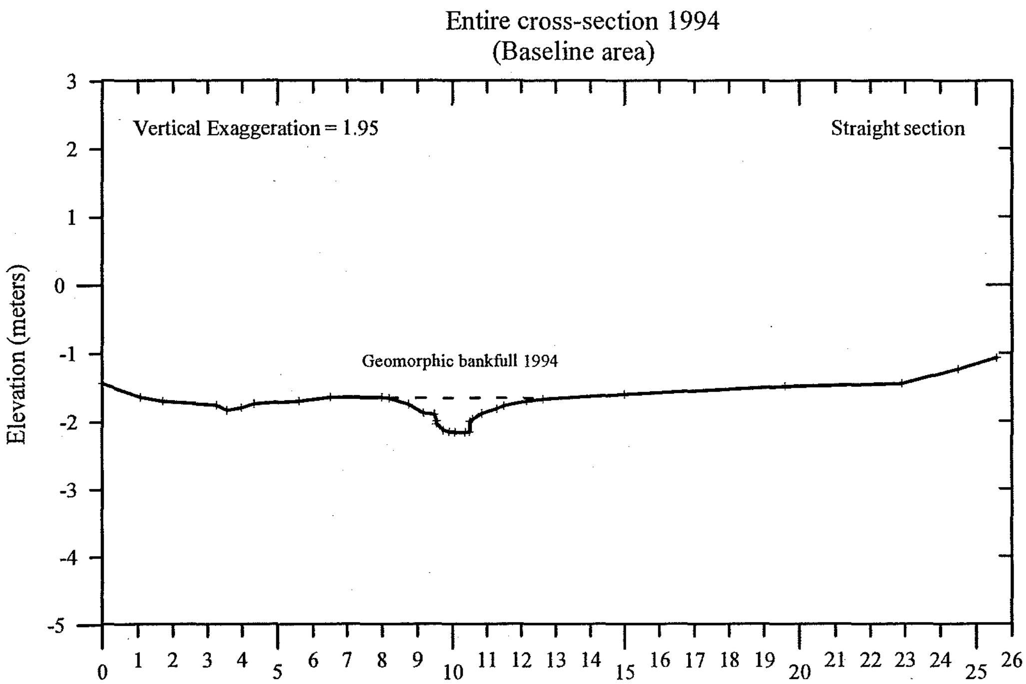


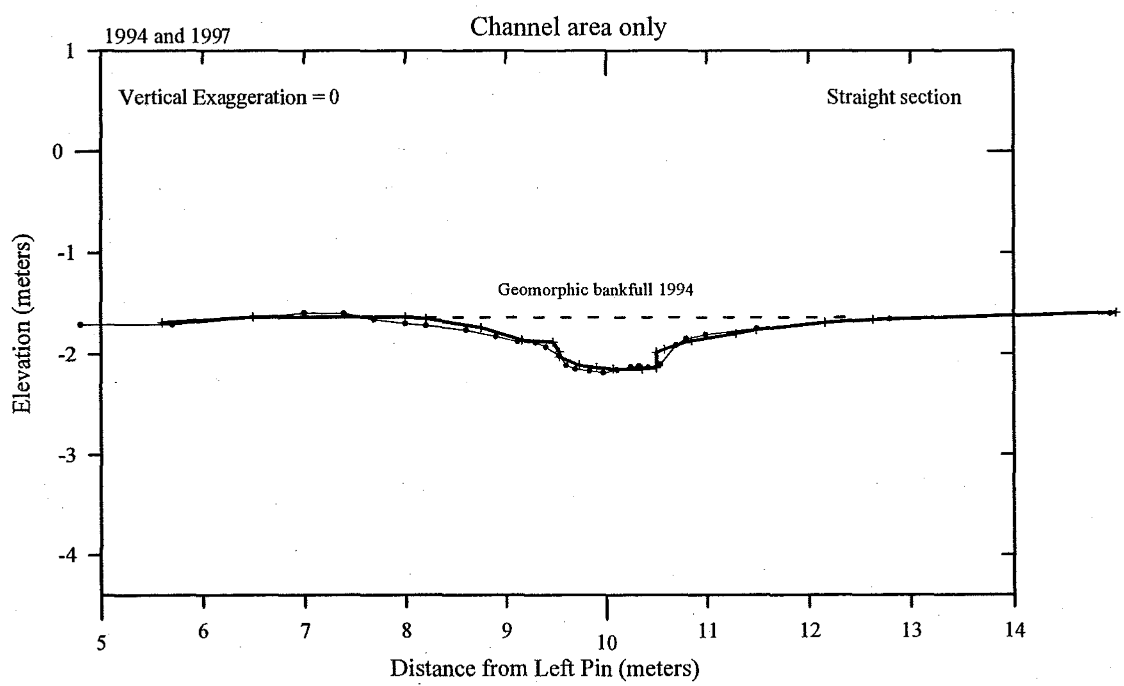
Lower Stinky Creek cross-section 1
New Cattle Exclosure
1994 and 1997



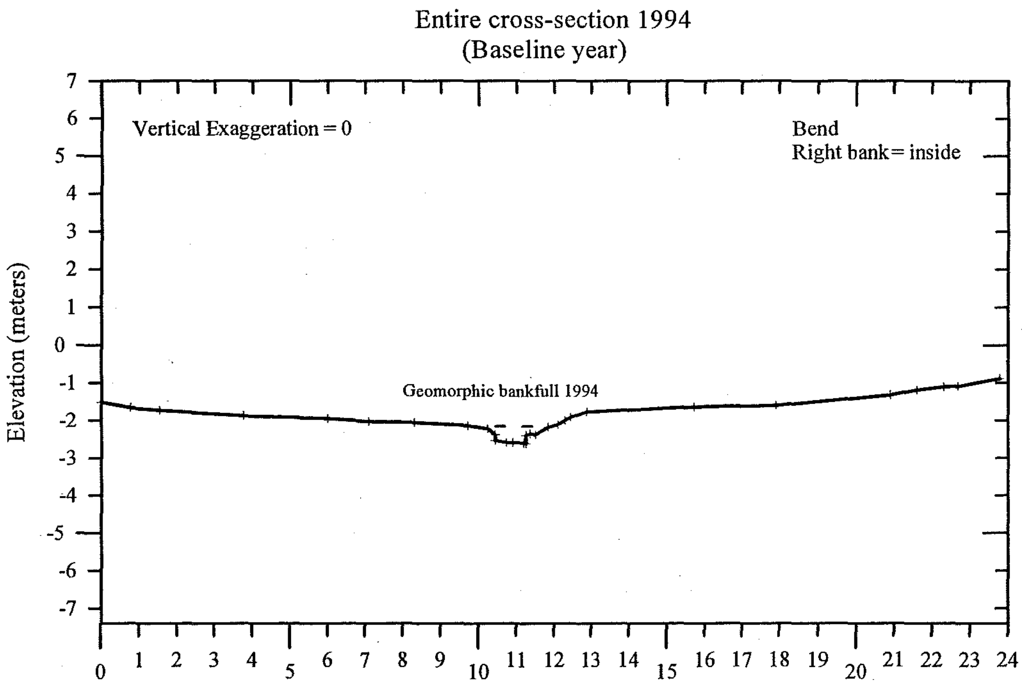


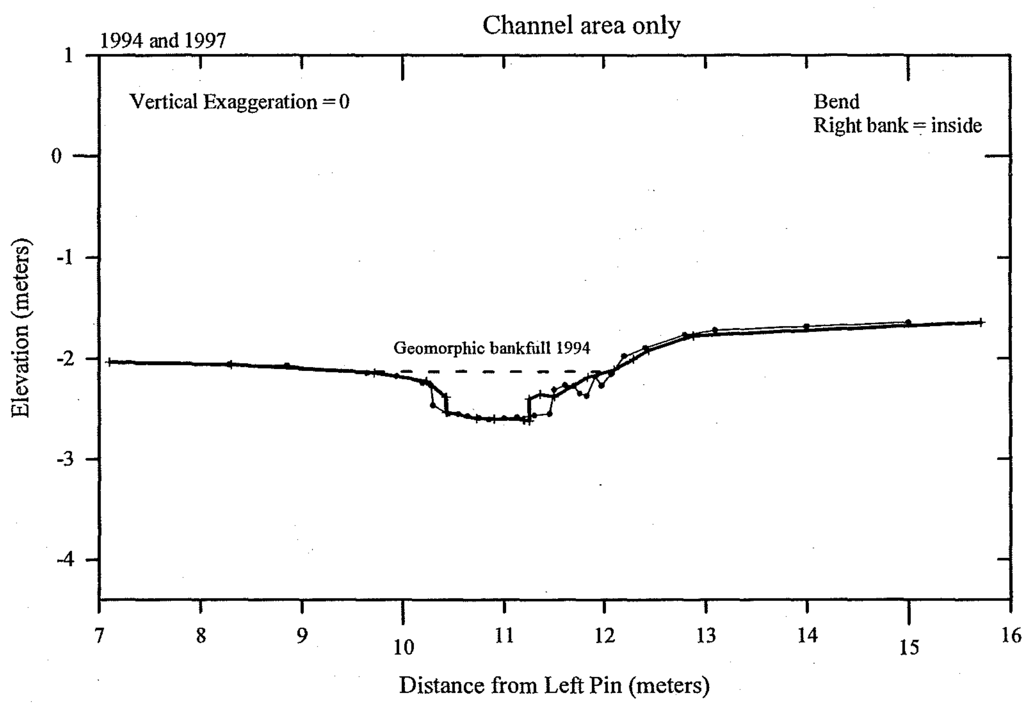
Lower Stinky Creek cross-section 2
New Cattle Exclosure
1994 and 1997



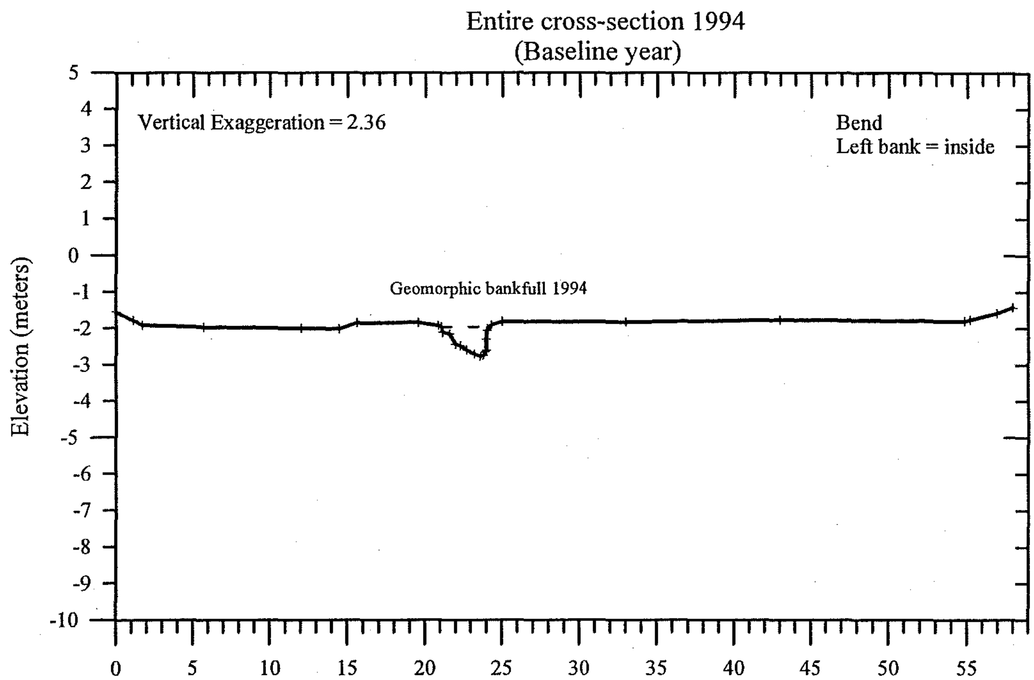


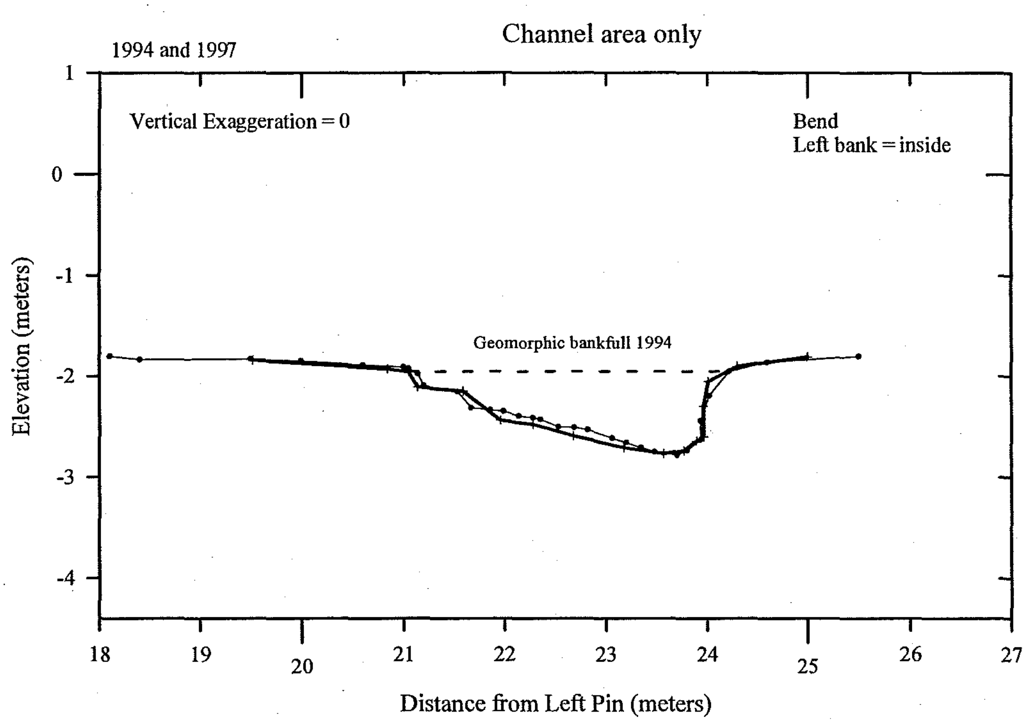
Lower Stinky Creek cross-section 3
New Cattle Exclosure
1994 and 1997



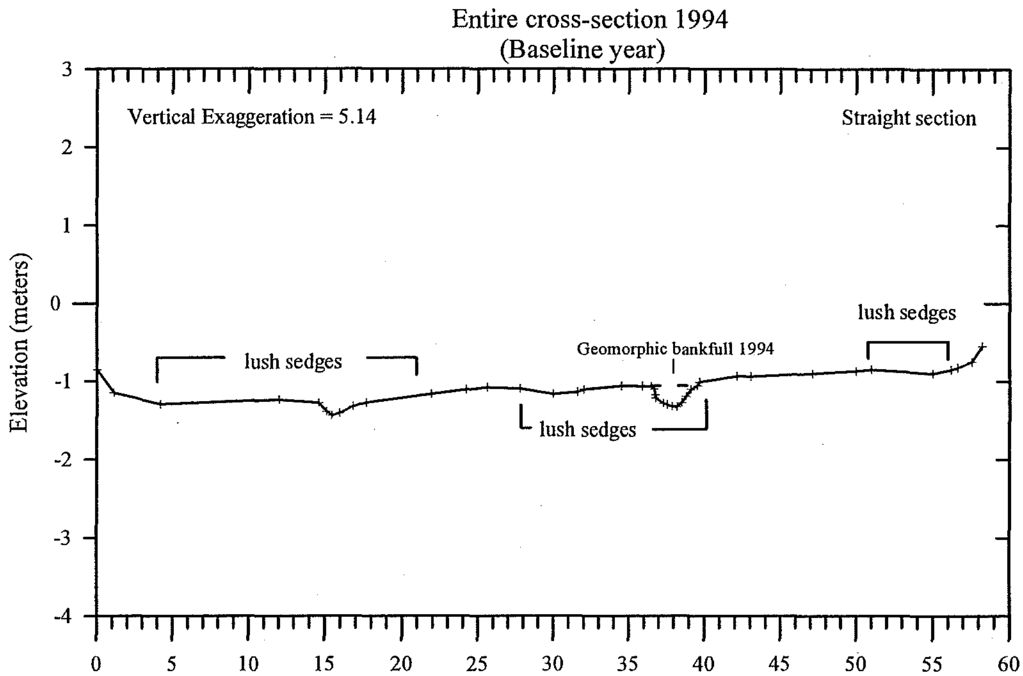


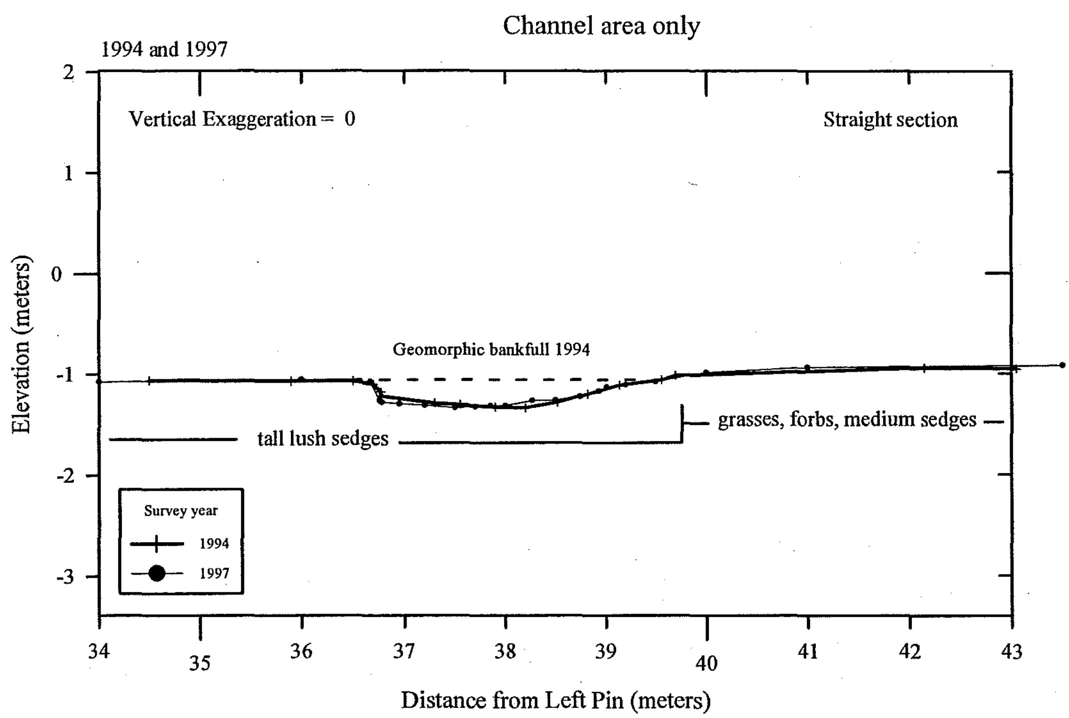
Lower Stinky Creek cross-section 4
New Cattle Exclosure
1994 and 1997



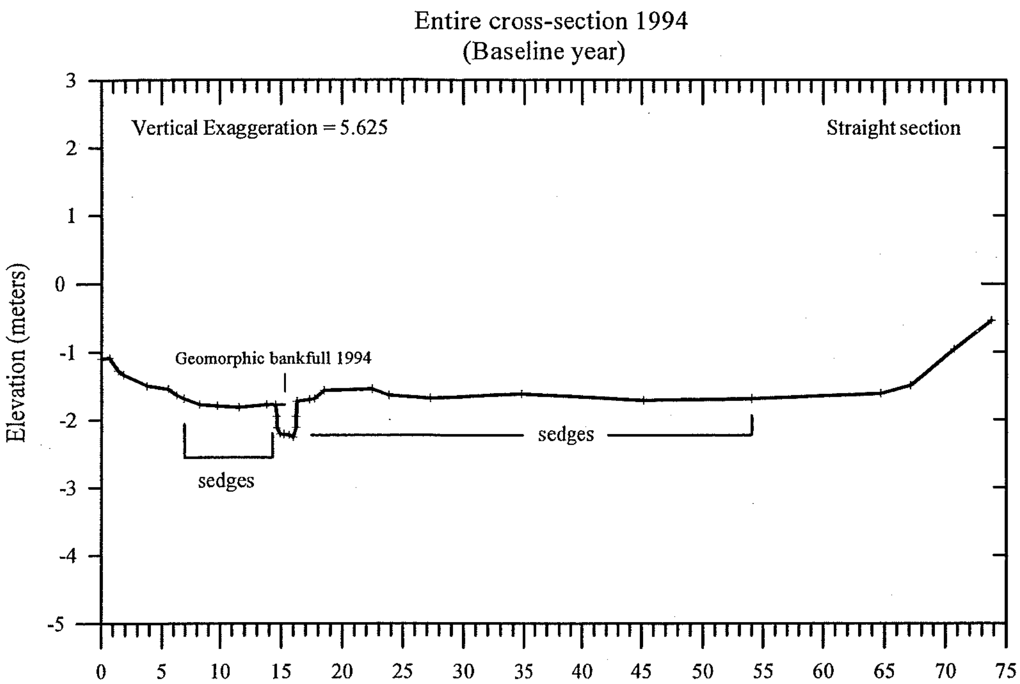


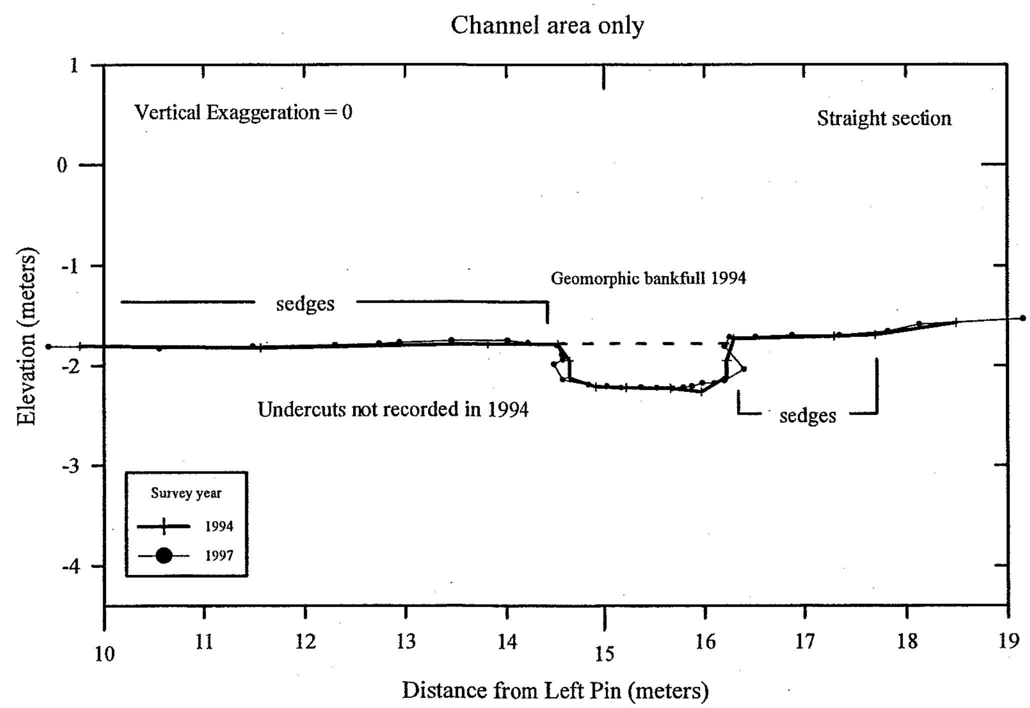
Lower Stinky Creek cross-section 5
New Cattle Exclosure
1994 and 1997





Mandan Creek cross-section 1
Special Emphasis Management Area
1994 and 1997

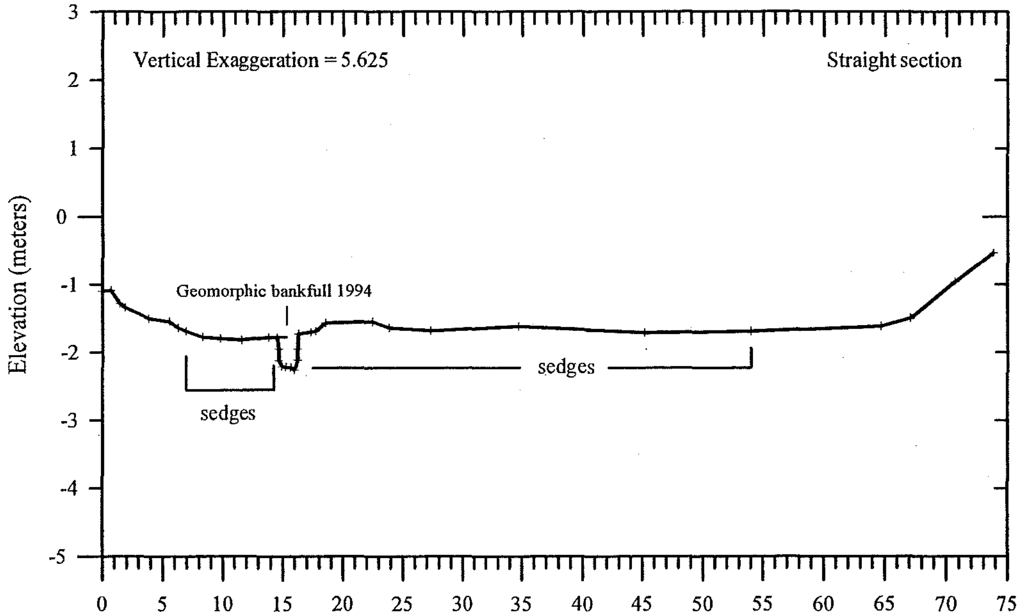




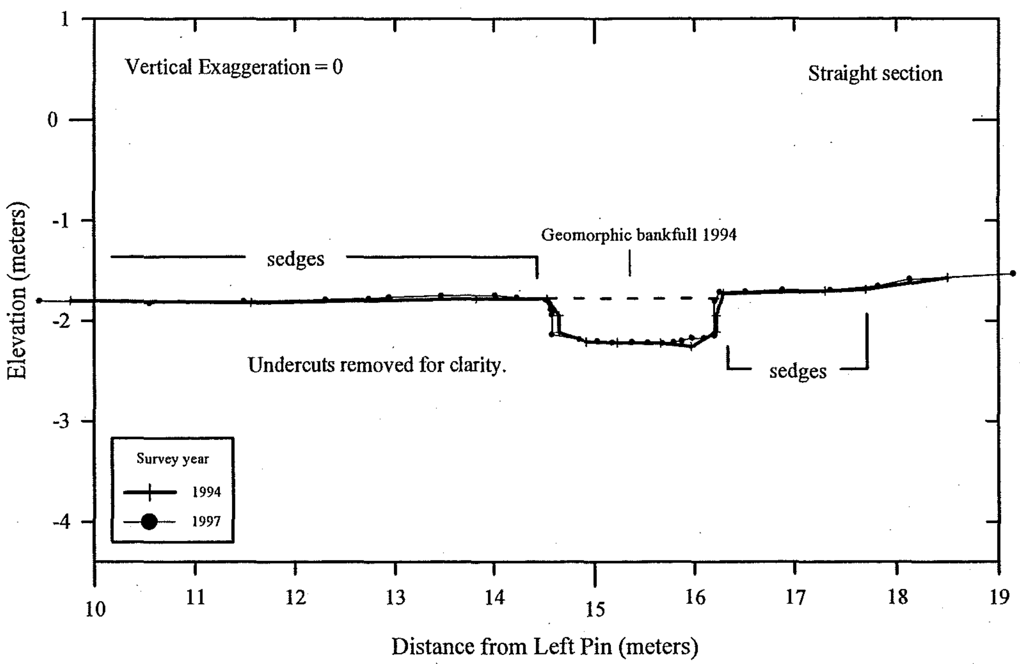
Mandan Creek cross-section 1 (continued)
Special Emphasis Management Area
1994 and 1997

Undercuts removed for clarity.

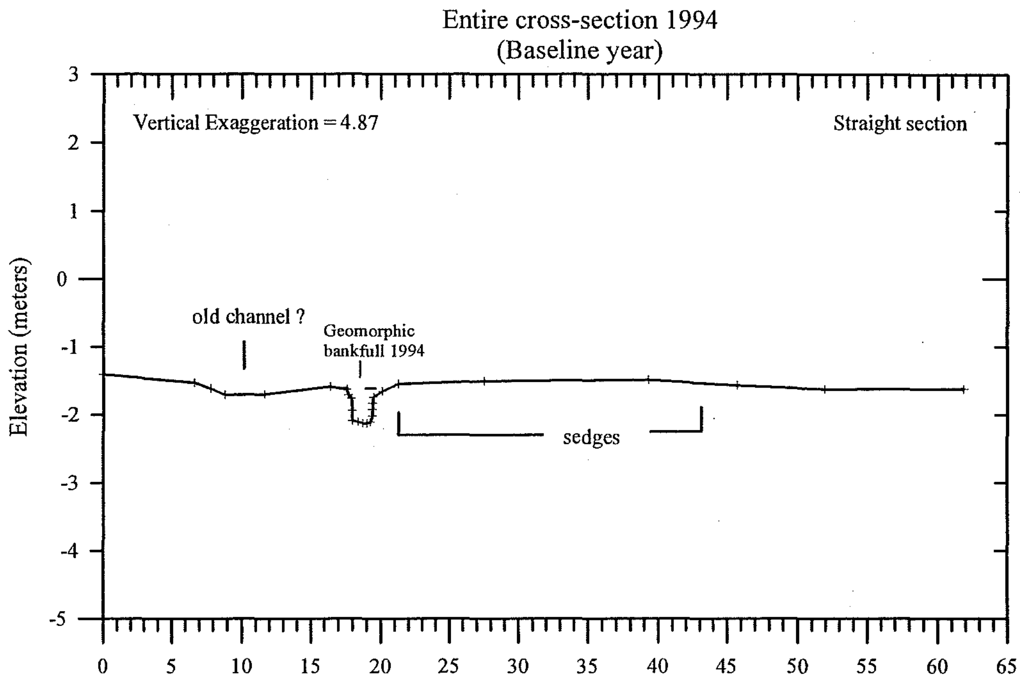
Entire cross-section 1994
(Baseline year)

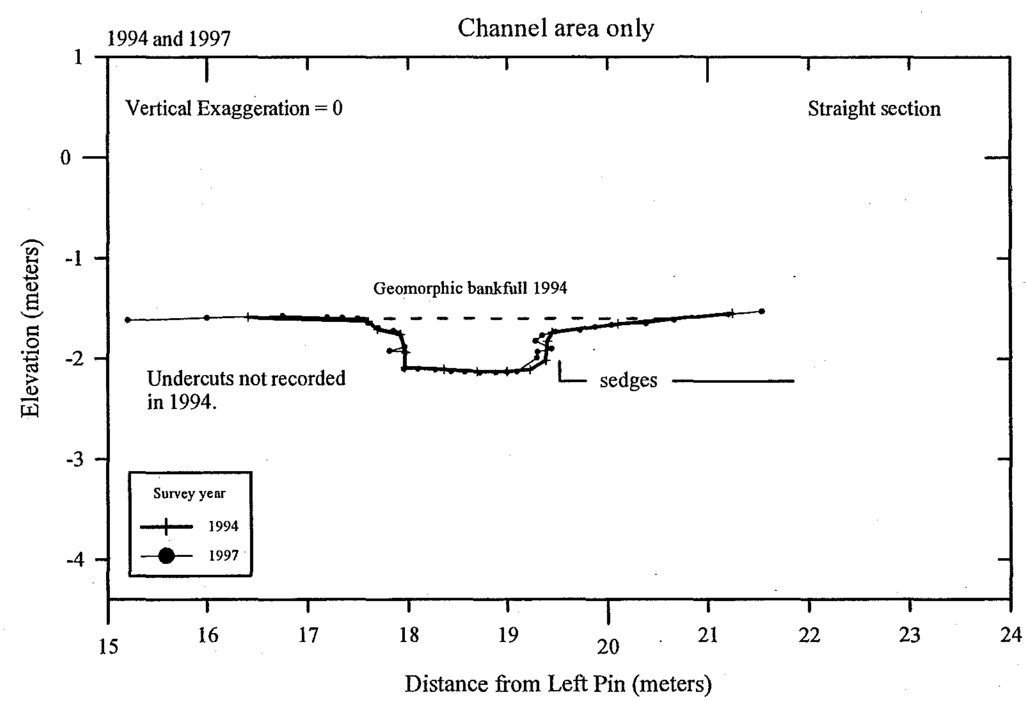


Channel area only



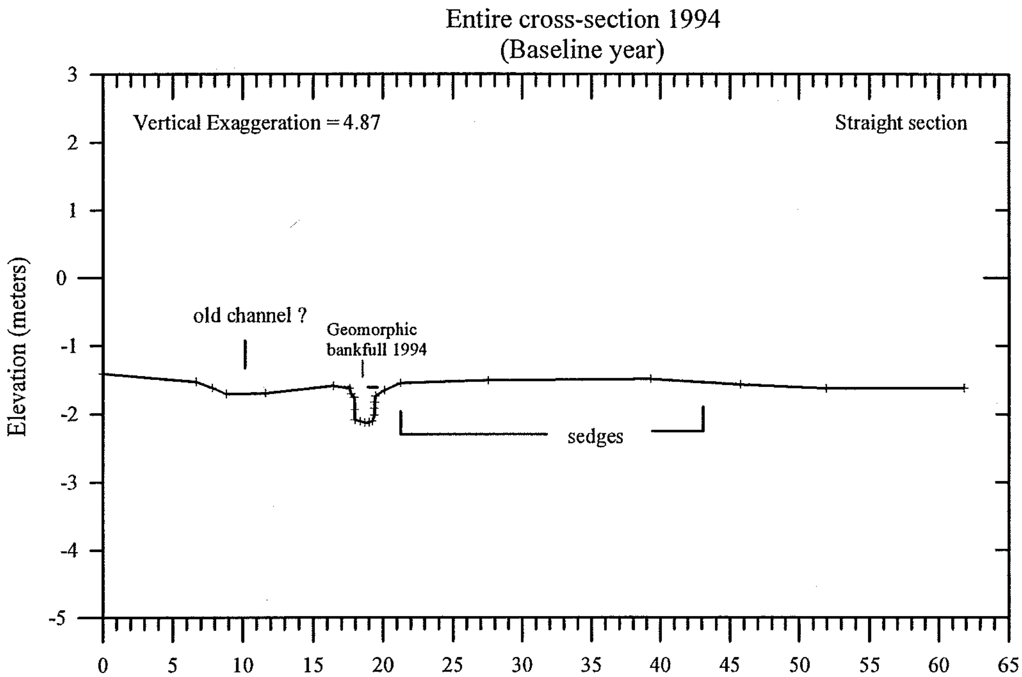
Mandan Creek cross-section 2
Special Emphasis Management Area
1994 and 1997

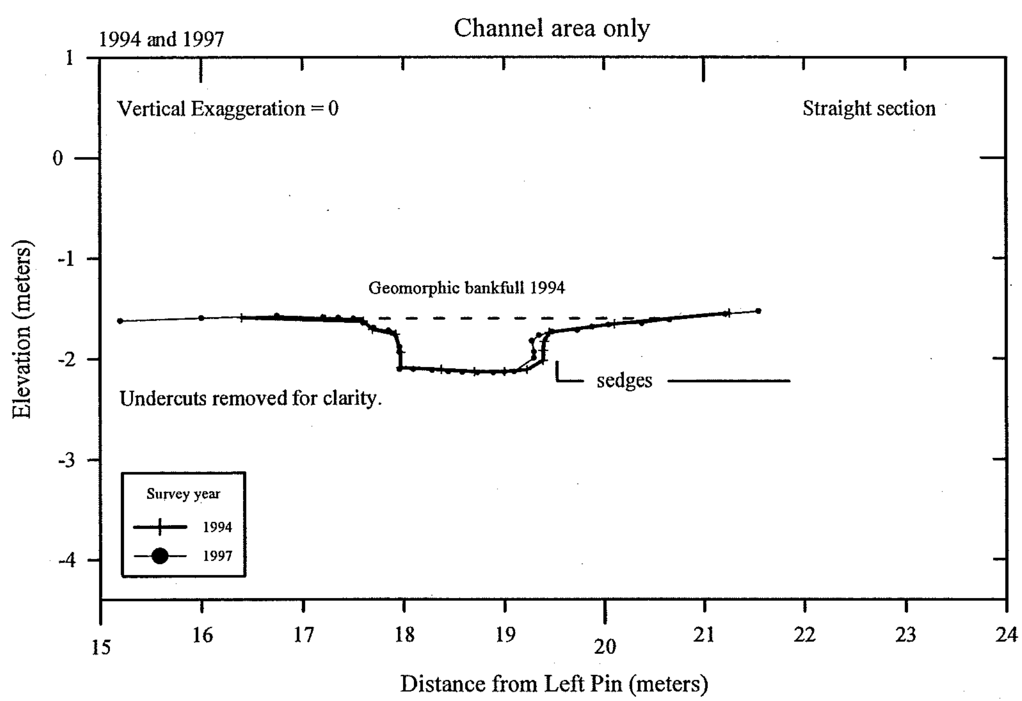




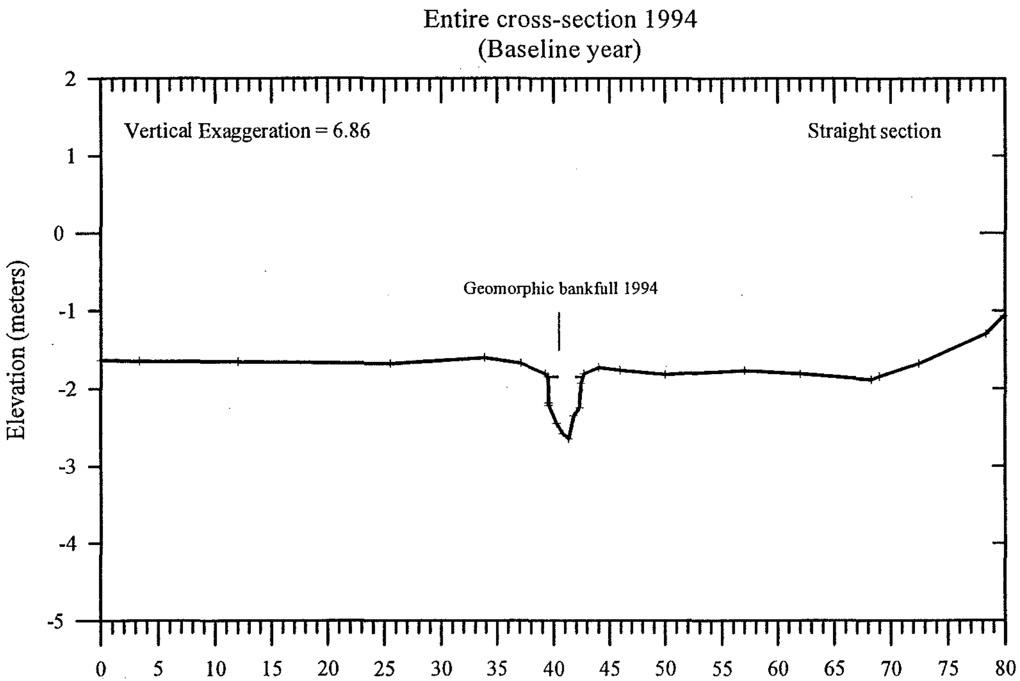
Mandan Creek cross-section 2 (continued)
Special Emphasis Management Area
1994 and 1997

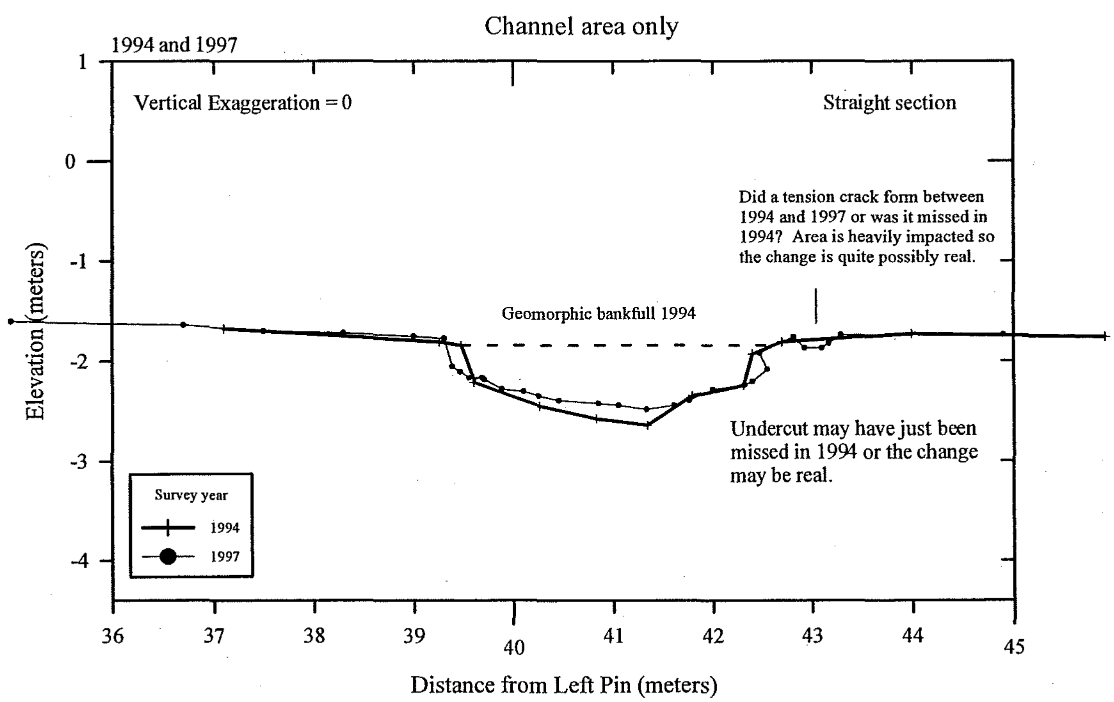
Undercuts removed for clarity.





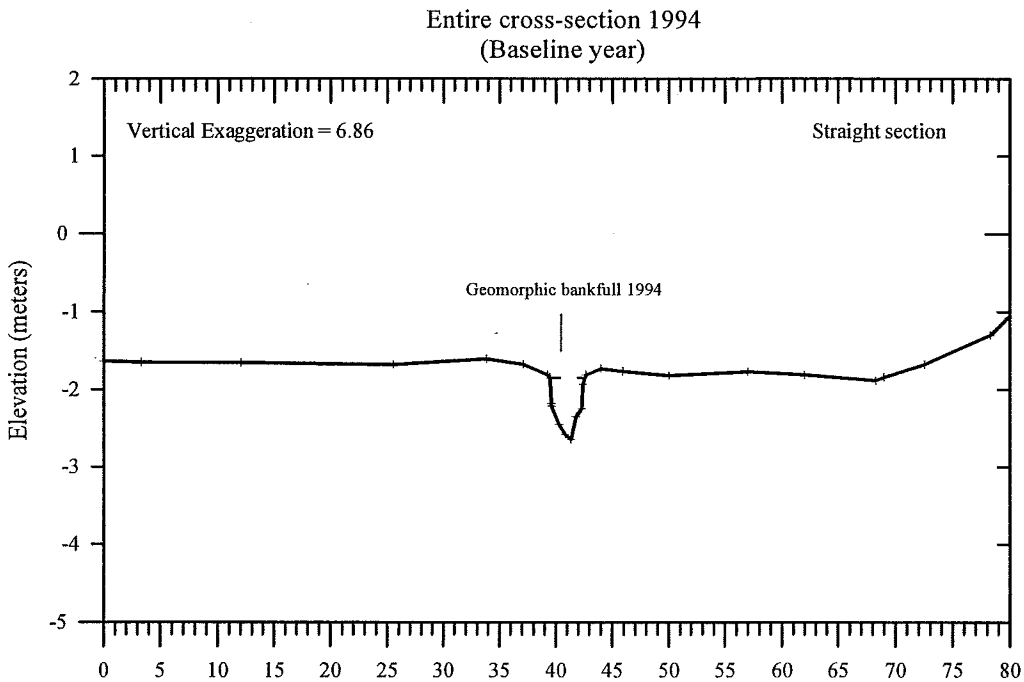
Mandan Creek cross-section 3
Special Emphasis Management Area
1994 and 1997

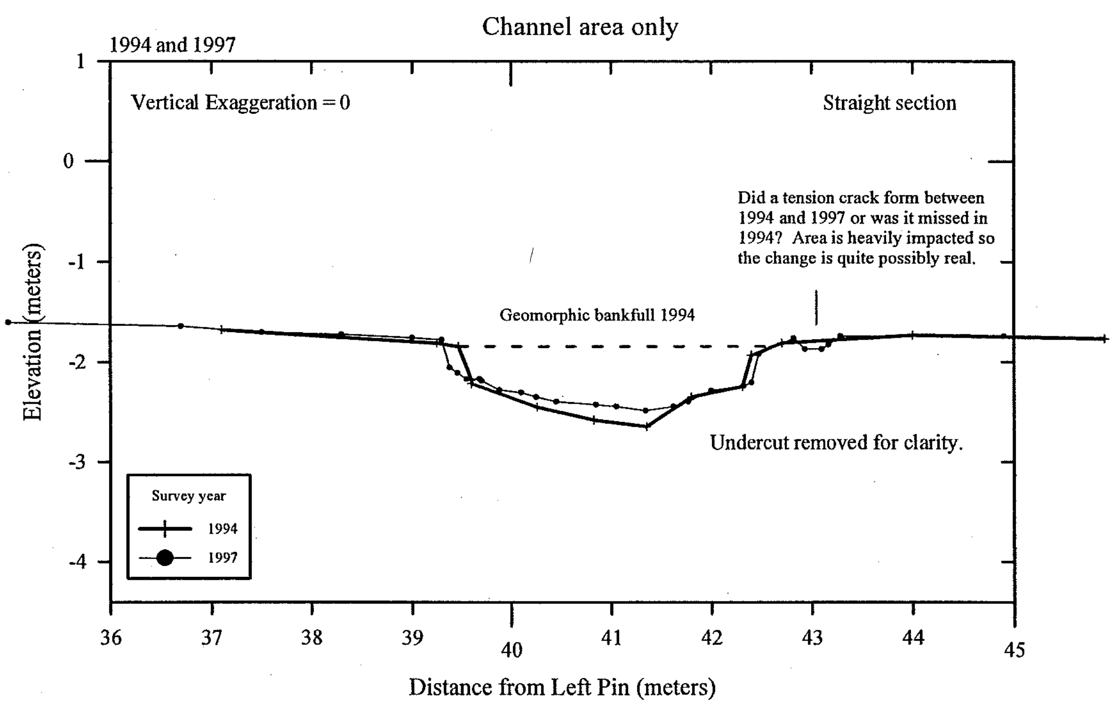




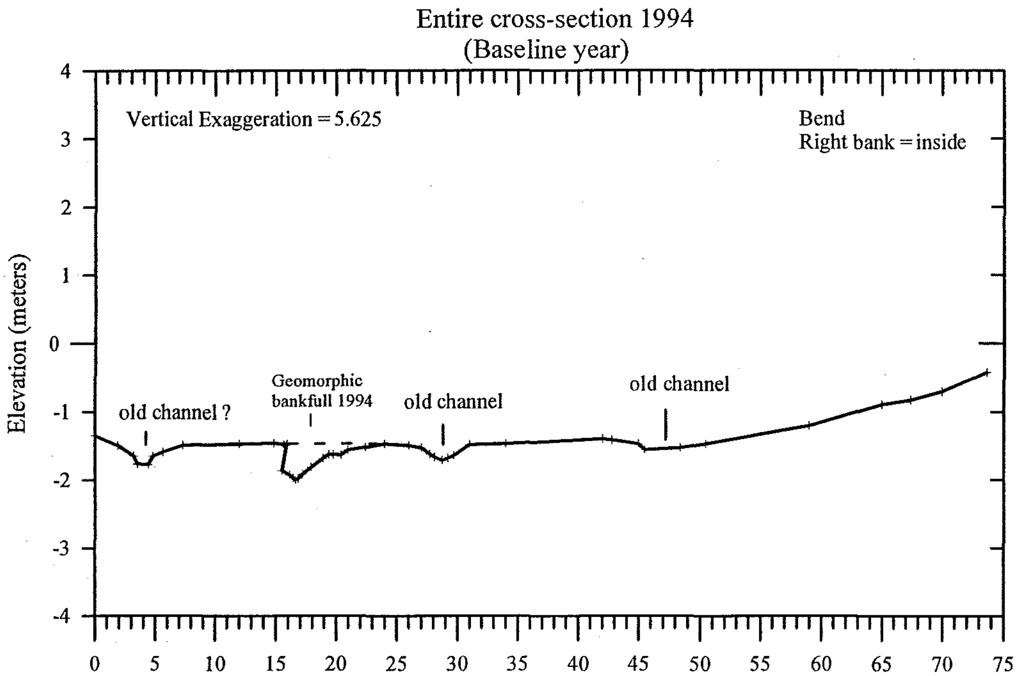
Mandan Creek cross-section 3 (continued)
Special Emphasis Management Area
1994 and 1997

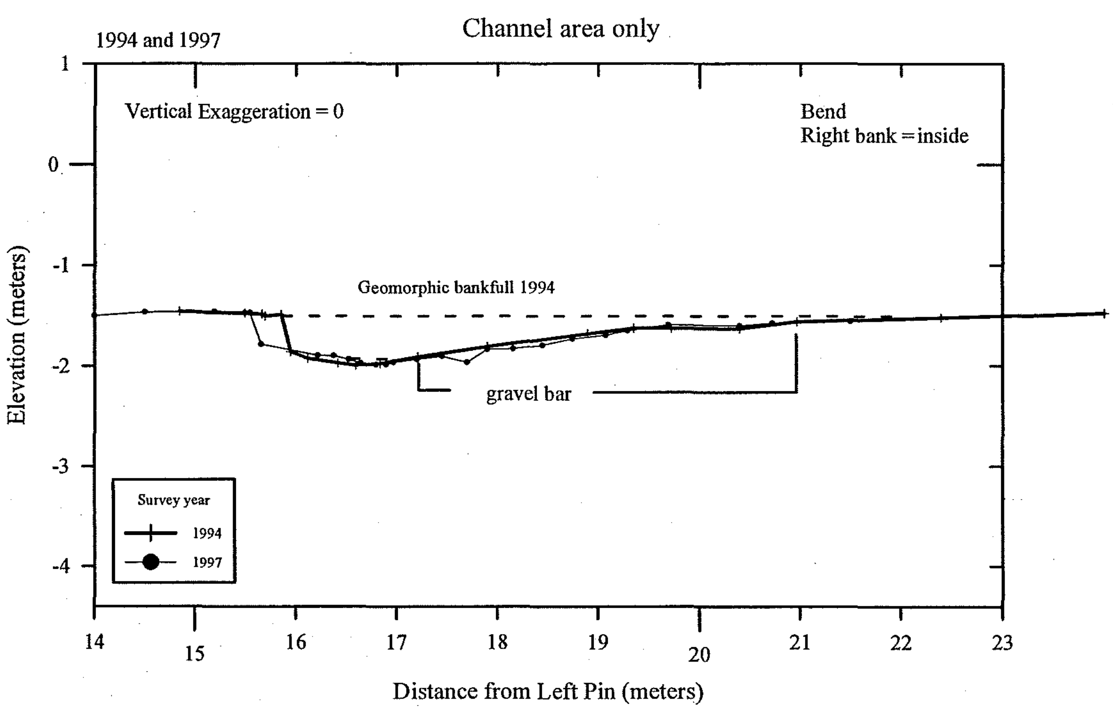
Undercut removed for clarity.



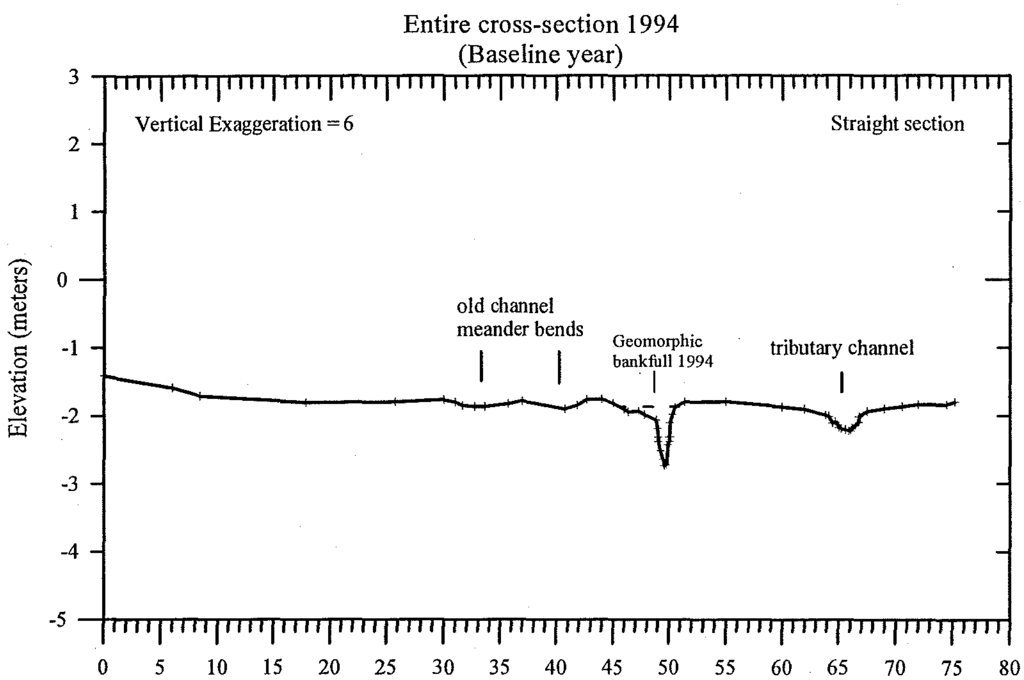


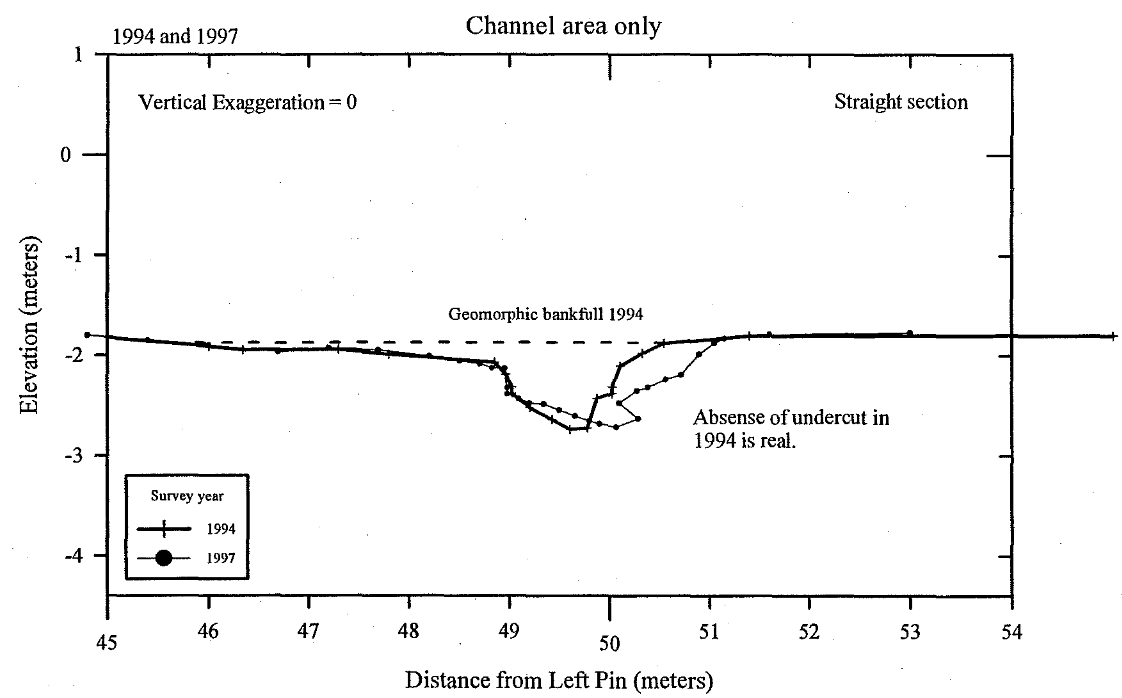
Mandan Creek cross-section 4
Special Emphasis Management Area
1994 and 1997





Mandan Creek cross-section 5
Special Emphasis Management Area
1994 and 1997

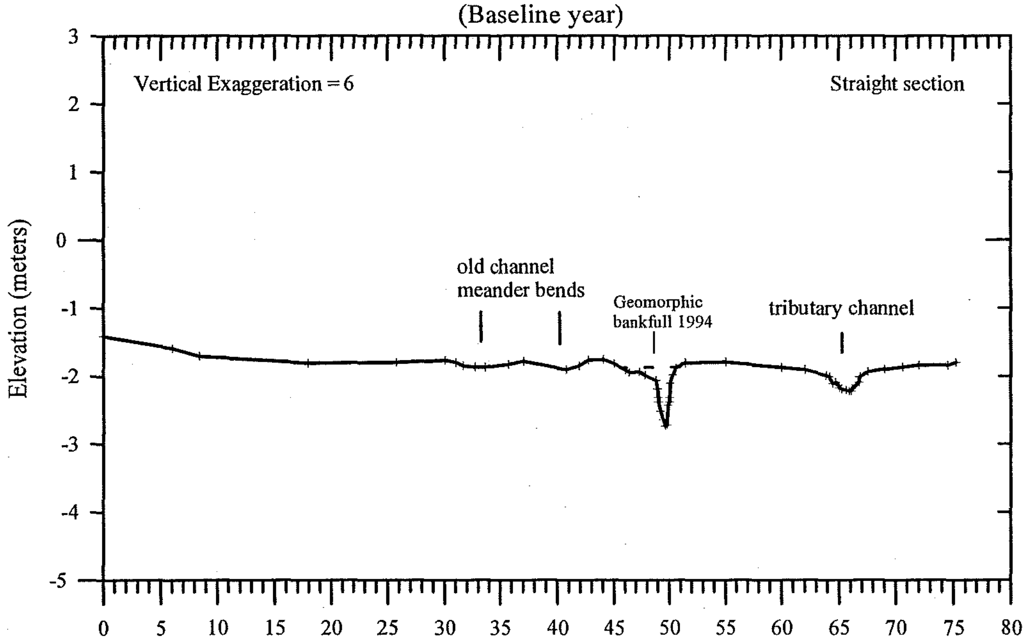




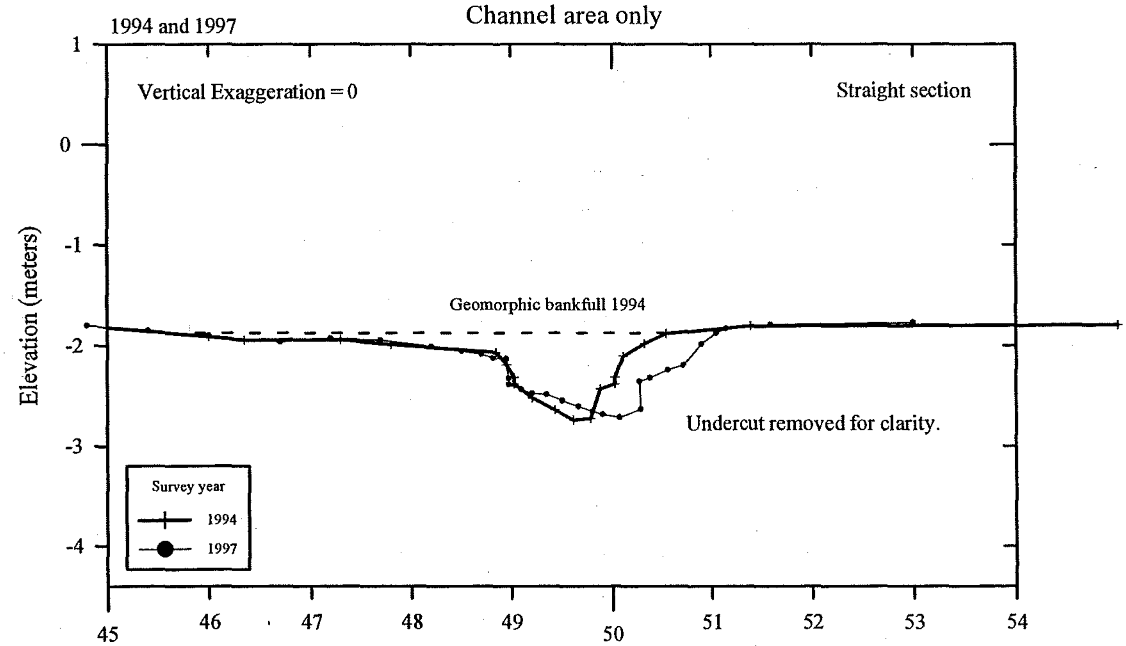
Mandan Creek cross-section 5 (continued)
Special Emphasis Management Area
1994 and 1997

Undercut removed for clarity.

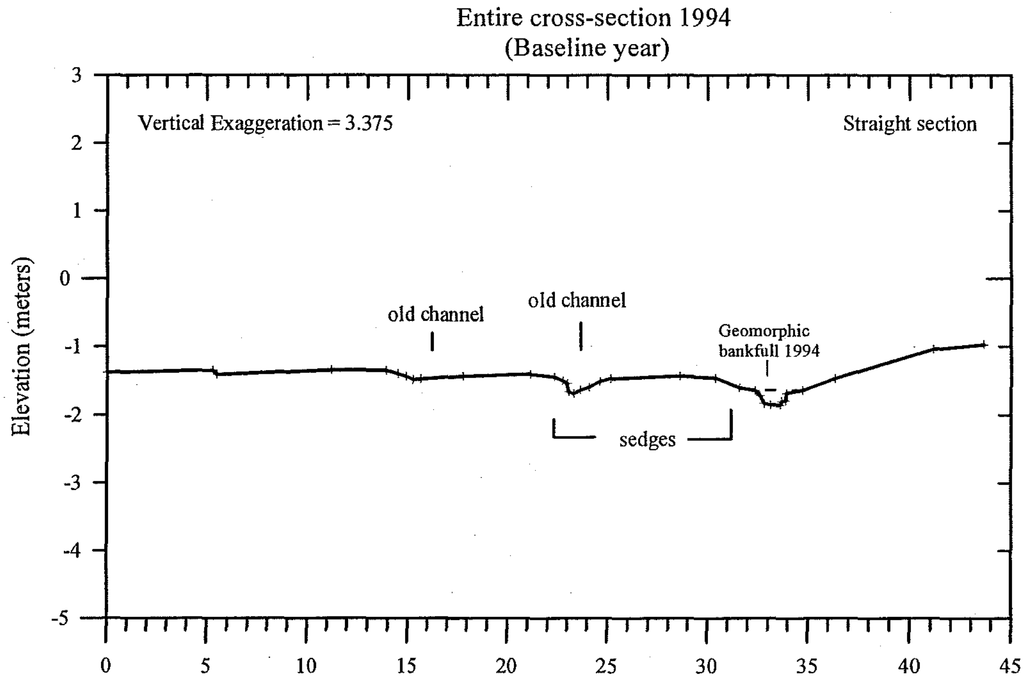
Entire cross-section 1994
(Baseline year)

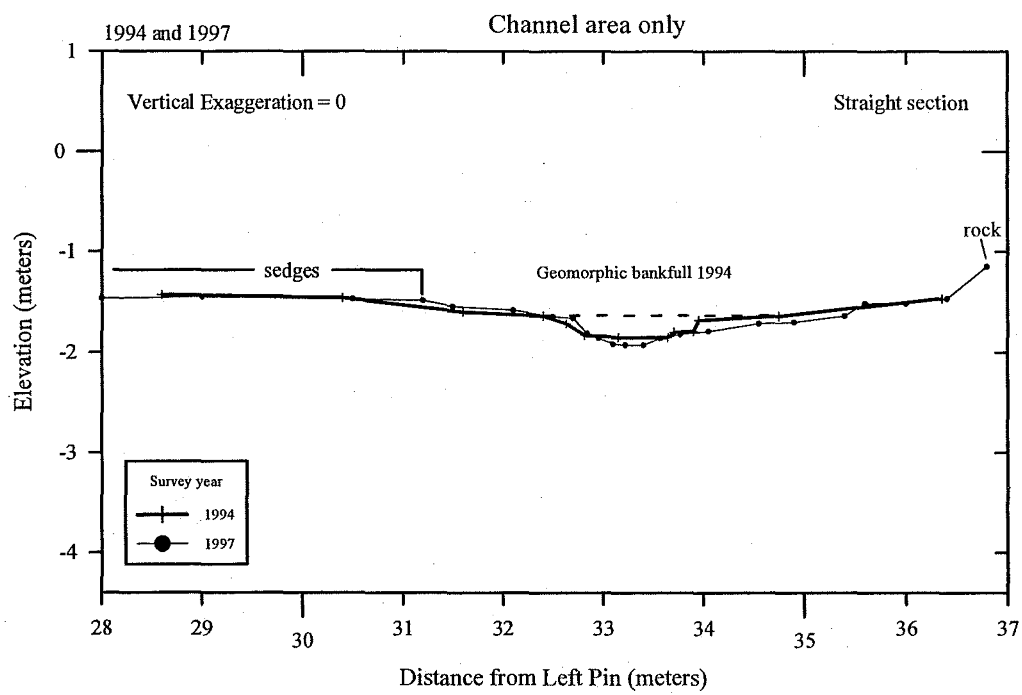


Channel area only



Mandan Creek cross-section 6
Special Emphasis Management Area
1994 and 1997





APPENDIX C

SUMMARY OF REACH DATA COLLECTED

Creek	Reach cross-sections	Reach Lengths (m)	Number of XSs	Treatment	Reach BF widths	Thalweg Depths	Thalweg resurvey?	Pebble Counts?
Main Basin	1, 2 and 3	69, 67	3	New EE	35	61	67	100
N. Basin	4, 5, 6 and 25	100, 100	4	New EE	51	126	101	101
S. Basin	7, 8, 9, 23 and 24	142, 140	5	New CE	56	141	141	100
S. Basin	10, 11, 12 and 13	163, 164	4	RG	55	141	168	229
Main Basin	14, 15 and 16	150, 150	3	RG	87	87	151	200
N. Basin	17, 18 and 26	100, 100	3	RG	50	143	99	100
N. Basin	19, 20, 21, 22	150	4	RG	51	196	no resurvey	no count
Main Basin	27 and 28	100, 100	2	RG	55	73	101	no count
Muddy	1, 2, 26, 30, 31, 32	unknown, 200	6	Old CE	50	50	152	401
Muddy	3, 4	210, 232	2	RG	70	70	146	446
Muddy	5, 6	150, 137	2	RG	71	71	91	281
Muddy	7, 8, 9	68, 114	3	RG	59	50	76	375
Muddy	10, 11	149, 130	2	RG	50	50	86	103
Muddy	12, 13, 25	152, 154, 146	3	Old CE	51	51	102, 96	200
Muddy	14, 15	149, 152, 152	2	RG	50	50	101, 101	296
Muddy	16, 17	149, 152	2	RG	50	50	101	361
Muddy	18, 19	149, 152	2	RG	50	50	101	200
Muddy	22	107, 107	1	New CE	53	53	69	224
Muddy	23, 24	149, 81	2	New CE	50	50	111	220

Creek	Reach cross-sections	Reach Lengths (m)	Number of XSs	Treatment	Reach BF widths	Thalweg Depths	Thalweg resurvey?	Pebble Counts?
Price	2	152	1	RG/BD controlled	50	50	no resurvey	96
Price	13, 14, 15, 33	115, 121, 115	4	New EE/BD controlled	50	50	91, 106	200
Price	16, 17, 18	100, 100	3	RG/BD controlled	no count	86	99	100
Price	19, 20, 21	100	3	New CE/BD controlled	beaver pond	90	no resurvey	beaver pond
Price	22 - 27	200, 150, 100	6	New CE/BD controlled	beaver pond	46	61, 83	beaver pond
Price	28, 29	100, 100	2	New CE/BD controlled	beaver pond	50	100	beaver pond
Price	30	100	1	New CE/BD controlled	beaver pond	113	no resurvey	beaver pond
W. Fk Price	4, 5	152, 145	2	RG	50	50	102	101
W. Fk Price	6, 7	152	2	RG	50	50	no resurvey	100
W. Fk Price	31, 32	100	2	RG	no count	96	no resurvey	100
Hayground	1	150	1	SEMA	50	50	no resurvey	100
Hayground	2, 3	150, 152	2	SEMA	50	50	50	195
Hayground	4, 5, 6	115, 115	3	New EE	50	50	50	196
Hayground	7, 8, 9	115, 115	3	New CE	50	50	50	223
Home	1, 2	113, 100	2	New CE	51	37	51	no count
Lower Burro	1, 2	100	2	SEMA	51	52	no resurvey	202
Lower Burro	3, 4	114	2	SEMA	51	50	no resurvey	101
Lower Burro	5	137	1	SEMA	26	50	no resurvey	101
Lower Stinky	1, 2	57	2	New CE	25	73	no resurvey	102
Lower Stinky	3	57	1	New CE	25	73	no resurvey	no count
Lower Stinky	4, 5	152	2	New CE	26	101	no resurvey	92
Mandan	1, 2	152, 152	2	SEMA	50	50	50	99
Mandan	3, 4, 5, 6	150, 150	4	SEMA	49	50	49	201

Creek	Reach cross-sections	Reach Lengths (m)	Number of XSs	Treatment	Reach BF widths	Thalweg Depths	Thalweg resurvey?	Pebble Counts?
Total reaches and cross-sections	42		108					
Total with data					39	42	29	34
% with data					86%	100%	69%	81%

APPENDIX D

REACH CHARACTERISTICS

Creek	XS	Treatment [1]	Drainage Area (sq. km)	Elevation (m)	Valley Floor Width (m)	Valley Floor Gradient (%) [2]	Water Surface Slope (%)	Channel Sinuosity
Main Basin	1, 2, 3	NEE	7.0	2140	23	4.2	2.8	1.31
North Basin	4, 5, 6, 25	NEE	2.3	2140	10, 24, 27, -	4.5	1.4 (XS 4 - lower), 5 (XS 5 - upper)	1.32
South Basin	7, 8, 9, 23, 24	NCE	4.7	2146	67, 57, -, 21, 40	3.2 (XS 7, 8 - lower)	2.3 (XS 7, 8 - lower), 4.8 (XS 9 - upper)	1.69
South Basin	10, 11	RG	4.7	2149	47	3.5	1.90	1.67
South Basin	12, 13	RG	4.7	2149	no value. use XS 10, 11	3.5	0.80	1.67
Main Basin	14, 15, 16	RG	7.1	2121	83, - , 62	3.9	1.7 (XS 14 - lower), 3.6 (XS 15, 16 - upper)	1.8
North Basin	17, 18, 26	RG	2.1	2149	- , 51, -	1.6	3.0	1.6
North Basin	19, 20, 21, 22	RG	2.1	2158	55, 56, 16, 13	1.6	3.2	1.45
Main Basin	27, 28	RG	7.2	2120	32, 25	2.4	3.0	1.8

Creek	XS	Treatment[1]	Drainage Area (sq. km)	Elevation (m)	Valley Floor Width (m)	Valley Floor Gradient (%)[2]	Water Surface Slope (%)	Channel Sinuosity
Muddy	1, 2, 26, 30, 31, 32	OCE	76	2015	20, 20, -, 22, - , 16	**0.46**	0.5% (XS 1 - lower), 1.2% (XS 2 - upper)	1.68
Muddy	3, 4	RG	70	2018	16, -	**0.46**	0.3	1.4 (XS 3), 2 (XS 4)
Muddy	5, 6		69	2018	198	**0.46**	0.3	1.94
Muddy	7, 8, 9	RG	61	2048	20, 21, 15	**0.4**	0.2 (XS 7, 8 - lower), 0.4 (XS 9 - upper)	2
Muddy	10, 11	RG	60	2048	-, 17	**0.4**	0.1	1.84
Muddy	12, 13, 25	OCE	54	2060	-, 24, -	**0.4**	0.2	1.45
Muddy	14, 15	RG	53	2060	24, 22	**0.4**	0.4	1.47
Muddy	16, 17	RG	52	2060	33, -	**0.4**	0.4	1.75
Muddy	18, 19	RG	51	2073	15, 27	**0.6**	0.5	1.5
Muddy	22	NCE	10	2170	51	**1.1**	2.6	1.3
Muddy	23, 24	NCE	6	2213	47, -	**1.9**	4.2	1.46
Price	2	RG/Beaver dam influence	14.7	2066	33	**1.8**	1.2	1.85

Creek	XS	Treatment[1]	Drainage Area (sq. km)	Elevation (m)	Valley Floor Width (m)	Valley Floor Gradient (%)[2]	Water Surface Slope (%)	Channel Sinuosity
Price	13, 14, 15, 33	NEE/Beaver dam controlled	8.3	2103	53	**2.1**	0.5	1.48
Price	16, 17, 18	RG/Beaver dam influence	14.3	2073	26, 18	**1.8**	2.0	1.46
Price	19, 20, 21	NCE/Beaver dam controlled	8.7	2103	70, 41	**2.1**	0.8[6]	1.97 - 2.14
Price	22 - 27	NCE/Beaver dam controlled	8.8	2085	41, 31, 29,29	**2.5**	0.85	2
Price	28, 29	NCE/Beaver dam controlled	8.9	2079	17, 21.5	**2.3**	1.3	1.47
Price	30	NCE/Beaver dam controlled	9.0	2079	31	**2.3**	0.9	1.8
W. Fk Price	4, 5	RG	3.9	2097	20	**2.4**	1.6	1.49
W. Fk Price	6, 7	RG	4.0	2084	18.3	**2.4**	1.6	not measured
W. Fk Price	31, 32	RG	5.3	2084	34, 39	**2.4**	1.0	1.49, 2.4 (?)
Hayground	1	SEMA	4.5	2646	43	2.9	2.4	1.07
Hayground	2, 3	SEMA	4.5	2646	30	1	1.3 (XS 3), 2.3 (XS 2)	1.4

Creek	XS	Treatment[1]	Drainage Area (sq. km)	Elevation (m)	Valley Floor Width (m)	Valley Floor Gradient (%)[2]	Water Surface Slope (%)	Channel Sinuosity
Hayground	4, 5, 6	NEE	4.9	2633	43	1	0.39	1.39
Hayground	7, 8, 9	NCE	4.7	2633	79	1	0.31	1.9
Home	1, 2	NCE	2.8	2573	23, 79	1.4	0.8	1.02
Lower Burro	1, 2	SEMA	13.7	2694	67	0.5	0.03	1.27
Lower Burro	3, 4	SEMA	12.7	2701	79	0.5	0.2	2
Lower Burro	5	SEMA	9.8	2701	137[5]	0.5	not measured	1.64
Lower Stinky	1, 2	NCE	6.1	2603	15	**2**	1.0	1.3
Lower Stinky	3	NCE	6.1	2579	27	**2**	1.0	1.3
Lower Stinky	4, 5	NCE	6	2579	54	**2**	0.8	1.8
Mandan	1, 2	SEMA	3.8	2701	25	0.5	0.03	1.1
Mandan	3, 4, 5, 6	SEMA	3	2701	76	0.5	0.4	1.48

Creek	XS	Bank Stratigraphy	Bank Composition[3]	Channel Bed Composition[4]	Beaver Ponds?		
Main Basin	1, 2, 3	homogeneous	sandy loam to clay loam. Depends on XS	34% cobbles, 36% gravel	no		
N. Basin	4, 5, 6, 25	homogeneous	sandy loam	24% cobbles, 48% gravel, 20% sand	no		
S. Basin	7, 8, 9, 23, 24	homogeneous	sandy loam/loam	25% cobbles, 52% gravel	no		
S. Basin	10, 11	homogeneous	sandy loam	19% cobbles, 48% gravel, 21% sand	no		
S. Basin	12, 13	homogeneous	clay loam/silty clay loam	19% cobbles, 48% gravel, 21% sand	no		
Main Basin	14, 15, 16	homogeneous	sandy loam to silty clay. Depends on XS	30% cobbles, 37% gravel, 30% sand	no		
N. Basin	17, 18, 26	homogeneous	clay	50% gravel, 19% sand, 20% silt/clay	no		
N. Basin	19, 20, 21, 22	homogeneous	sandy loam/loam	no pebble count	no		
Main Basin	27, 28	homogeneous	sandy loam	no pebble count	no		

Creek	XS	Bank Stratigraphy	Bank Composition[3]	Channel Bed Composition[4]	Beaver Ponds?		
Muddy	1, 2, 26, 30, 31, 32	homogeneous	no sample	26% gravel; 25% sand; 42% silt/clay	no		
Muddy	3, 4	homogeneous	no sample	32.5% gravel; 28.5% sand; 32.5% silt/clay	no		
Muddy	5, 6	homogeneous	clay	14% cobbles; 33% gravel; 42.5% sand	no		
Muddy	7, 8, 9	homogeneous	clay	62% gravel;24.5% sand; 13.5% silt/clay	no		
Muddy	10, 11	homogeneous	no sample	71% gravel; 12.5% sand; 16.5% silt/clay	no		
Muddy	12, 13, 25	homogeneous	no sample	31% gravel; 36% sand; 32% silt/clay	no		
Muddy	14, 15	homogeneous	sandy loam to loam	50% gravel; 30% sand; 21% silt/clay	no		
Muddy	16, 17	homogeneous	no sample	43% gravel; 35% sand; 22% silt/clay	no		
Muddy	18, 19	homogeneous	no sample	43% gravel; 18% sand; 35% silt/clay	no		
Muddy	22	homogeneous	silt loam	15% cobbles; 42% gravel; 15% sand; 28% silt/clay	no		
Muddy	23, 24	homogeneous	no sample	18% cobbles; 27% gravel; 24% sand; 28% silt/clay	no		
Price	2	homogeneous		41% sand; 42% silt/clay	no		

Creek	XS	Bank Stratigraphy	Bank Composition[3]	Channel Bed Composition[4]	Beaver Ponds?		
Price	13, 14, 15, 33	homogeneous	sandy loam	29% gravel; 24% sand; 41% silt/clay	no/yes		
Price	16, 17, 18	homogeneous	sandy loam	37% cobbles, 40% gravels	no		
Price	19, 20, 21	homogeneous	sandy loam	sand, silt, clay and some gravels (beaver pond)	yes		
Price	22 - 27	homogeneous	loam to clay loam. Depends on XS	sand, silt, clay and some gravels (beaver pond)	yes		
Price	28, 29	homogeneous	sany loam	sand, silt, clay and some gravels (beaver pond)	yes/no		
Price	30	homogeneous		sand, silt, clay and some gravels (beaver pond)	yes/no		
W. Fk Price	4, 5	homogeneous		17% gravel; 20% sand; 57% silt/clay	no		
W. Fk Price	6, 7	homogeneous		21% gravel; 15% sand; 62% silt/clay	no		
W. Fk Price	31, 32	homogeneous	sandy loam	48% sand; 47% silt/clay	no		
Hayground	1	homogeneous		no pebble count	no		
Hayground	2, 3	homogeneous	loam/silt loam	38% cobbles; 35% gravel	no		

Creek	XS	Bank Stratigraphy	Bank Composition[3]	Channel Bed Composition[4]	Beaver Ponds?		
Hayground	4, 5, 6	homogeneous	silty clay	24% cobbles; 26% gravels; 42% silt/clay	no		
Hayground	7, 8, 9	homogeneous	clay (XS 8), silt loam (XS 7)	no pebble count -- lightening storm	no		
Home	1, 2	homogeneous	clay loam/silty clay loam	no pebble count -- lightening storm	no		
Lower Burro	1, 2	homogeneous	sandy loam	41% gravel; 25% sand	no		
Lower Burro	3, 4	homogeneous	loam/silt loam	no pebble count -- lightening storm	no		
Lower Burro	5	homogeneous	loam/silt loam	no pebble count -- lightening storm	no		
Lower Stinky	1, 2	homogeneous	loam/silt loam	no pebble count -- lightening storm	no		
Lower Stinky	3	homogeneous	loam/silt loam	no pebble count -- lightening storm	no		
Lower Stinky	4, 5	homogeneous	sandy loam to silt loam. Depends on XS	no pebble count -- lightening storm	no		
Mandan	1, 2	homogeneous	silty clay loam/clay loam	no pebble count	no		
Mandan	3, 4, 5, 6	homogeneous	silty clay loam/clay loam	50% gravel; 49% silt/clay	no		

[1] NEE = New Elk Exclosure, NCE = New Cattle Exclosure, OCE = Old Cattle Exclosure, RG = Riparian Guidelines, SEMA = Special Emphasis Management Area

[2] Valley floor gradient % measured in the field with survey equipment unless BOLD. Values in **BOLD** were determined from a 1:24,000 topographic map.

[3] Bank compositions determined using the Soil Conservation Survey method (Soil Survey Staff 1995).

[4] Channel bed compositions determined from pebble counts using the Wolman (1954) pebble count method.

[5] The valley floor width of 137 for L. Burro 5 is a visual estimate. Too many cows with horns to make a measurement safe.

[6] Price XS 19 through 21. Three water surface slopes were taken = 1% (below beaver dam), 0.7% (above beaver dam), and 10% (at beaver dam).

APPENDIX E

HYDROLOGIC BANKFULL CROSS-SECTION AREAS BASED ON STAGE INDICATORS NOTED IN THE FIELD

Creek	XS	Reach number[1]	Drainage Area (sq. km)	Geomorphic Baseline Channel XS Area (sq. m)	Hydrologic Bankfull XS Area based on field stage indicators (sq. m)[2]	Channel Segment
Main Basin	1	1	7	1.59	0.93	Straight
Main Basin	2	1	7	3.29	0.85	Straight
Main Basin	3	1	7	2.69	1.26	Straight
N. Basin	4	2	2.3	1.35	0.42	LB = inside
N. Basin	5	2	2.3	0.38	*****	Straight
N. Basin	6	2	2.3	1.81	0.33	LB = inside
S. Basin	7	3	4.7	1.39	0.41	Straight
S. Basin	8	3	4.7	10.25	*****	RB = inside
S. Basin	9	3	4.7	6.69	1.35	Straight
S. Basin	10	4	4.7	7.99	*****	LB = inside
S. Basin	11	4	4.7	7.21	0.43	Straight
S. Basin	12	4	4.7	4.42	1.21	Straight
S. Basin	13	4	4.7	2.32	1.05	Straight
Main Basin	14	5	7.1	5.57	1.36	RB = inside
Main Basin	15	5	7.1	3.12	0.90	Straight
Main Basin	16	5	7.1	3		LB = inside
N. Basin	17	6	2.1	2.12	0.15	Straight
N. Basin	18	6	2.1	0.87	0.39	Straight
N. Basin	19	7	2.1	1.08	0.26	Straight
N. Basin	20	7	2.1	2.35	0.22	Straight
N. Basin	21	7	2.1	1.17	0.32	Straight
N. Basin	22	7	2.1	1.37	0.30	Straight
S. Basin	23	3	4.7	1.97	0.31	Straight
S. Basin	24	3	4.7	5.39	*****	LB = inside
N. Basin	25	2	2.3	1.39	*****	Straight
N. Basin	26	6	2.1	3.19	*****	LB = inside
Main Basin	27	8	7.2	1.91	0.73	Straight
Main Basin	28	8	7.2	2.16	0.56	RB = inside
Muddy	1	1	76	4.27	1.350	RB = inside
Muddy	2	1	76	3.91	1.800	Straight
Muddy	3	2	70	1.96	*****	Straight
Muddy	4	2	70	1.29	0.910	LB = inside
Muddy	5	3	69	0.81	0.497	Straight
Muddy	6	3	69	1.66	0.810	RB = inside
Muddy	7	4	61	3.21	1.360	RB = inside
Muddy	8	4	61	2	0.485	LB = inside
Muddy	9	4	61	1.21	0.430	Straight
Muddy	10	5	60	1.44	0.820	LB = inside
Muddy	11	5	60	1.8	1.010	RB = inside
Muddy	12	6	54	2.58	1.460	RB = inside

Creek	XS	Reach number[1]	Drainage Area (sq. km)	Geomorphic Baseline Channel XS Area (sq. m)	Hydrologic Bankfull XS Area based on field stage indicators (sq. m)[2]	Channel Segment
Muddy	13	6	54	1.63	0.716	Straight
Muddy	14	6	53	1.02	*****	RB = inside
Muddy	15	6	53	0.76	0.743	Straight
Muddy	16	6	52	2.18	0.823	Straight
Muddy	17	6	52	2.2	1.200	LB = inside
Muddy	18	6	51	1.37	0.883	Straight
Muddy	19	6	51	1.84	1.226	RB = inside
Muddy	22	7	10	1.13	0.520	Straight
Muddy	23	8	6	0.98	0.097	Straight
Muddy	24	8	6	0.14	0.284	Straight
Muddy	25	6	54	2.54	0.920	Straight
Muddy	26	1	76	1.04	0.850	Straight
Muddy	30	1	76	0.53	*****	Straight
Muddy	31	1	76	1	1.051	RB = inside
Muddy	32	1	76	3.45	0.548	Straight
Price	2	1	14.7	4.66	*****	RB = inside
Price	13a	2	8.3	1.54	*****	RB = inside
Price	13b	2	8.3	0.87	*****	RB = inside
Price	13c	2	8.3	1.54	*****	RB = inside
Price	14a	2	8.3	1.35	*****	Straight
Price	14b	2	8.3	0.72	*****	Straight
Price	14c	2	8.3	1.35	*****	Straight
Price	15a	2	8.3	1.87	*****	Straight
Price	15b	2	8.3	0.12	*****	Straight
Price	15c	2	8.3	1.87	*****	Straight
Price	16	3	14.3	4.39	*****	Straight
Price	17a	3	14.3	6.9	*****	Straight
Price	17d	3	14.3	6.9	*****	Straight
Price	17f	3	14.3	6.9	*****	Straight
Price	17b	3	14.3	6.9	*****	Straight
Price	17c	3	14.3	6.9	*****	Straight
Price	17e	3	14.3	6.9	*****	Straight

Creek	XS	Reach number[1]	Drainage Area (sq. km)	Geomorphic Baseline Channel XS Area (sq. m)	Hydrologic Bankfull XS Area based on field stage indicators (sq. m)[2]	Channel Segment
Price	18a	3	14.3	3.63	*****	Straight
Price	18c	3	14.3	3.79	*****	Straight
Price	18b	3	14.3	3.63	*****	Straight
Price	19a	4	8.7	1.23	*****	Straight
Price	19c	4	8.7	1.19	*****	Straight
Price	19b	4	8.7	1.23	*****	Straight
Price	20a	4	8.7	3.07	*****	RB = inside
Price	20c	4	8.7	2.3	*****	RB = inside
Price	20b	4	8.7	3.07	*****	RB = inside
Price	21a	4	8.7	2.09	*****	Straight
Price	21c	4	8.7	1.81	*****	Straight
Price	21b	4	8.7	2.09	*****	Straight
Price	22a	5	8.8	2.22	*****	Straight
Price	22c	5	8.8	2.25	*****	Straight
Price	22b	5	8.8	2.22	*****	Straight
Price	23a	5	8.8	1.68	*****	Straight
Price	23c	5	8.8	1.49	*****	Straight
Price	23b	5	8.8	1.68	*****	Straight
Price	24a	5	8.8	2.39	*****	Straight (at angle to stream)
Price	24c	5	8.8	2.39	*****	Straight (at angle to stream)
Price	24b	5	8.8	2.39	*****	Straight (at angle to stream)
Price	25a	5	8.8	1.6	*****	Straight
Price	25c	5	8.8			Straight
Price	25b	5	8.8	1.6	*****	Straight
Price	26a	5	8.8	2.71	*****	Straight
Price	26c	5	8.8			Straight

Creek	XS	Reach number[1]	Drainage Area (sq. km)	Geomorphic Baseline Channel XS Area (sq. m)	Hydrologic Bankfull XS Area based on field stage indicators (sq. m)[2]	Channel Segment
Price	26b	5	8.8	2.71	*****	Straight
Price	27a	5	8.8	4.09	*****	LB = inside
Price	27c	5	8.8			LB = inside
Price	27b	5	8.8	4.09	*****	LB = inside
Price	28a	6	8.9	1.43	*****	Straight
Price	28c	6	8.9	1.43	*****	Straight
Price	28b	6	8.9	1.43	*****	Straight
Price	29a	6	8.9	0.95	*****	LB = inside
Price	29c	6	8.9	0.95	*****	LB = inside
Price	29b	6	8.9	0.95	*****	LB = inside
Price	30a	7	9	1.63	*****	Straight
Price	30c	7	9	1.63	*****	Straight
Price	30b	7	9	16.3	*****	Straight
Price	33	2	8.3	1.18	*****	Straight
W. Fk Price	4	8	3.9	0.203	0.095	Straight
W. Fk Price	5	8	3.9	0.745	0.145	Straight
W. Fk Price	6	9	4	0.465	0.323	Straight
W. Fk. Price	7	9	4	0.472	0.363	Straight
W. Fk Price	31	10	5.3	0.11	*****	Straight
W. Fk. Price	32a	10	5.3	0.31	*****	Straight
W. Fk. Price	32c	10	5.3	0.31	*****	Straight
W. Fk. Price	32b	10	5.3	0.31	*****	Straight
Hayground	1	1	4.5	1.427	0.46	Straight
Hayground	2	2	4.5	0.93	0.41	Straight
Hayground	3	2	4.5	1	*****	RB = inside
Hayground	4	3	4.9	1.64	*****	RB = inside
Hayground	5	3	4.9	0.59	*****	Straight
Hayground	6	3	4.9	2.62	1.94	Straight
Hayground	7	4	4.7	0.72	*****	RB = inside

Creek	XS	Reach number[1]	Drainage Area (sq. km)	Geomorphic Baseline Channel XS Area (sq. m)	Hydrologic Bankfull XS Area based on field stage indicators (sq. m)[2]	Channel Segment
Hayground	8	4	4.7	0.66	*****	RB = inside
Hayground	9	4	4.7	0.58	*****	Straight
Home	1	1	2.8	0.56	*****	LB = inside
Home	2	1	2.8	0.495	0.14	Straight
L. Burro	1	1	13.7	2.01	1.43	Straight
L. Burro	2	1	13.7	1.086	*****	Straight
L. Burro	3	2	12.7	1.46	0.85	Straight
L. Burro	4	2	12.7	2.02	*****	RB = inside
L. Burro	5	3	9.8	1.395	*****	Straight
L. Stinky	1	1	6.1	0.99	0.87	Straight
L. Stinky	2	1	6.1	0.86	0.54	Straight
L. Stinky	3	2	6.1	0.53	*****	RB = inside
L. Stinky	4	3	6	1.56	*****	LB = inside
L. Stinky	5	3	6	0.505	0.505	Straight
Mandan	1	1	3.8	0.68	*****	Straight
Mandan	2	1	3.8	0.84	0.52	Straight
Mandan	3	2	3	1.68	*****	Straight
Mandan	4	2	3	1.47	*****	RB = inside
Mandan	5	2	3	1.1	*****	Straight
Mandan	6	2	3	0.266	*****	Straight

[1] Reach number is assigned as a means ot identifying cross-sections in the same reach. There is no spatial meaning to the numbers (i.e. 1 does not equal most upstream or downstream reach).

[2] (*****) indicates that no hydrologic bankfull elevation was identified in the field at this cross-section

APPENDIX F

ANNUAL AND NET CHANGES IN CROSS-SECTION AREA AS A FUNCTION OF CREEK, CROSS-SECTION, TREATMENT, CHANNEL SEGMENT, AND BASELINE CROSS-SECTION AREA

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
2	9597	Main Basin	1	7	1.59	-0.07	-0.14	-4	-9
2	9597	Main Basin	2	6.69	3.29	-0.13	-0.25	-4	-8
2	9597	Main Basin	3	6.68	2.69	-0.13	-0.25	-5	-9
2	9597	N. Basin	4	2.31	1.35	-0.01	-0.01	0	-1
2	9597	N. Basin	5	2.3	0.38	-0.10	-0.19	-25	-50
2	9597	N. Basin	6	2.29	1.81	-0.11	-0.21	-6	-12
2	9597	S. Basin	7	4.7	1.39	-0.05	-0.09	-3	-6
2	9597	S. Basin	8	4.68	10.25	-0.15	-0.3	-1	-3
2	9597	S. Basin	9	4.67	6.69	-0.18	-0.36	-3	-5
2	9597	S. Basin	10	4.63	7.99	0.09	0.17	1	2
2	9597	S. Basin	11	4.64	7.21	-0.08	-0.16	-1	-2
2	9597	S. Basin	12	4.65	4.42	-0.02	-0.05	-1	-1
2	9597	S. Basin	13	4.66	2.32	0.01	0.02	0	1
2	9597	Main Basin	14	7.1	5.57	-0.07	-0.13	-1	-2
2	9597	Main Basin	15	7.09	3.12	-0.03	-0.05	-1	-2
2	9597	Main Basin	16	7.08	3	-0.02	-0.04	-1	-1
2	9597	N. Basin	17	2.1	2.12	0.11	0.21	5	10
2	9597	N. Basin	18	2.09	0.87	0.04	0.08	5	9
2	9597	N. Basin	19	2.08	1.08	0.09	0.18	8	17
2	9597	N. Basin	20	2.07	2.35	0.02	0.04	1	2
2	9597	N. Basin	21	2.06	1.17	-0.01	-0.02	-1	-2

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
2	9597	N. Basin	22	2.05	1.37	0.00	0.01	0	1
2	9597	S. Basin	23	4.71	1.97	-0.04	-0.07	-2	-4
2	9597	S. Basin	24	4.69	5.39	0.10	0.2	2	4
2	9597	N. Basin	25	2.29	1.39	-0.13	-0.25	-9	-18
2	9597	N. Basin	26	2.11	3.19	-0.11	-0.21	-3	-7
2	9597	Main Basin	27	7.2	1.91	0.01	0.01	0	1
2	9597	Main Basin	28	7.19	2.16	0.13	0.25	6	12
2	9395	Muddy	1a	76	4.27	-0.02	-0.04	0	-1
3	9598	Muddy	1b	76	4.27	0.00	0.01	0	0
5	9398	Muddy	1c	76	4.27	-0.01	-0.03	0	-1
2	9395	Muddy	2a	75.98	3.91	0.07	0.14	2	4
3	9598	Muddy	2b	75.98	3.91	-0.06	-0.19	-2	-5
5	9398	Muddy	2c	75.98	3.91	-0.01	-0.05	0	-1
3	9598	Muddy	3	70	1.96	-0.02	-0.05	-1	-3
2	9395	Muddy	4a	69.99	1.29	0.02	0.04	2	3
3	9598	Muddy	4b	69.99	1.29	-0.05	-0.14	-4	-11
5	9398	Muddy	4c	69.99	1.29	-0.02	-0.1	-2	-8

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
2	9395	Muddy	5a	69	0.81	-0.05	-0.09	-6	-11
3	9598	Muddy	5b	69	0.81	0.01	0.02	1	2
5	9398	Muddy	5c	69	0.81	-0.01	-0.07	-2	-9
2	9395	Muddy	6a	68.99	1.66	-0.06	-0.11	-3	-7
3	9598	Muddy	6b	68.99	1.66	-0.05	-0.15	-3	-9
5	9398	Muddy	6c	68.99	1.66	-0.05	-0.26	-3	-16
5	9398	Muddy	7	61	3.21	0.00	-0.01	0	0
5	9398	Muddy	8	60.99	2	-0.02	-0.08	-1	-4
5	9398	Muddy	9	60.98	1.21	-0.02	-0.09	-1	-7
5	9398	Muddy	10	60	1.44	-0.05	-0.23	-3	-16
5	9398	Muddy	11	59.99	1.8	-0.06	-0.29	-3	-16
2	9395	Muddy	12a	54	2.58	0.31	0.62	12	24
3	9598	Muddy	12b	54	2.58	0.06	0.17	2	7

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
5	9398	Muddy	12c	54	2.58	0.16	0.79	6	31
2	9395	Muddy	13a	53.99	1.63	0.07	0.13	4	8
3	9598	Muddy	13b	53.99	1.63	0.02	0.07	1	4
5	9398	Muddy	13c	53.99	1.63	0.04	0.2	2	12
2	9395	Muddy	14a	53	1.02	-0.04	-0.07	-3	-7
3	9598	Muddy	14b	53	1.02	-0.01	-0.02	-1	-2
5	9398	Muddy	14c	53	1.02	-0.02	-0.09	-2	-9
2	9395	Muddy	15a	52.99	0.76	-0.04	-0.07	-5	-9
3	9598	Muddy	15b	52.99	0.76	-0.02	-0.06	-3	-8
5	9398	Muddy	15c	52.99	0.76	-0.03	-0.13	-3	-17
2	9395	Muddy	16a	52	2.18	0.04	0.08	2	4
3	9598	Muddy	16b	52	2.18	0.02	0.06	1	3
5	9398	Muddy	16c	52	2.18	0.03	0.14	1	6
2	9395	Muddy	17a	51.99	2.2	0.15	0.3	7	14
3	9598	Muddy	17b	51.99	2.2	0.22	0.65	10	30
5	9398	Muddy	17c	51.99	2.2	0.19	0.95	9	43

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
5	9398	Muddy	18	51	1.37	-0.04	-0.18	-3	-13
5	9398	Muddy	19	50.99	1.84	0.04	0.22	2	12
2	9395	Muddy	22a	10	1.13	-0.03	-0.05	-2	-4
3	9598	Muddy	22b	10	1.13	-0.08	-0.23	-7	-20
5	9398	Muddy	22c	10	1.13	-0.05	-0.27	-5	-24
2	9395	Muddy	23a	6	0.98	-0.12	-0.23	-12	-23
3	9598	Muddy	23b	6	0.98	-0.01	-0.02	-1	-2
5	9398	Muddy	23c	6	0.98	-0.05	-0.25	-5	-26
2	9395	Muddy	24a	5.99	0.14	0.02	0.04	14	29
3	9598	Muddy	24b	5.99	0.14	-0.01	-0.03	-7	-21
5	9398	Muddy	24c	5.99	0.14	0.00	0.01	1	7
3	9598	Muddy	25	54.01	2.54	0.00	0	0	0
3	9598	Muddy	26	76.01	1.04	-0.01	-0.02	-1	-2

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
2	9698	Muddy	30	76.03	0.53	0.05	0.1	9	19
2	9698	Muddy	31d	76.04	1	0.03	0.05	3	5
2	9698	Muddy	32	75.99	3.45	0.01	0.01	0	0
4	9498	Price	2	14.7	4.66	0.35	1.39	7	30
3	9497	Price	13a	8.3	1.54	-0.22	-0.666	-14	-43
1	9798	Price	13b	8.3	0.87	0.24	0.24	28	28
4	9498	Price	13c	8.3	1.54	-0.11	-0.43	-7	-28
3	9497	Price	14a	8.31	1.35	-0.21	-0.63	-16	-47
1	9798	Price	14b	8.31	0.72	0.15	0.15	21	21

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
4	9498	Price	14c	8.31	1.35	-0.12	-0.48	-9	-36
3	9497	Price	15a	8.32	1.87	-0.58	-1.75	-31	-94
1	9798	Price	15b	8.32	0.12	0.53	0.53	442	442
4	9498	Price	15c	8.32	1.87	-0.31	-1.22	-16	-65
4	9498	Price	16	14.3	4.39	0.24	0.95	5	22
1	9495	Price	17a	14.29	6.9	-0.06	-0.06	-1	-1
2	9597	Price	17b	14.29	6.9	0.03	0.06	0	1
1	9798	Price	17c	14.29	6.9	0.00	0	0	0
3	9497	Price	17d	14.29	6.9	0.00	0	0	0
4	9498	Price	17e	14.29	6.9	0.00	0	0	0
3	9598	Price	17f	14.29	6.9	0.02	0.06	0	1

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
1	9495	Price	18a	14.28	3.63	0.16	0.16	4	4
3	9598	Price	18b	14.28	3.79	0.00	-0.01	0	0
4	9498	Price	18c	14.28	3.63	0.04	0.15	1	4
2	9597	Price	19a	8.71	1.23	-0.02	-0.04	-2	-3
1	9798	Price	19b	8.71	1.19	-0.02	-0.02	-2	-2
3	9598	Price	19c	8.71	1.23	-0.02	-0.06	-2	-5
2	9597	Price	20a	8.7	3.07	-0.39	-0.77	-13	-25
1	9798	Price	20b	8.7	2.3	1.06	1.06	46	46
3	9598	Price	20c	8.7	3.07	0.10	0.29	3	9
2	9597	Price	21a	8.69	2.09	-0.14	-0.28	-7	-13

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
1	9798	Price	21b	8.69	1.81	0.21	0.21	12	12
3	9598	Price	21c	8.69	2.09	-0.02	-0.07	-1	-3
2	9597	Price	22a	8.77	2.22	0.02	0.03	1	1
1	9798	Price	22b	8.77	2.25	0.04	0.04	2	2
3	9598	Price	22c	8.77	2.22	0.02	0.07	1	3
2	9597	Price	23a	8.78	1.68	-0.10	-0.19	-6	-11
1	9798	Price	23b	8.78	1.49	0.53	0.53	36	36
3	9598	Price	23c	8.78	1.68	0.11	0.34	7	20
2	9597	Price	24a	8.79	2.39	0.63	1.26	26	53

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
1	9798	Price	24b	8.79	2.39	-0.02	-0.02	-1	-1
3	9598	Price	24c	8.79	2.39	0.41	1.24	17	52
2	9597	Price	25a	8.8	1.6	0.02	0.04	1	3
1	9798	Price	25b	8.8	1.64	-0.03	-0.03	-2	-2
3	9598	Price	25c	8.8	1.6	0.00	0.01	0	1
2	9597	Price	26a	8.81	2.71	-0.14	-0.27	-5	-10
1	9798	Price	26b	8.81	2.44	0.27	0.27	11	11
3	9598	Price	26c	8.81	2.71	0.00	0	0	0
2	9597	Price	27a	8.81	4.09	-0.20	-0.4	-5	-10

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
1	9798	Price	27b	8.81	3.69	0.39	0.39	11	11
3	9598	Price	27c	8.81	4.09	0.00	-0.01	0	0
2	9597	Price	28a	8.9	1.43	0.03	0.06	2	4
1	9798	Price	28b	8.9	1.43	0.03	0.03	2	2
3	9598	Price	28c	8.9	1.43	0.03	0.09	2	6
2	9597	Price	29a	8.91	0.95	0.62	1.24	65	131
1	9798	Price	29b	8.91	0.95	0.10	0.1	11	11
3	9598	Price	29c	8.91	0.95	0.45	1.34	47	141
2	9597	Price	30a	9	1.63	0.47	0.93	29	57

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
1	9798	Price	30b	9	1.63	0.93	0.93	57	57
3	9598	Price	30c	9	16.3	0.62	1.86	4	11
1	9798	Price	33	8.29	1.18	1.08	1.08	92	92
4	9498	W. Fk. Price	4	3.89	0.203	-0.01	-0.028	-3	-14
4	9498	W. Fk. Price	5	3.9	0.745	0.03	0.119	4	16
4	9498	W. Fk. Price	6	4	0.465	-0.01	-0.025	-1	-5
4	9498	W. Fk. Price	7	4.1	0.472	-0.01	-0.048	-3	-10
2	9597	W. Fk. Price	31	5.3	0.11	0.03	0.06	27	55
2	9597	W. Fk. Price	32a	5.29	0.31	-0.01	-0.01	-2	-3
1	9798	W. Fk. Price	32b	5.29	0.31	0.02	0.02	6	6
3	9598	W. Fk. Price	32c	5.29	0.31	0.00	0.01	1	3

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
3	9497	Hayground	1	4.49	1.427	0.03	0.093	2	7
3	9497	Hayground	2	4.5	0.93	0.02	0.05	2	5
3	9497	Hayground	3	4.51	1	-0.04	-0.11	-4	-11
3	9497	Hayground	4	4.91	1.64	-0.10	-0.3	-6	-18
3	9497	Hayground	5	4.89	0.59	0.03	0.09	5	15
3	9497	Hayground	6	4.9	2.62	0.02	0.05	1	2
3	9497	Hayground	7	4.7	0.72	-0.01	-0.02	-1	-3
3	9497	Hayground	8	4.69	0.66	0.03	0.09	5	14
3	9497	Hayground	9	4.71	0.58	-0.01	-0.02	-1	-3
3	9497	Home	1	2.8	0.56	-0.02	-0.06	-4	-11
3	9497	Home	2	2.79	0.495	-0.01	-0.021	-1	-4
3	9497	Lower Burro	1	13.7	2.01	-0.03	-0.1	-2	-5
3	9497	Lower Burro	2	13.69	1.086	0.01	0.034	1	3
3	9497	Lower Burro	3	12.7	1.46	0.02	0.05	1	3
3	9497	Lower Burro	4	12.69	2.02	-0.05	-0.135	-2	-7
3	9497	Lower Burro	5	9.8	1.395	0.05	0.144	3	10
3	9497	Lower Stinky	1	6.1	0.99	-0.06	-0.19	-6	-19

Yrs Btwn Surveys	Comparison Years	Creek	XS	Drainage Area (sq. km)	Baseline XS Area (sq. m)	ANNUAL Rate of Change in Baseline XS Area (sq. m/yr)[1]	NET Change in Baseline XS Area (sq. m)[2]	ANNUAL % Change in Baseline XS Area	NET % Change in Baseline XS Area
3	9497	Lower Stinky	2	6.09	0.86	0.03	0.09	3	10
3	9497	Lower Stinky	3	6.08	0.53	0.02	0.07	4	13
3	9497	Lower Stinky	4	6	1.56	-0.03	-0.092	-2	-6
3	9497	Lower Stinky	5	5.99	0.505	0.00	0.003	0	1
3	9497	Mandan	1	3.8	0.68	0.00	-0.01	0	-1
3	9497	Mandan	2	3.79	0.84	-0.01	-0.016	-1	-2
3	9497	Mandan	3	3.31	1.68	-0.05	-0.15	-3	-9
3	9497	Mandan	4	3	1.47	0.05	0.14	3	10
3	9497	Mandan	5	2.99	1.1	0.10	0.29	9	26
3	9497	Mandan	6	2.98	0.266	0.03	0.084	11	32

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9597	Main Basin	1	Straight	New Elk Excl.	N/A	N/A
9597	Main Basin	2	Straight	New Elk Excl.	N/A	N/A
9597	Main Basin	3	Straight	New Elk Excl.	N/A	N/A
9597	N. Basin	4	LB = inside	New Elk Excl.	N/A	N/A
9597	N. Basin	5	Straight	New Elk Excl.	N/A	N/A
9597	N. Basin	6	LB = inside	New Elk Excl.	N/A	N/A
9597	S. Basin	7	Straight	New Cattle Excl.	N/A	N/A
9597	S. Basin	8	RB = inside	New Cattle Excl.	N/A	N/A
9597	S. Basin	9	Straight	New Cattle Excl.	N/A	N/A
9597	S. Basin	10	LB = inside	Rip. Guidelines	N/A	N/A
9597	S. Basin	11	Straight	Rip. Guidelines	N/A	N/A
9597	S. Basin	12	Straight	Rip. Guidelines	N/A	N/A
9597	S. Basin	13	Straight	Rip. Guidelines	N/A	N/A
9597	Main Basin	14	RB = inside	Rip. Guidelines	N/A	N/A
9597	Main Basin	15	Straight	Rip. Guidelines	N/A	N/A
9597	Main Basin	16	LB = inside	Rip. Guidelines	N/A	N/A
9597	N. Basin	17	Straight	Rip. Guidelines	N/A	N/A
9597	N. Basin	18	Straight	Rip. Guidelines	N/A	N/A
9597	N. Basin	19	Straight	Rip. Guidelines	N/A	N/A
9597	N. Basin	20	Straight	Rip. Guidelines	N/A	N/A
9597	N. Basin	21	Straight	Rip. Guidelines	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9597	N. Basin	22	Straight	Rip. Guidelines	N/A	N/A
9597	S. Basin	23	Straight	New Cattle Excl.	N/A	N/A
9597	S. Basin	24	LB = inside	New Cattle Excl.	N/A	N/A
9597	N. Basin	25	Straight	New Elk Excl.	N/A	N/A
9597	N. Basin	26	LB = inside	Rip. Guidelines	N/A	N/A
9597	Main Basin	27	Straight	Rip. Guidelines	N/A	N/A
9597	Main Basin	28	RB = inside	Rip. Guidelines	N/A	N/A
9395	Muddy	1a	RB = inside	Old Cattle Excl.	N/A	N/A
9598	Muddy	1b	RB = inside	Old Cattle Excl.	N/A	N/A
9398	Muddy	1c	RB = inside	Old Cattle Excl.	N/A	N/A
9395	Muddy	2a	Straight	Old Cattle Excl.	N/A	N/A
9598	Muddy	2b	Straight	Old Cattle Excl.	N/A	N/A
9398	Muddy	2c	Straight	Old Cattle Excl.	N/A	N/A
9598	Muddy	3	Straight	Rip. Guidelines	N/A	N/A
9395	Muddy	4a	LB = inside	Rip. Guidelines	N/A	N/A
9598	Muddy	4b	LB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	4c	LB = inside	Rip. Guidelines	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9395	Muddy	5a	Straight	Rip. Guidelines	N/A	N/A
9598	Muddy	5b	Straight	Rip. Guidelines	N/A	N/A
9398	Muddy	5c	Straight	Rip. Guidelines	N/A	N/A
9395	Muddy	6a	RB = inside	Rip. Guidelines	N/A	N/A
9598	Muddy	6b	RB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	6c	RB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	7	RB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	8	LB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	9	Straight	Rip. Guidelines	N/A	N/A
9398	Muddy	10	LB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	11	RB = inside	Rip. Guidelines	N/A	N/A
9395	Muddy	12a	RB = inside	Old Cattle Excl.	N/A	N/A
9598	Muddy	12b	RB = inside	Old Cattle Excl.	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9398	Muddy	12c	RB = inside	Old Cattle Excl.	N/A	N/A
9395	Muddy	13a	Straight	Old Cattle Excl.	N/A	N/A
9598	Muddy	13b	Straight	Old Cattle Excl.	N/A	N/A
9398	Muddy	13c	Straight	Old Cattle Excl.	N/A	N/A
9395	Muddy	14a	RB = inside	Rip. Guidelines	N/A	N/A
9598	Muddy	14b	RB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	14c	RB = inside	Rip. Guidelines	N/A	N/A
9395	Muddy	15a	Straight	Rip. Guidelines	N/A	N/A
9598	Muddy	15b	Straight	Rip. Guidelines	N/A	N/A
9398	Muddy	15c	Straight	Rip. Guidelines	N/A	N/A
9395	Muddy	16a	Straight	Rip. Guidelines	N/A	N/A
9598	Muddy	16b	Straight	Rip. Guidelines	N/A	N/A
9398	Muddy	16c	Straight	Rip. Guidelines	N/A	N/A
9395	Muddy	17a	LB = inside	Rip. Guidelines	N/A	N/A
9598	Muddy	17b	LB = inside	Rip. Guidelines	N/A	N/A
9398	Muddy	17c	LB = inside	Rip. Guidelines	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9398	Muddy	18	Straight	Rip. Guidelines	N/A	N/A
9398	Muddy	19	RB = inside	Rip. Guidelines	N/A	N/A
9395	Muddy	22a	Straight	New Cattle Excl.	N/A	N/A
9598	Muddy	22b	Straight	New Cattle Excl.	N/A	N/A
9398	Muddy	22c	Straight	New Cattle Excl.	N/A	N/A
9395	Muddy	23a	Straight	New Cattle Excl.	N/A	N/A
9598	Muddy	23b	Straight	New Cattle Excl.	N/A	N/A
9398	Muddy	23c	Straight	New Cattle Excl.	N/A	N/A
9395	Muddy	24a	Straight	New Cattle Excl.	N/A	N/A
9598	Muddy	24b	Straight	New Cattle Excl.	N/A	N/A
9398	Muddy	24c	Straight	New Cattle Excl.	N/A	N/A
9598	Muddy	25	Straight	Old Cattle Excl.	N/A	N/A
9598	Muddy	26	Straight	Old Cattle Excl.	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9698	Muddy	30	Straight	Old Cattle Excl.	N/A	N/A
9698	Muddy	31d	RB = inside	Old Cattle Excl.	N/A	N/A
9698	Muddy	32	Straight	Old Cattle Excl.	N/A	N/A
9498	Price	2	RB = inside	Rip. Guidelines/Failing BD	13	Partially intact in 1994. Fully breaches between 1994 and 1998. Probably breached in 1995.
9497	Price	13a	RB = inside	New Elk Excl./Intact BD	5	Partially intact in 1994 survey. Repaired between 1994 and 1995
9798	Price	13b	RB = inside	New Elk Excl./Failing BD	5	Breaching by 1997, but still exerting strong influence in 1997 and 1998.
9498	Price	13c	RB = inside	New Elk Excl./Intact to Failing BD	5	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9497	Price	14a	Straight	New Elk Excl./Intact BD	15	Intact dam exists in 1994 about 15 m downstream of cross-section. Dam failed between the 1994 and 1997 surveys and was gone by 1997. Another built 36 m downstream of XS 14, below XS 15 post 1994 survey.
9798	Price	14b	Straight	New Elk Excl./Failing BD	36	Dam downstream of XS 15 begins breaching btwn 1997 and 1998. Still influencing sediment in 1997 and 1998.

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9498	Price	14c	Straight	New Elk Excl./Intact to Failing BD	36	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9497	Price	15a	Straight	New Elk Excl./Intact BD	6	Intact dam exists in 1997. Built between the 1994 and 1995 surveys.
9798	Price	15b	Straight	New Elk Excl./Failing BD	6	Dam breaching in 1997, but is still exerting an influence on the cross-section in the 1997 and 1998 surveys.
9498	Price	15c	Straight	New Elk Excl./Intact to Failing BD	6	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9498	Price	16	Straight	RG/BD influence	21	Intact, but inactive beaver dam located 21 meters downstream of XS in 1994. Partially breached by 1995. Fully breached by 1997. No remnant remained by the 1998 survey.
9495	Price	17a	Straight	Rip. Guidelines	N/A	Partially intact dam located 44 m downstream of the XS in 1994. Dam exerted minimal to no influence.
9597	Price	17d	Straight	Rip. Guidelines	N/A	N/A
9798	Price	17f	Straight	Rip. Guidelines	N/A	N/A
9497	Price	17b	Straight	Rip. Guidelines	N/A	N/A
9498	Price	17c	Straight	Rip. Guidelines	N/A	N/A
9598	Price	17e	Straight	Rip. Guidelines	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9495	Price	18a	Straight	Failing BD/Rip. Guidelines	14	Remnant dam exists in 1994, 14.2 m downstream of XS. Exerting influence on sediment.
9598	Price	18b	Straight	Rip. Guidelines	14	Remnant gone by 1995. No beaver dam influence post-1995.
9498	Price	18c	Straight	Failing BD/Riparian Guidelines	14	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	19a	Straight	New Cattle Excl./Intact BD	35	Intact dam exists in 1995, 35 m downstream of XS.
9798	Price	19b	Straight	New Cattle Excl./Failing BD	35	Begins failing pre-1997, but still exerts strong influence in 1997 and 1998 because downstream by 35 m so breach has
9598	Price	19c	Straight	New Cattle Excl./Intact to Failing BD	35	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	20a	RB = inside	New Cattle Excl./Intact BD	9	Intact dam exists in 1995, 9 m downstream of XS.
9798	Price	20b	RB = inside	New Cattle Excl./Failing BD	9	Begins breaching post-1997 survey.
9598	Price	20c	RB = inside	New Cattle Excl./Intact to Failing BD	9	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	21a	Straight	New Cattle Excl./Intact BD	12	Intact dam exists in 1995, 12 m downstream of XS.

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9798	Price	21b	Straight	New Cattle Excl./Failing BD	12	Begins breaching post-1997 survey. Still exerting influence in 1998.
9598	Price	21c	Straight	New Cattle Excl./Intact to Failing BD	12	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	22a	Straight	New Cattle Excl./Intact BD	16	Intact dam exists in 1995, 16 m downstream of XS.
9798	Price	22b	Straight	New Cattle Excl./Failing BD	16	Begins breaching post-1997 survey. Gone by 1998. No major change noted. Why?
9598	Price	22c	Straight	New Cattle Excl./Intact to Failing BD	16	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	23a	Straight	New Cattle Excl./Intact BD	15	Intact dam exists in 1995, 15 m downstream of XS.
9798	Price	23b	Straight	New Cattle Excl./Failing BD	15	Breaches post-1997 survey.
9598	Price	23c	Straight	New Cattle Excl./Intact to Failing BD	15	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	24a	Straight (at angle to stream)	New Cattle Excl./Failing BD	3	Dam exists in 1995, 3 m downstream of XS. Breaches post-1995 survey.

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9798	Price	24b	Straight (at angle to stream)	New Cattle Excl./Failing BD	3	Completely breached by 1998.
9598	Price	24c	Straight (at angle to stream)	New Cattle Excl./Failing BD	3	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	25a	Straight	New Cattle Excl./Intact BD	19	Intact dam in 1995, 19 m downstream of XS. Also submerged BD just below XS. Base level control only.
9798	Price	25b	Straight	New Cattle Excl./Failing BD	19	Breaches post-1997 survey and is gone by 1998.
9598	Price	25c	Straight	New Cattle Excl./Intact to Failing BD	19	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	26a	Straight	New Cattle Excl./Intact BD	27	Intact dam exists in 1995, 27m downstream of XS.
9798	Price	26b	Straight	New Cattle Excl./Failing BD	27	Begins breaching post-1997 survey. Still exerting some influence in 1998.
9598	Price	26c	Straight	New Cattle Excl./Intact to Failing BD	27	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	27a	LB = inside	New Cattle Excl./Intact BD	11	Intact dam exists in 1995, 11 m downstream of XS.

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9798	Price	27b	LB = inside	New Cattle Excl./Failing BD	11	Begins breaching post-1997 survey. Still exerting some influence in 1998.
9598	Price	27c	LB = inside	New Cattle Excl./Intact to Failing BD	11	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	28a	Straight	New Cattle Excl./Failing BD	22	Intact dam exists in 1995, 22 m downstream of XS. Begins breaching post-1995 survey.
9798	Price	28b	Straight	New Cattle Excl./Failing BD	22	Minimal response seen btwn 95/97 and 97/98. May be due to a base level control of a submerged BD just downstream.
9598	Price	28c	Straight	New Cattle Excl./Failing BD	22	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	29a	LB = inside	New Cattle Excl./Failing BD	3	Intact dam exists in 1995, 3 m downstream of XS. Begins breaching post-1995 survey.
9798	Price	29b	LB = inside	New Cattle Excl./Failing BD	3	Gone by 1998.
9598	Price	29c	LB = inside	New Cattle Excl./Failing BD	3	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9597	Price	30a	Straight	New Cattle Excl./Failing BD	3	Intact dam exists in 1995 survey, 3 m downstream of XS. Begins breaching post-1995 survey.

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9798	Price	30b	Straight	New Cattle Excl./Failing BD	3	Dam still exerting some influence in 1997, but largely as base-level control. Completely fails post-1997.
9598	Price	30c	Straight	New Cattle Excl./Failing BD	3	Shift in treatment occurs during study period due to beaver trapping. Dams no longer maintained.
9798	Price	33	Straight	New Elk Excl./Failing BD	22	XS controlled by dam 22 m downstream (XS 13 dam). Dam breaching by 1997 but still exerting influence 1998.
9498	W. Fk. Price	4	Straight	Rip. Guidelines	N/A	N/A
9498	W. Fk. Price	5	Straight	Rip. Guidelines	N/A	N/A
9498	W. Fk. Price	6	Straight	Rip. Guidelines	N/A	N/A
9498	W. Fk. Price	7	Straight	Rip. Guidelines	N/A	N/A
9597	W. Fk. Price	31	Straight	Rip. Guidelines	N/A	N/A
9597	W. Fk. Price	32a	Straight	Rip. Guidelines	N/A	N/A
9798	W. Fk. Price	32b	Straight	Rip. Guidelines	N/A	N/A
9598	W. Fk. Price	32c	Straight	Rip. Guidelines	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9497	Hayground	1	Straight	SEMA	N/A	N/A
9497	Hayground	2	Straight	SEMA	N/A	N/A
9497	Hayground	3	RB = inside	SEMA	N/A	N/A
9497	Hayground	4	RB = inside	New Elk Excl.	N/A	N/A
9497	Hayground	5	Straight	New Elk Excl.	N/A	N/A
9497	Hayground	6	Straight	New Elk Excl.	N/A	N/A
9497	Hayground	7	RB = inside	New Cattle Excl.	N/A	N/A
9497	Hayground	8	RB = inside	New Cattle Excl.	N/A	N/A
9497	Hayground	9	Straight	New Cattle Excl.	N/A	N/A
9497	Home	1	LB = inside	New Cattle Excl.	N/A	N/A
9497	Home	2	Straight	New Cattle Excl.	N/A	N/A
9497	Lower Burro	1	Straight	SEMA	N/A	N/A
9497	Lower Burro	2	Straight	SEMA	N/A	N/A
9497	Lower Burro	3	Straight	SEMA	N/A	N/A
9497	Lower Burro	4	RB = inside	SEMA	N/A	N/A
9497	Lower Burro	5	Straight	SEMA	N/A	N/A
9497	Lower Stinky	1	Straight	New Cattle Excl.	N/A	N/A

Comparison Years	Creek	XS	Channel Segment Type	Treatment[3]	Distance Upstream of Beaver Dam (m)	Dam Condition (m)
9497	Lower Stinky	2	Straight	New Cattle Excl.	N/A	N/A
9497	Lower Stinky	3	RB = inside	New Cattle Excl.	N/A	N/A
9497	Lower Stinky	4	LB = inside	New Cattle Excl.	N/A	N/A
9497	Lower Stinky	5	Straight	New Cattle Excl.	N/A	N/A
9497	Mandan	1	Straight	SEMA	N/A	N/A
9497	Mandan	2	Straight	SEMA	N/A	N/A
9497	Mandan	3	Straight	SEMA	N/A	N/A
9497	Mandan	4	RB = inside	SEMA	N/A	N/A
9497	Mandan	5	Straight	SEMA	N/A	N/A
9497	Mandan	6	Straight	SEMA	N/A	N/A

[1] Annual Rate of Change in Baseline XS Area. Negative value = decrease in XS area, Positive value = increase in XS area.
[2] Net Change in Baseline XS area. Negative value = decrease in XS area, Positive value = increase in XS area.
[3] BD = Beaver Dam

APPENDIX G

STATISTICAL AND GRAPHICAL COMPARISON OF REACH AND CROSS-SECTION HYDROLOGIC BANKFULL WIDTHS

Statistical Analysis of Reach "Hydrologic" Bankfull Width Values Lumped by Treatment within a Creek[1]

			REACH VALUES				XS VALUES			
Year	**Creek**	**Treatment**[2]	**Sample size**	**Median Bf Width (m)**	**Av. Bf Width (m)**	**St. Dev (m)**	**XS sample size**	**Median Bf Width (m)**	**Av. Bf Width (m)**	**St. Dev (m)**
1995	Basin	New EE	86	1.7	1.98	1.2	6	2.3	3	0.7
1995	Basin	New CE	56	3.1	3.3	1.2	5	3.3	2.9	1.7
1995	Basin	RG	290	2.4	2.6	1.2	14	2.1	2.1	0.9
1995	*Basin*	*all*	*432*	*2.3*	*2.5*	*1.3*	*25*	*2.3*	*2.5*	*1.1*
1993	Muddy	Old CE	101	2.8	3.6	2.6	4	2.6	2.7	1.3
1993	Muddy	New CE	103	1.1	1.2	0.7	2	1.4	1.4	1
1993	Muddy	RG	399	1.9	2	0.8	13	2.2	2.1	0.7
1993	*Muddy*	*all*	*603*	*1.8*	*2.1*	*1.6*	*19*	*2.2*	*2.1*	*0.9*
1994	Price	New EE/BD controlled[3]	50	2.2	2.3	0.6	2	2.88	2.88	0.87
1994	Price, West Fork	RG	100	1.2	1.3	0.5	4	1	1.1	0.6
1994	Price	RG/BD controlled[3]	50	2.8	2.84	0.81	no XS values	no data	no data	no data
1994	*Price*	*all*	*200*	*1.8*	*1.9*	*0.93*	*9*	*2.15*	*1.87*	*0.91*
1997	White Mts	New EE	50	2.6	2.7	0.7	2	2.15	2.15	
1997	White Mts	New CEs	177	1.7	1.76	0.38	9	2.5	2.4	0.7
1997	White Mts	SEMAs	327	2.5	2.8	1.1	14	3.2	3.6	1.8
1997	*White Mts*	*all*	*554*	***2.3***	***2.4***	***1***	*25*	*2.7*	*3.2*	*1.6*

Statistical Analysis of Reach "Hydrologic" Bankfull Width Values Lumped by Treatment[1]

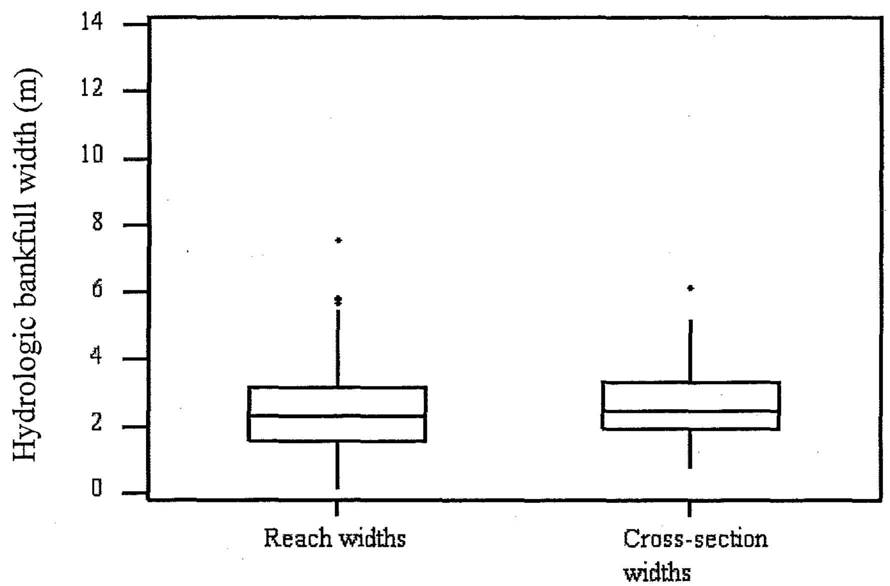
			REACH VALUES					XS VALUES			
	Creek	**Treatment**[2]	**Sample size**	**Median Bf Width (m)**	**Av. Bf Width (m)**	**St. Dev (m)**		**XS sample size**	**Median Bf Width (m)**	**Av. Bf Width (m)**	**St. Dev (m)**
	Muddy	Old CEs	101	2.8	3.6	2.6		4	2.6	2.69	1.28
	Basin, Muddy, White Mts	New CEs	336	1.65	1.84	1		16	2.4	2.44	1.17
	Basin, White Mts	New EEs	136	2.3	2.3	1.1		8	3.24	3.28	1.23
	Basin, Muddy, Price	RGs	790	1.8	2.1	1.04		31	2.05	1.96	0.82
	White Mts	SEMAs	327	2.5	2.8	1.1		14	3.16	3.55	1.78
	Price	BD controlled	100	2.48	2.55	0.77		5	2.26	2.5	0.56

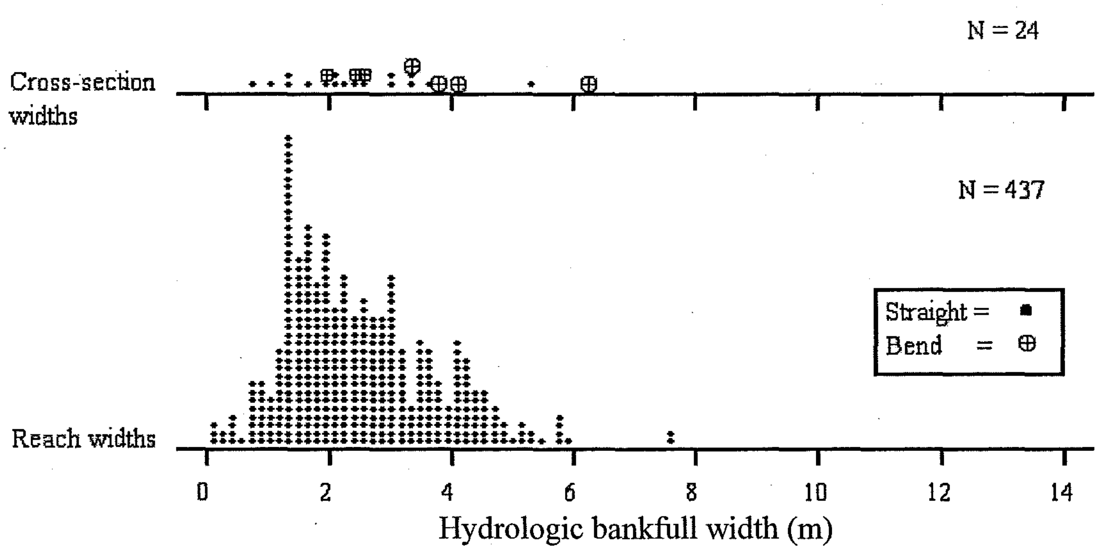
1 The hydrologic significance of the "hydrologic" bankfull reach and cross-section widths is uncertain. The streams are continuing to be altered by livestock grazing and channel aggradation and incision and have therefore not stabilized. However, the features used to select the widths were the same for the cross-section and reach measurements and are, therefore, comparable.

2 Old CE = Old Cattle Exclosure, New CE = New Cattle Exclosure, New EE = New Elk Exclosure, RG = Riparian Guidelines, SEMA = Special Emphasis Management Area

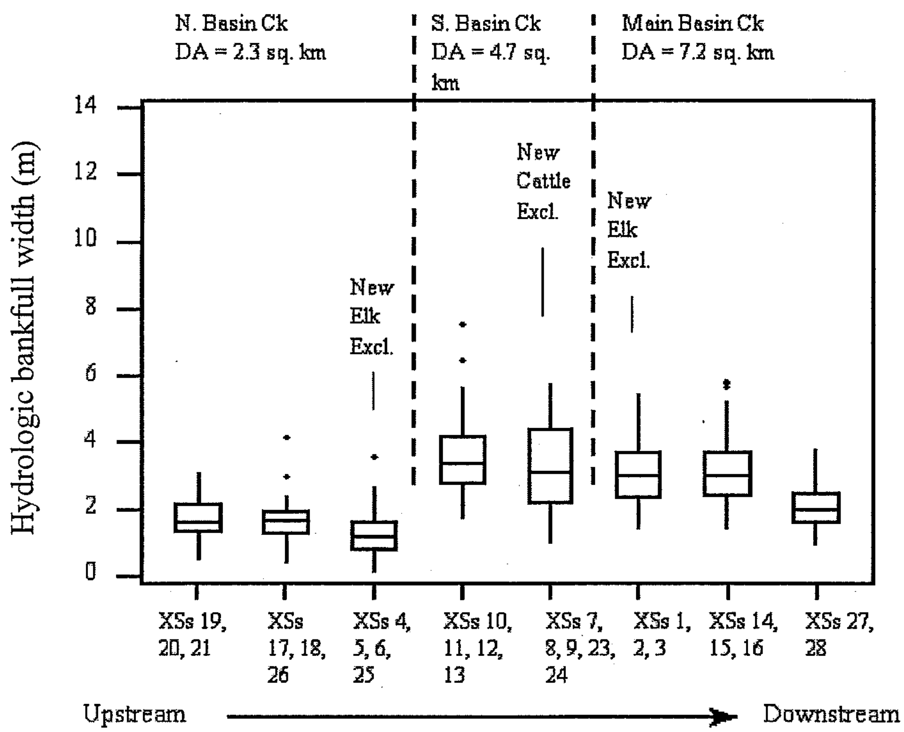
3 Dams were old and had failed in this reach at the time of the 1994 survey.

1995 Basin Creek summary comparison of reach and cross-section widths and distributions.

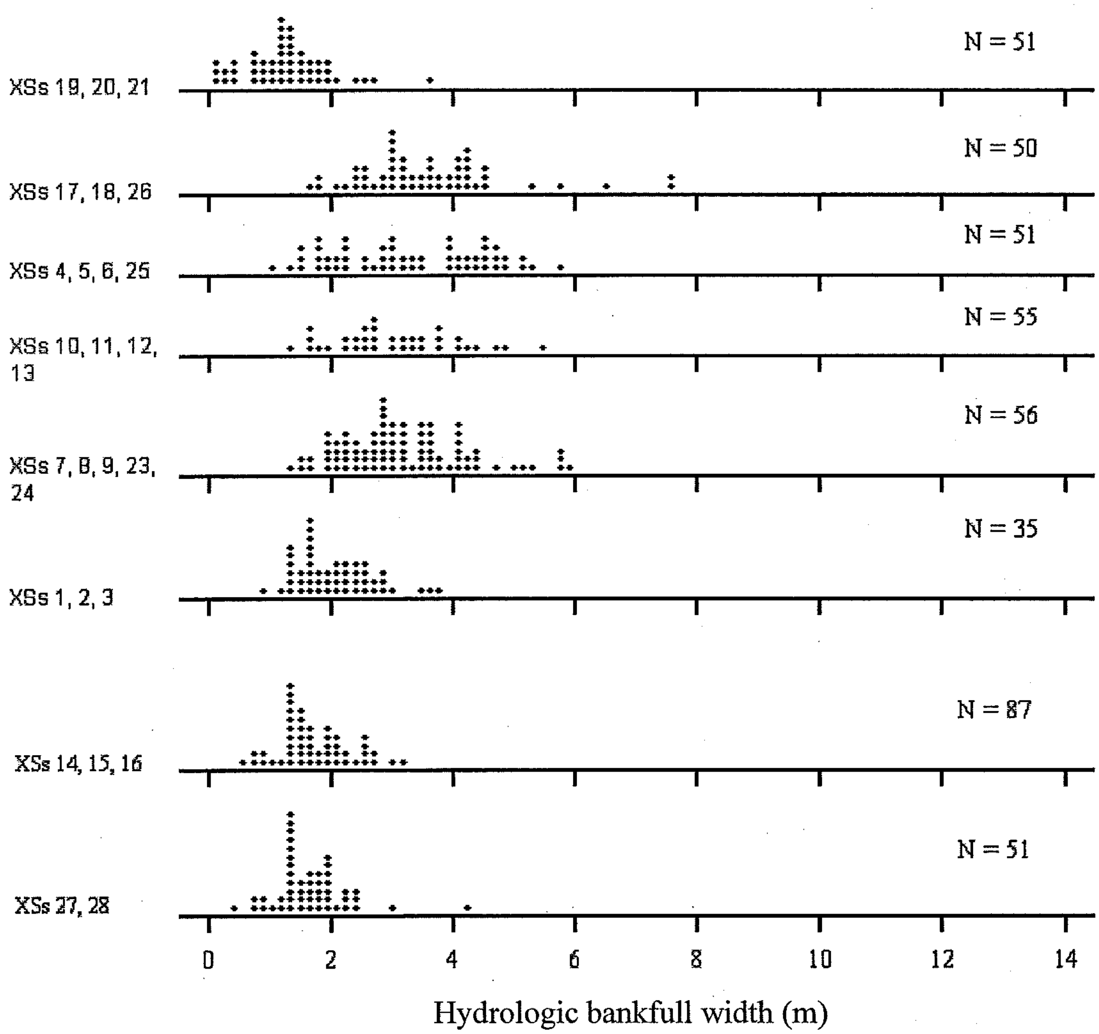




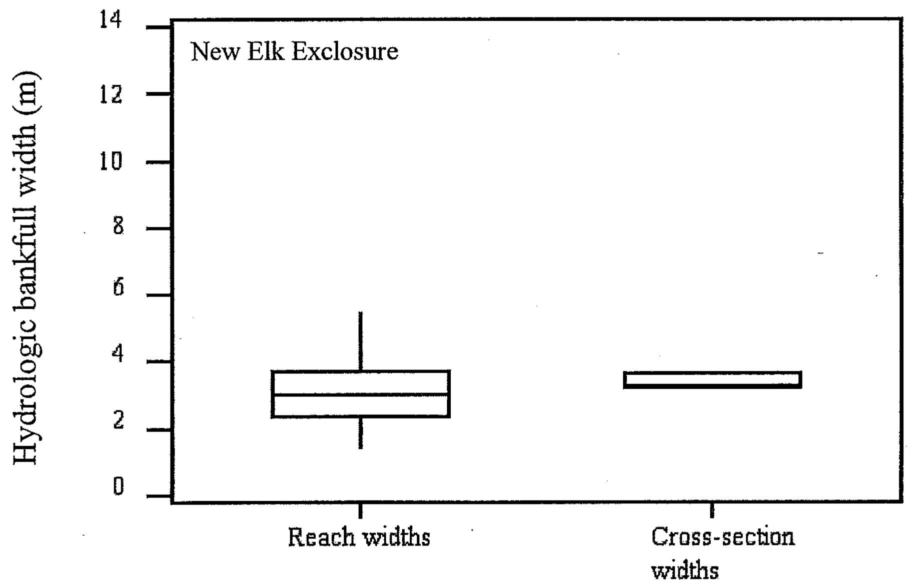
1995 Basin Creek reach comparison of bankfull widths and distributions. Treatment = Riparian Guidelines unless otherwise noted.

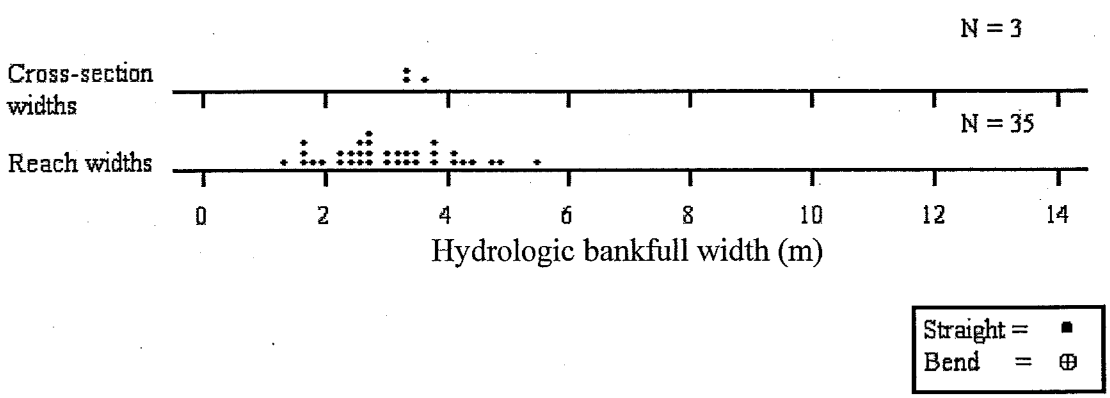


1995 Basin Creek reach comparisons of bankfull widths and distributions.

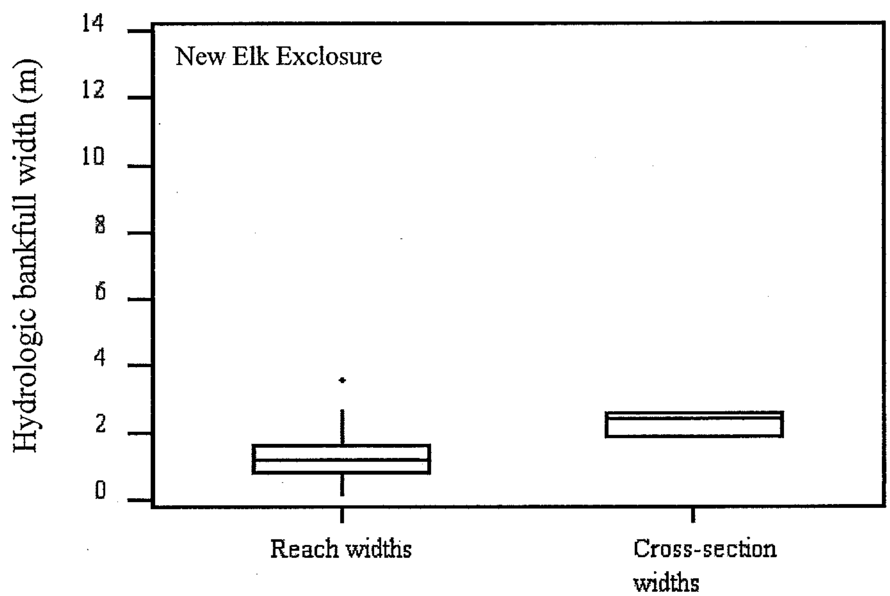


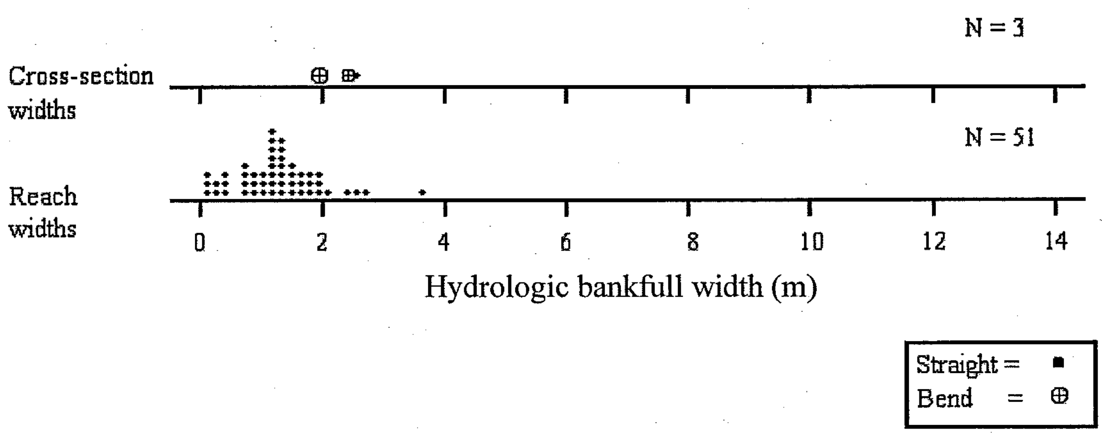
1995 Basin Creek reach containing cross-sections 1, 2, and 3.



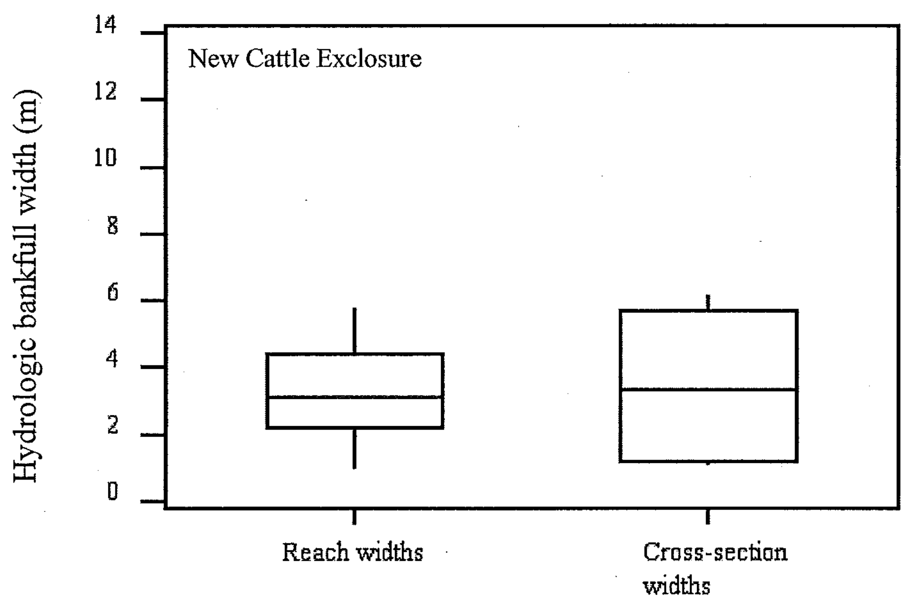


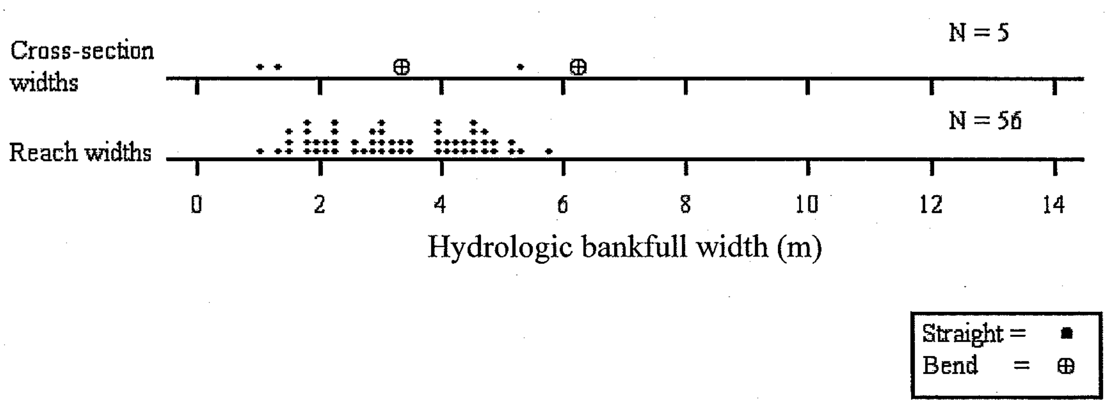
1995 Basin Creek reach containing cross-sections 4, 5, 6, and 25.



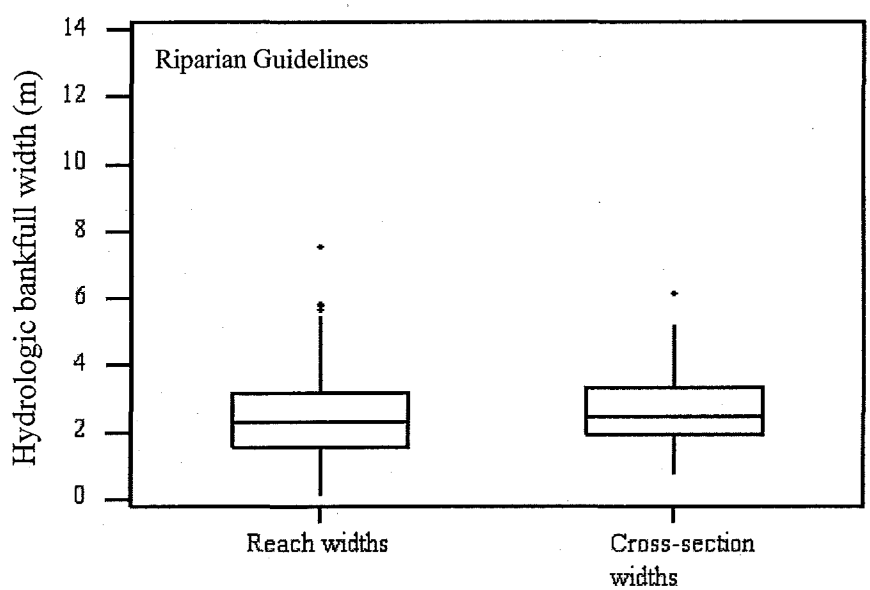


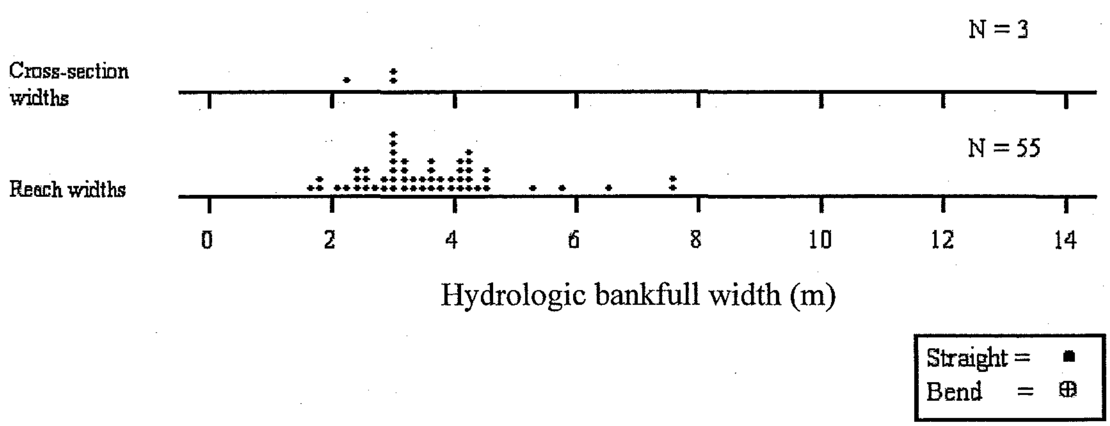
1995 Basin Creek reach containing cross-sections 7, 8, 9, 23, and 24.



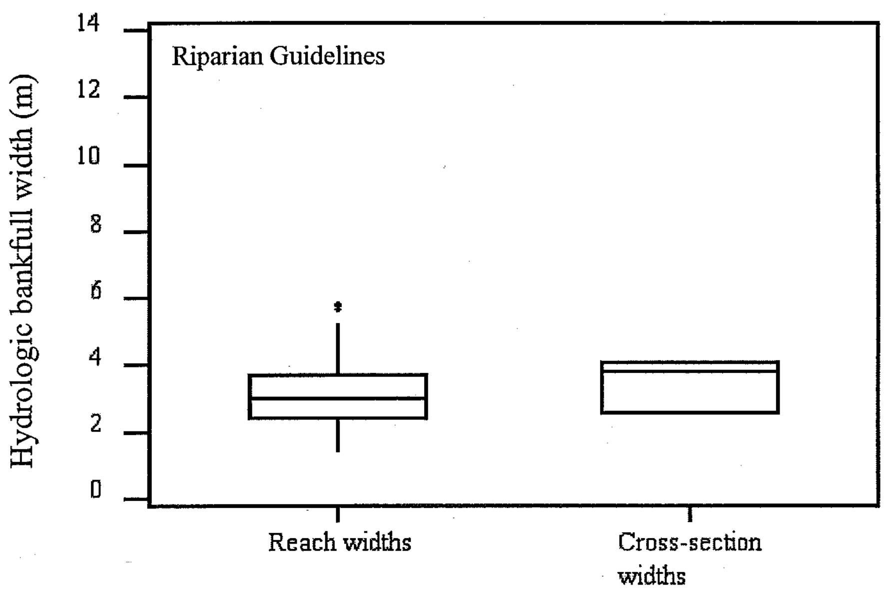


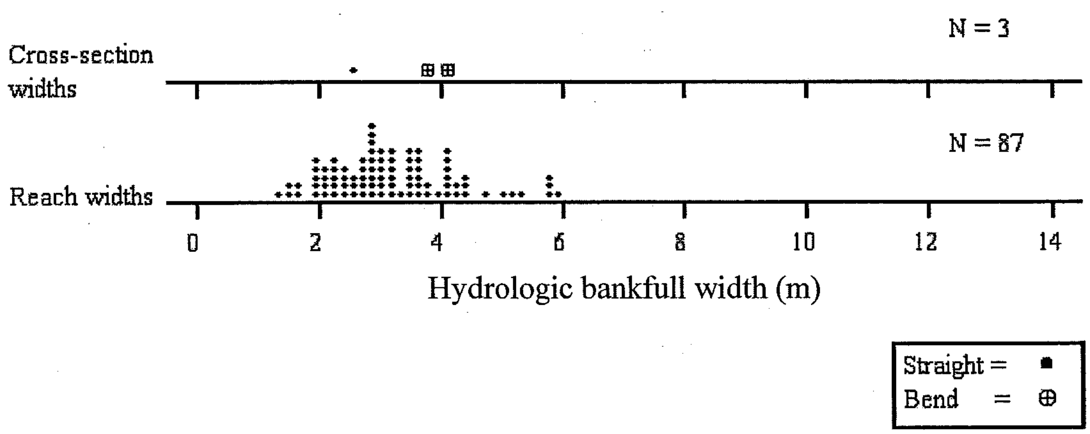
1995 Basin Creek reach containing cross-section 10, 11, 12, and 13.



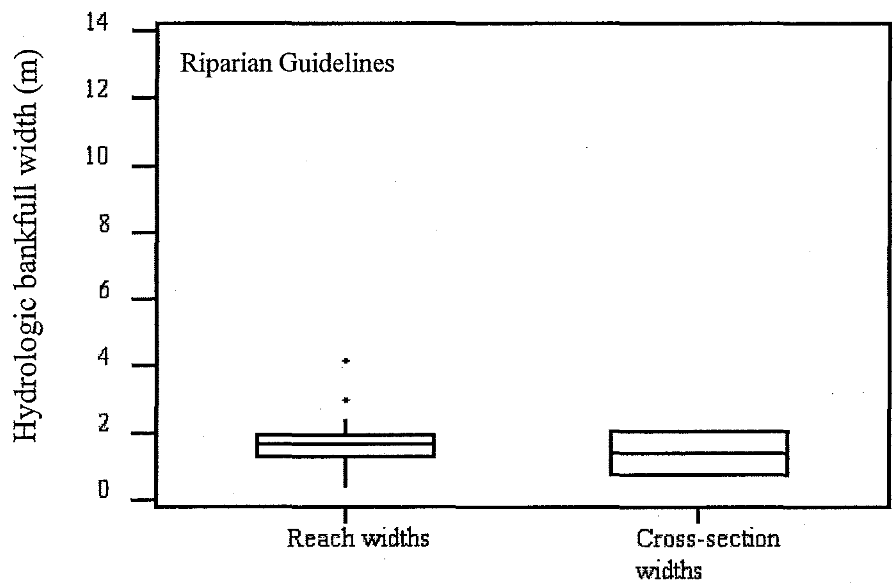


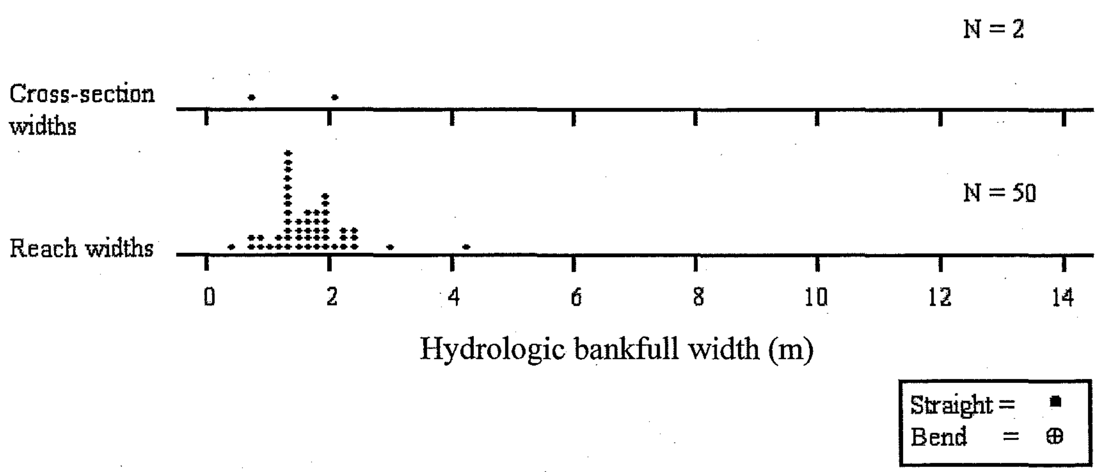
1995 Basin Creek reach containing cross-sections 14, 15, and 16.



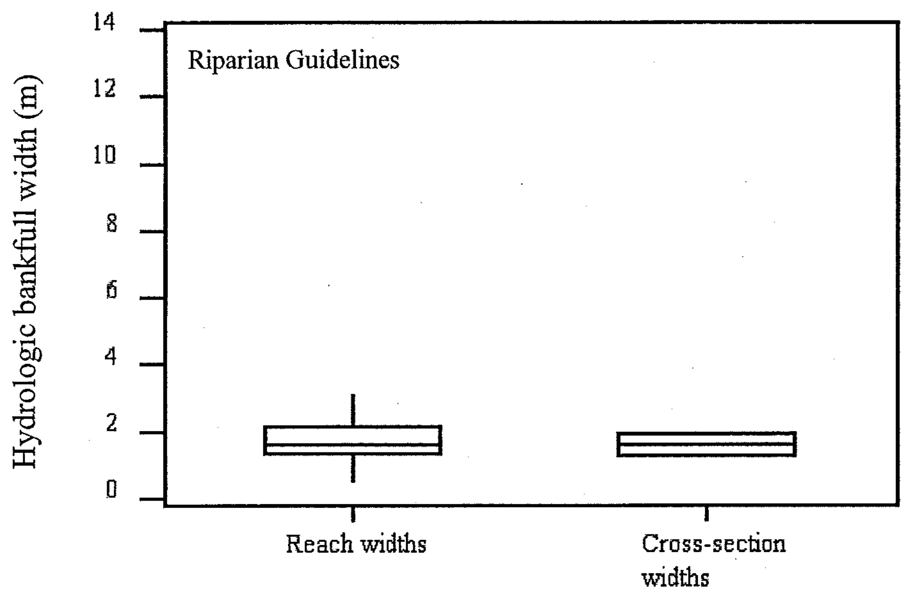


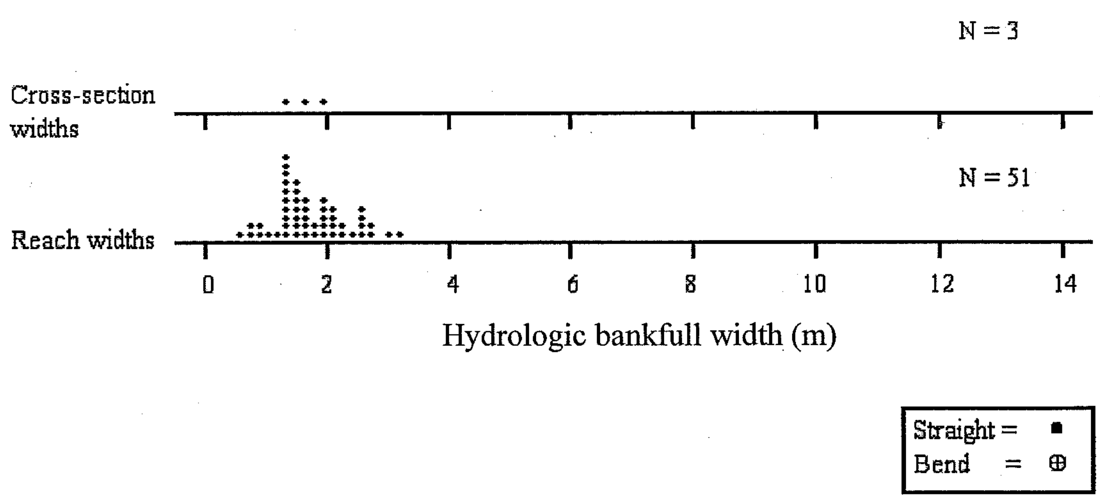
1995 Basin Creek reach containing cross-sections 17, 18, and 26.



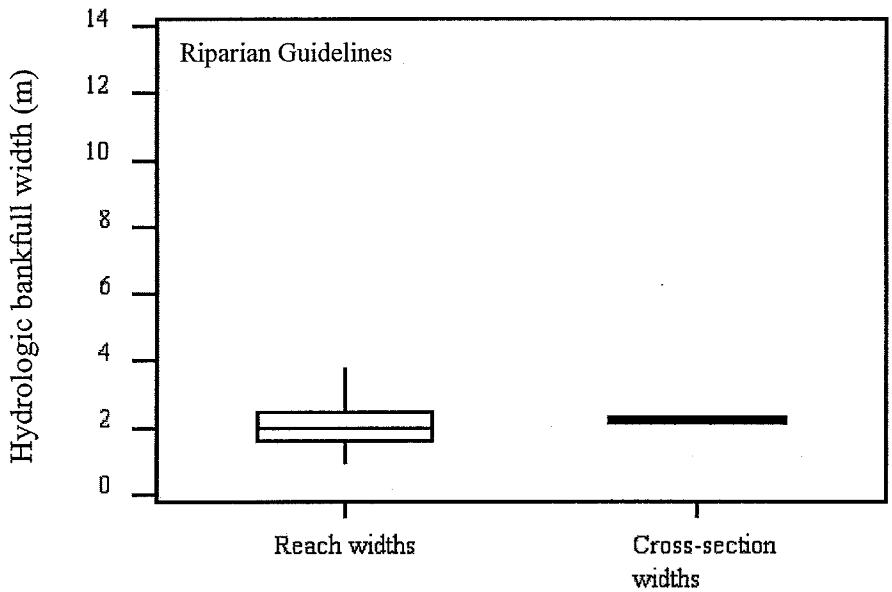


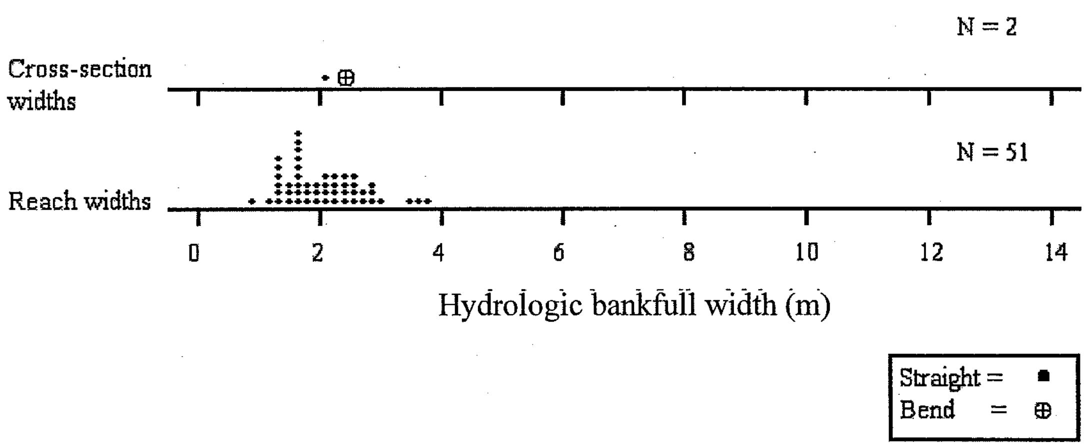
1995 Basin Creek reach containing cross-sections 19, 20, and 21.



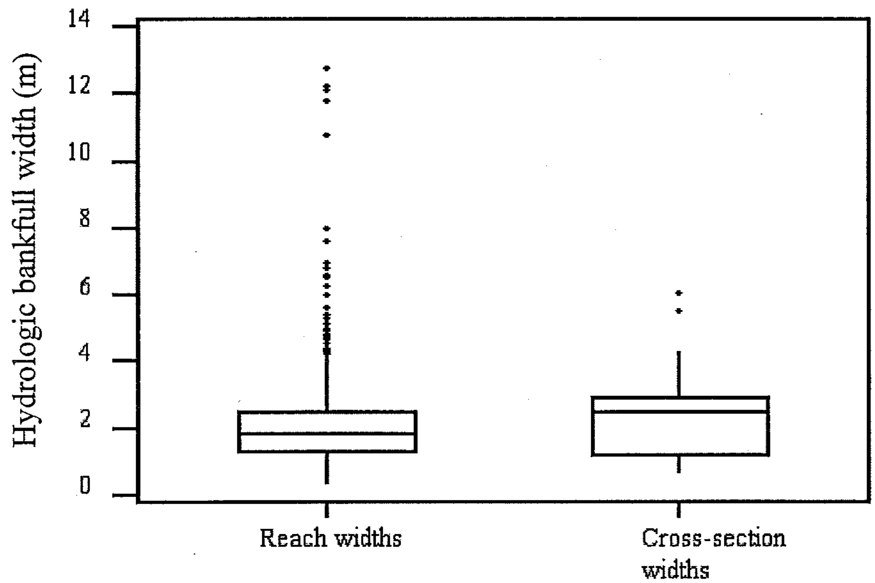


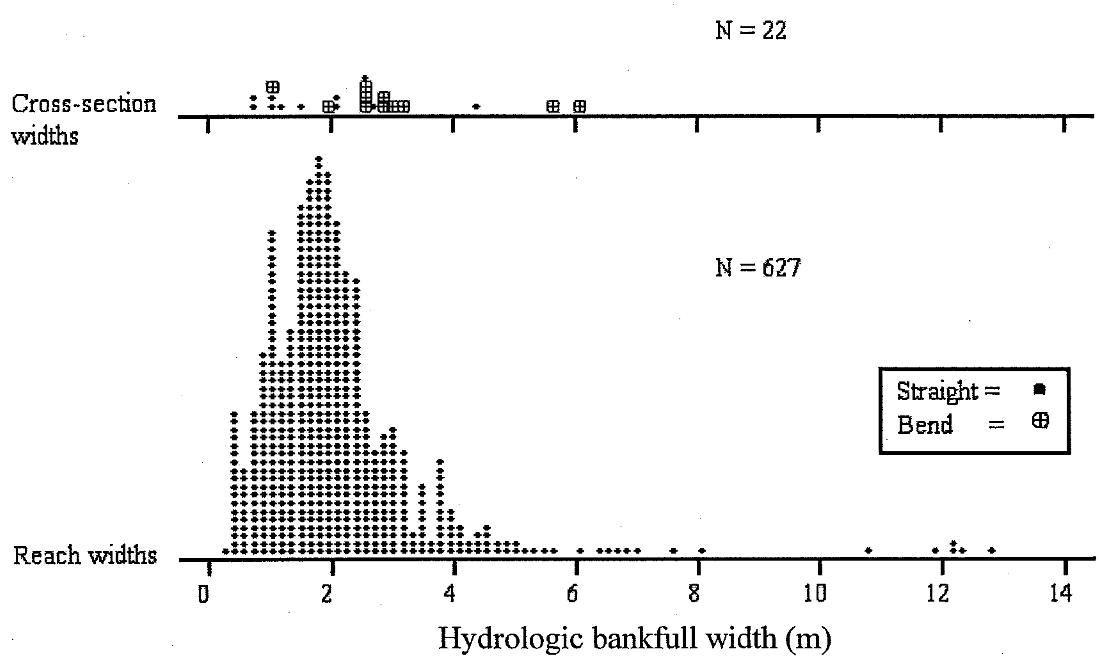
1995 Basin Creek reach containing cross-sections 27 and 28.



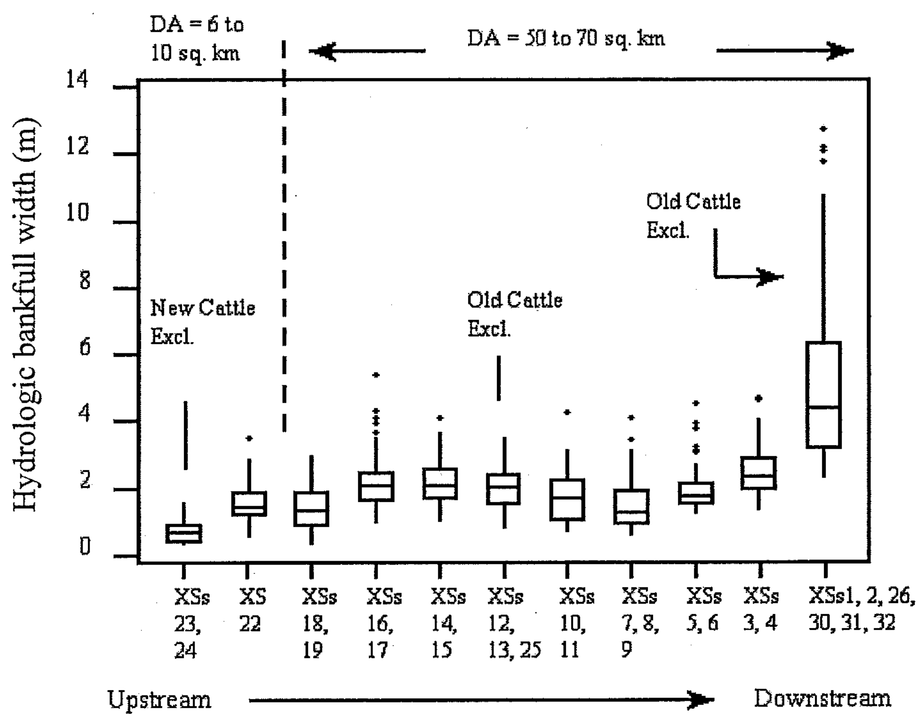


1993 Muddy Creek summary comparison of reach and cross-section widths and distributions.

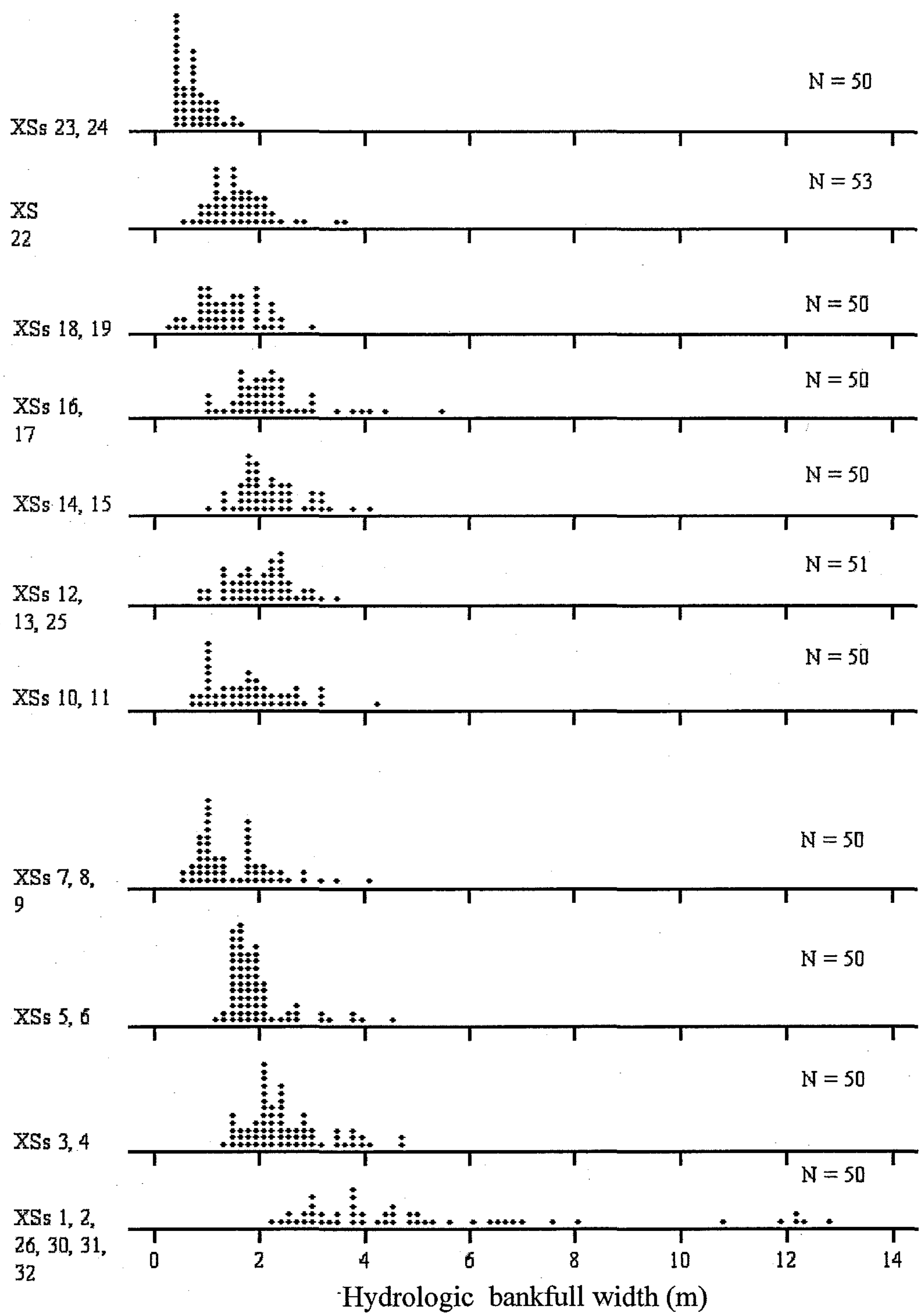




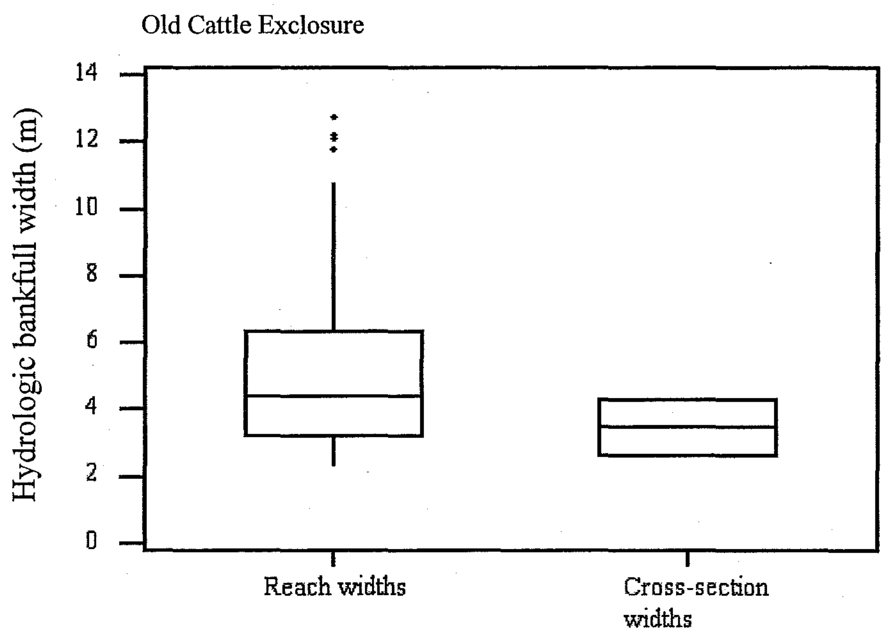
1993 Muddy Creek reach comparison of bankfull widths and distributions. Treatment = Riparian Guidelines unless otherwise noted.

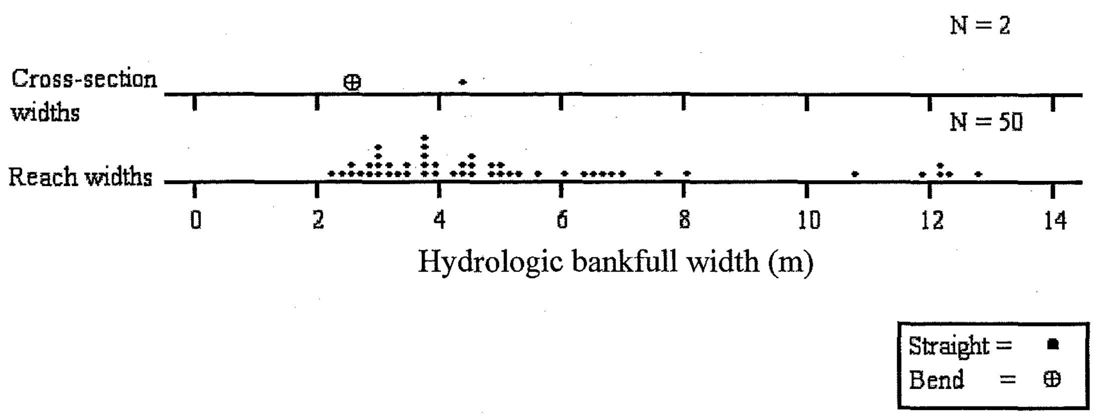


1993 Muddy Creek reach comparison of bankfull widths and distributions.

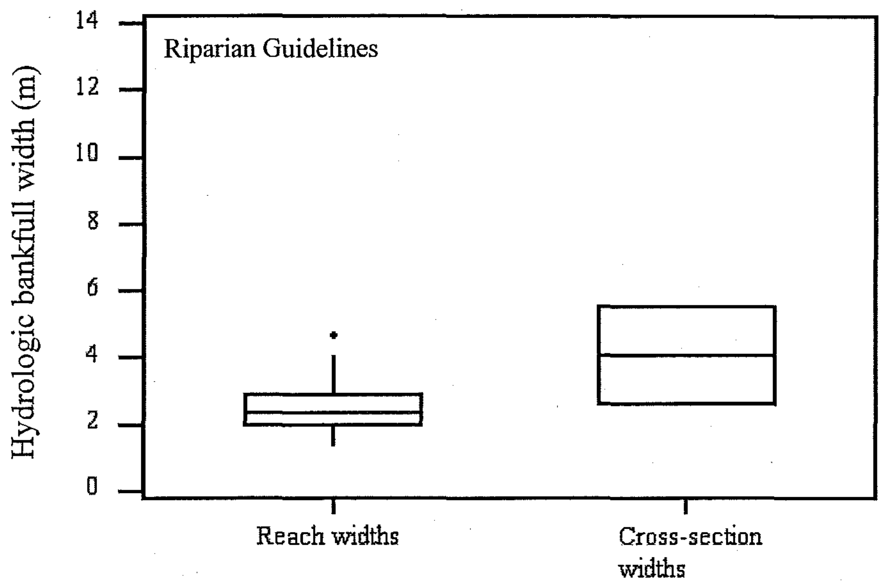


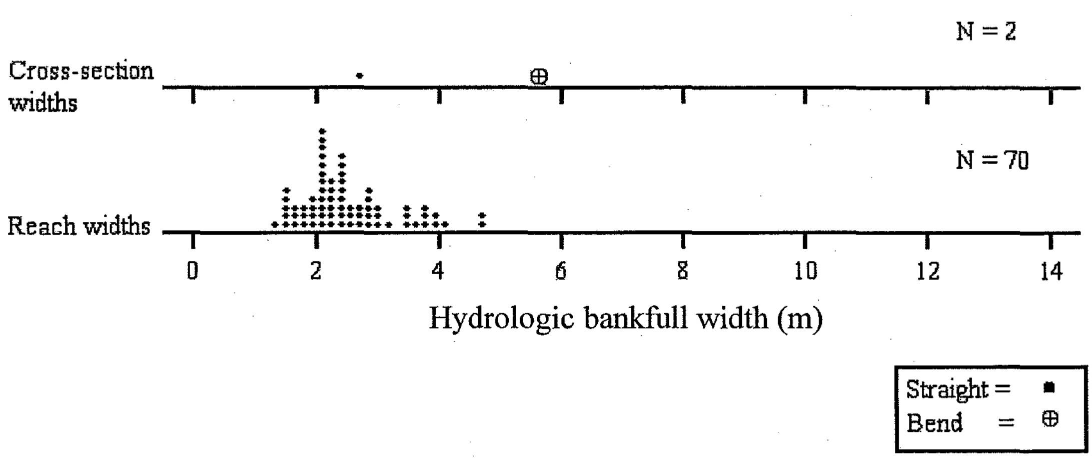
1993 Muddy Creek reach containing cross-sections 1, 2, 26, 30, 31, 32.



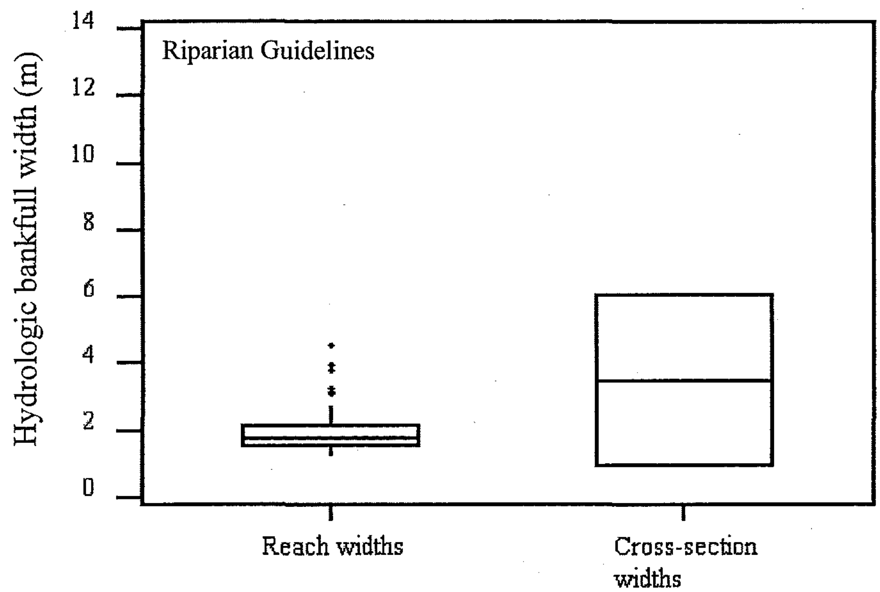


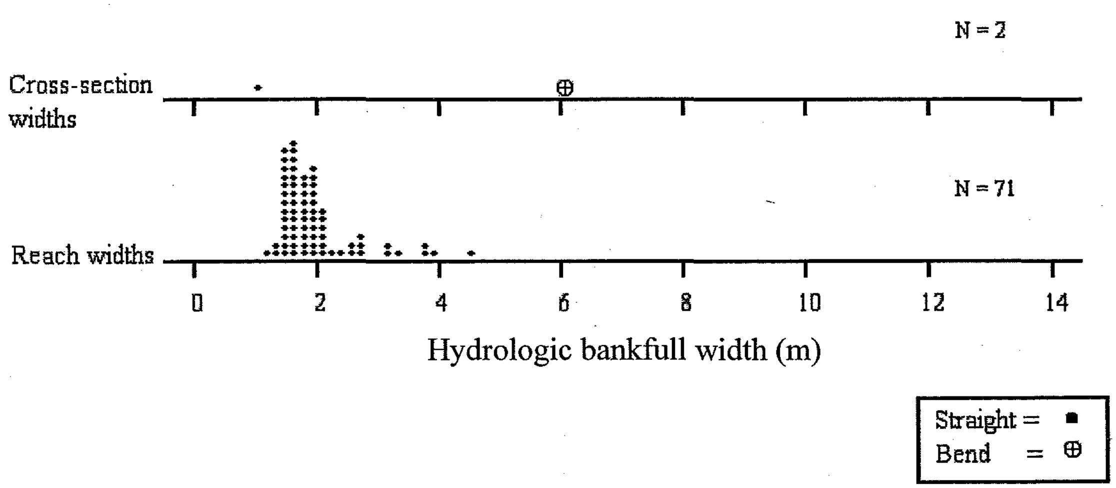
1993 Muddy Creek reach containing cross-sections 3 and 4.



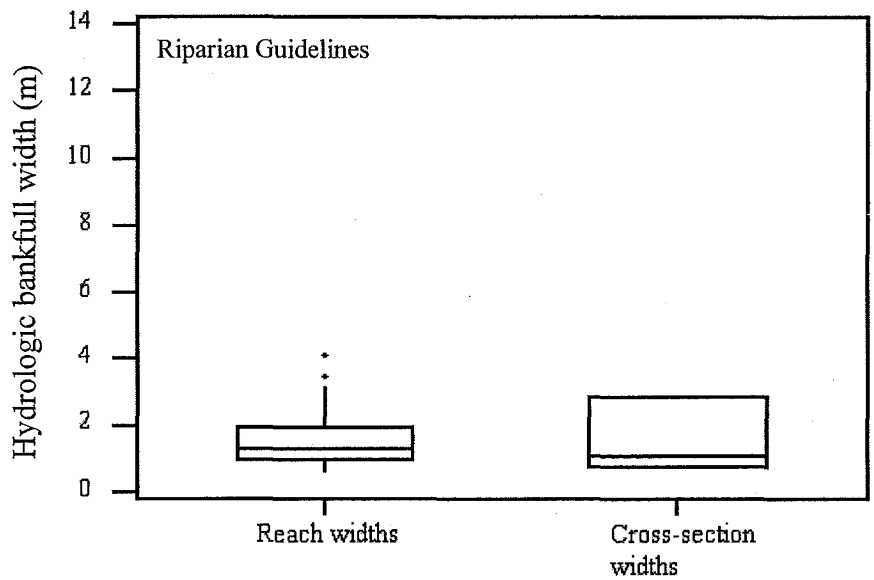


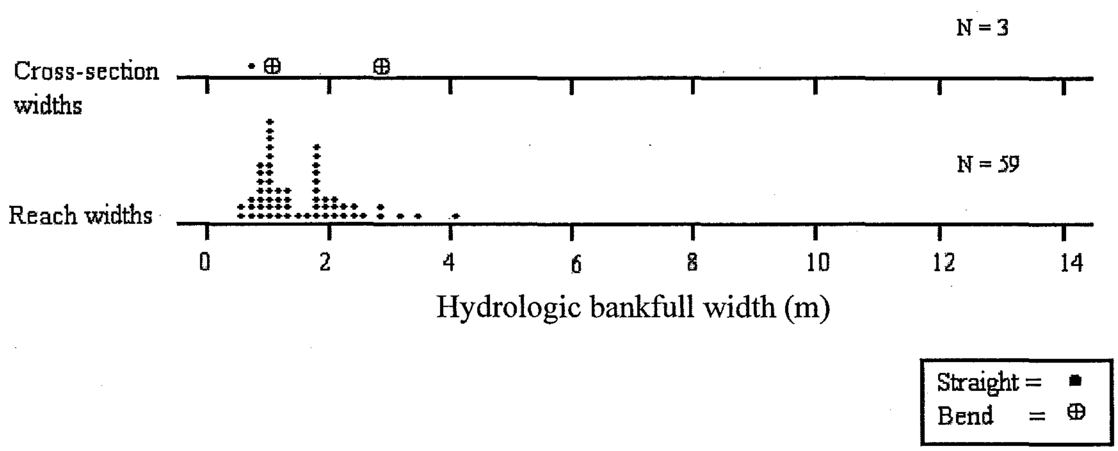
1993 Muddy Creek reach containing cross-sections 5 and 6.



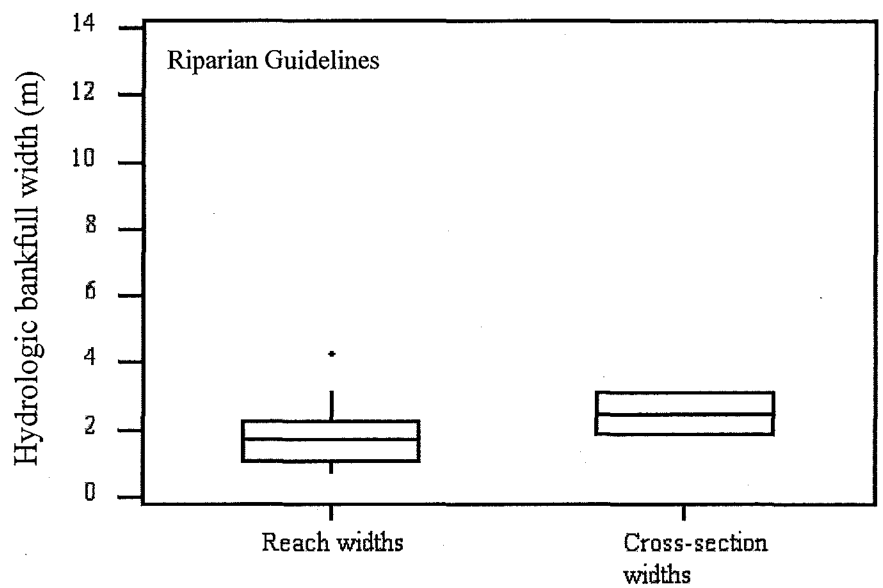


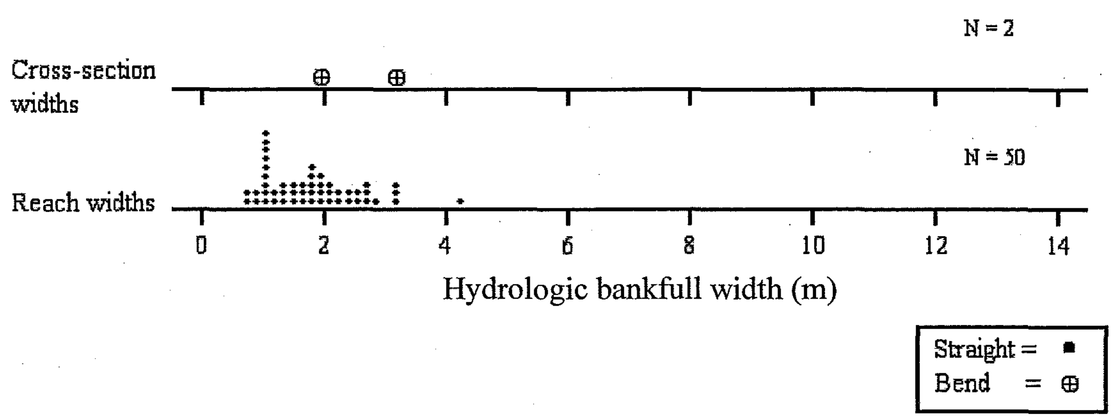
1993 Muddy Creek reach containing cross-sections 7, 8, and 9.



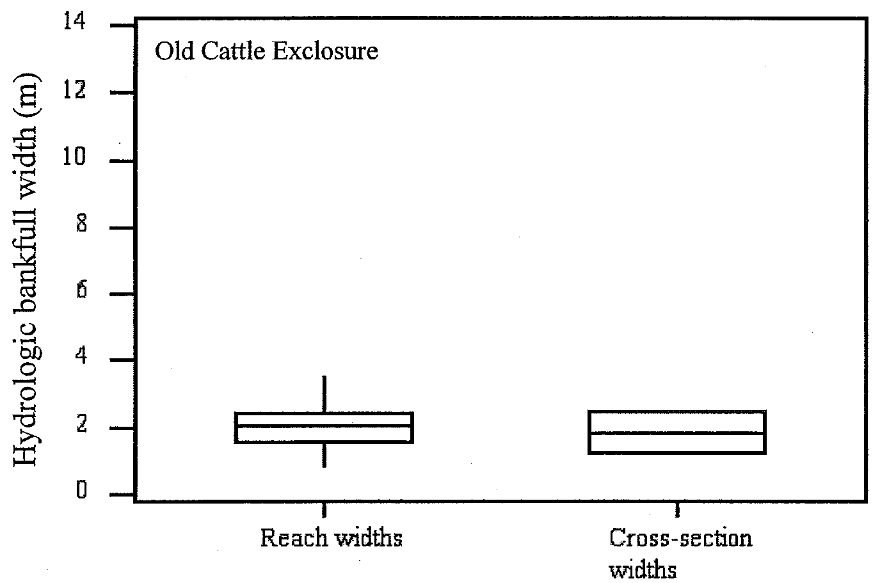


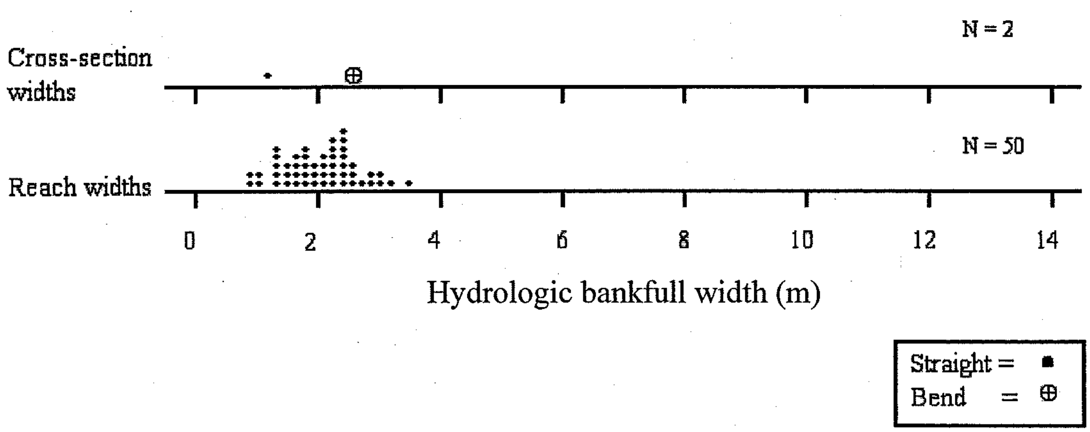
1993 Muddy Creek reach containing cross-sections 10 and 11.



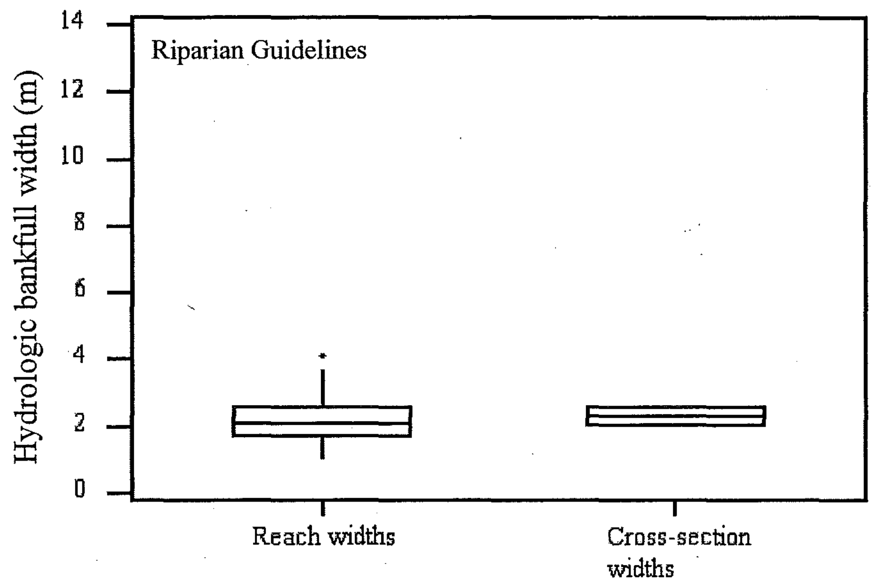


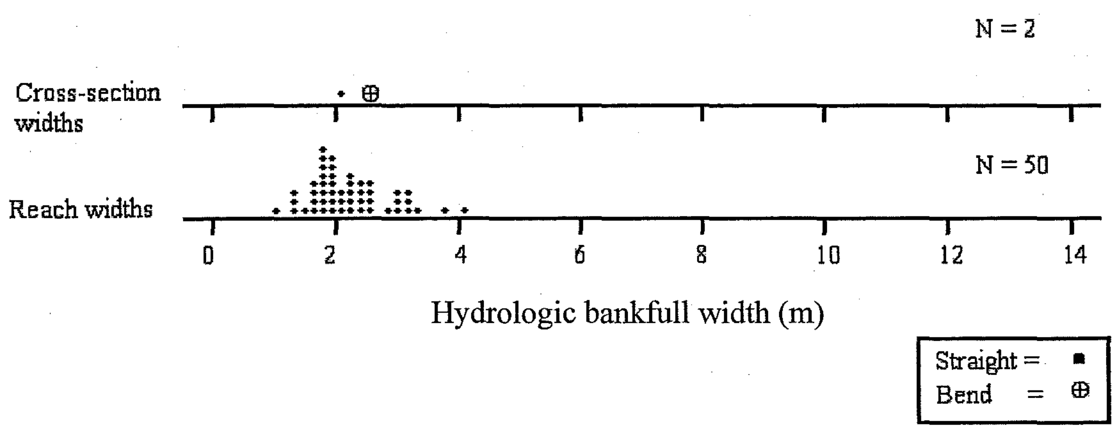
1993 Muddy Creek reach containing cross-sections 12, 13, and 25.



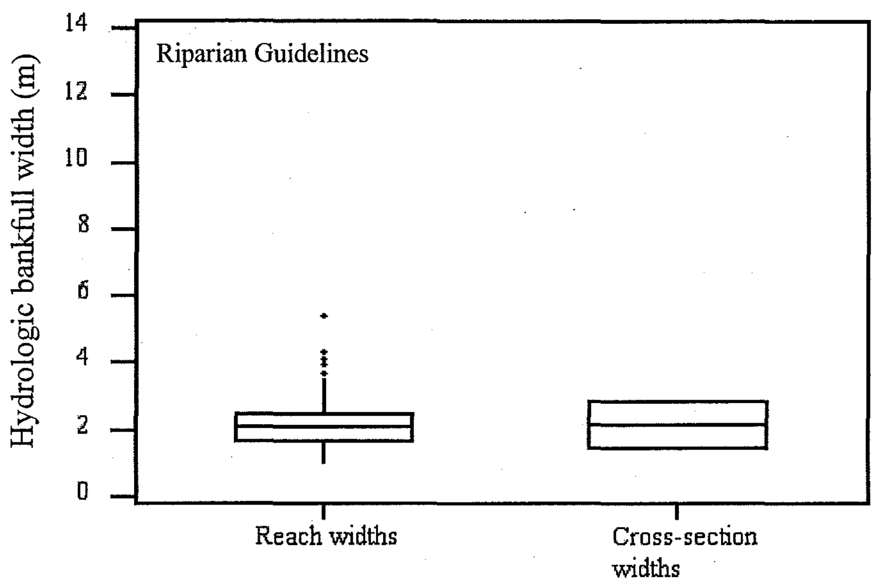


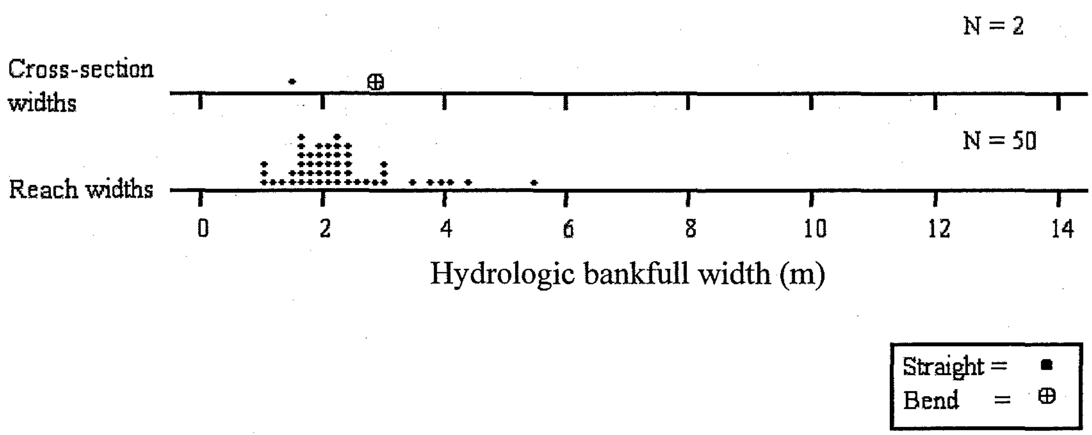
1993 Muddy Creek reach containing cross-sections 14 and 15.



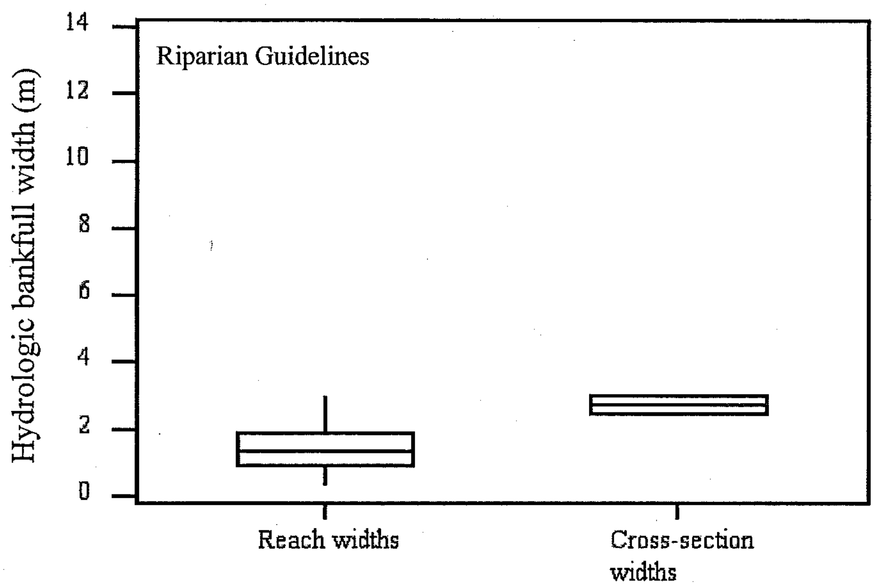


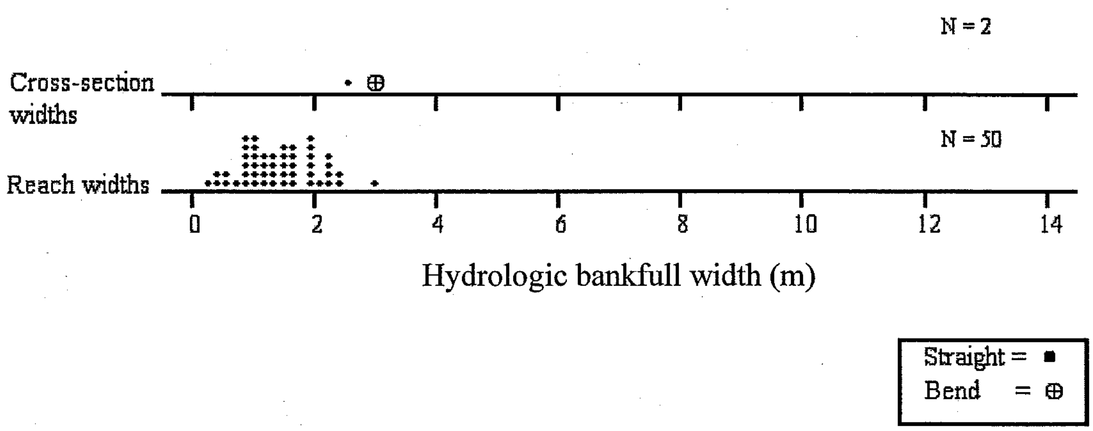
1993 Muddy Creek reach containing cross-sections 16 and 17.



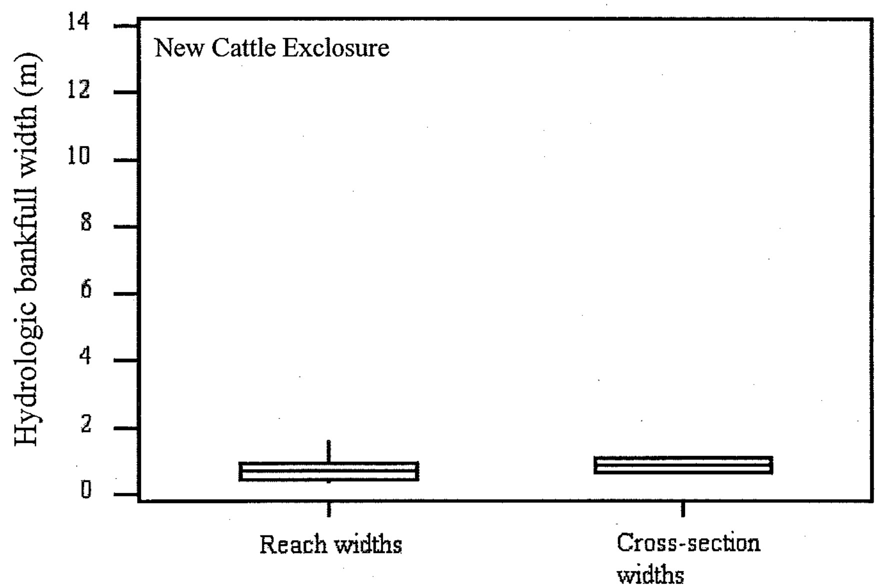


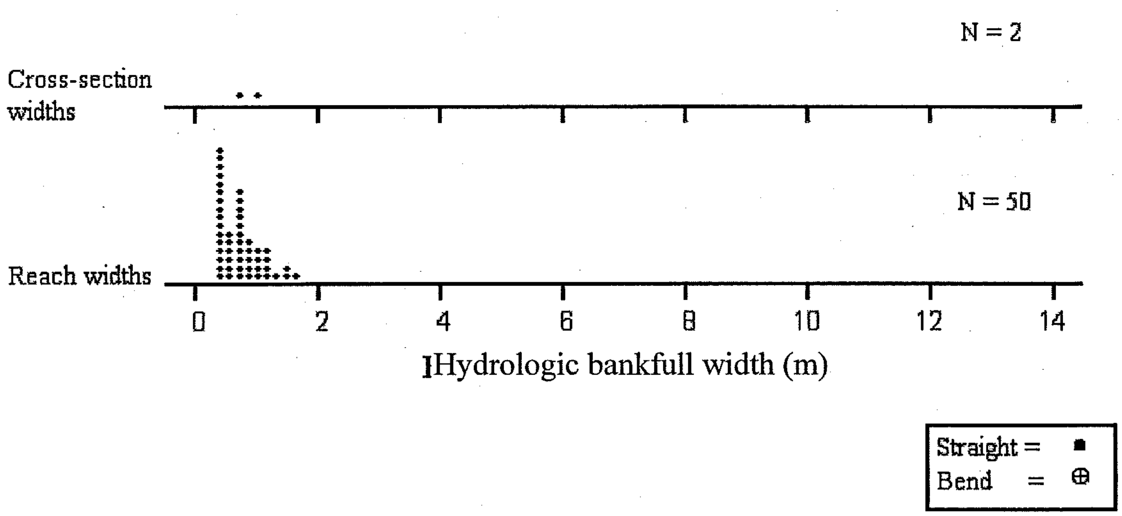
1993 Muddy Creek reach containing cross-sections 18 and 19.



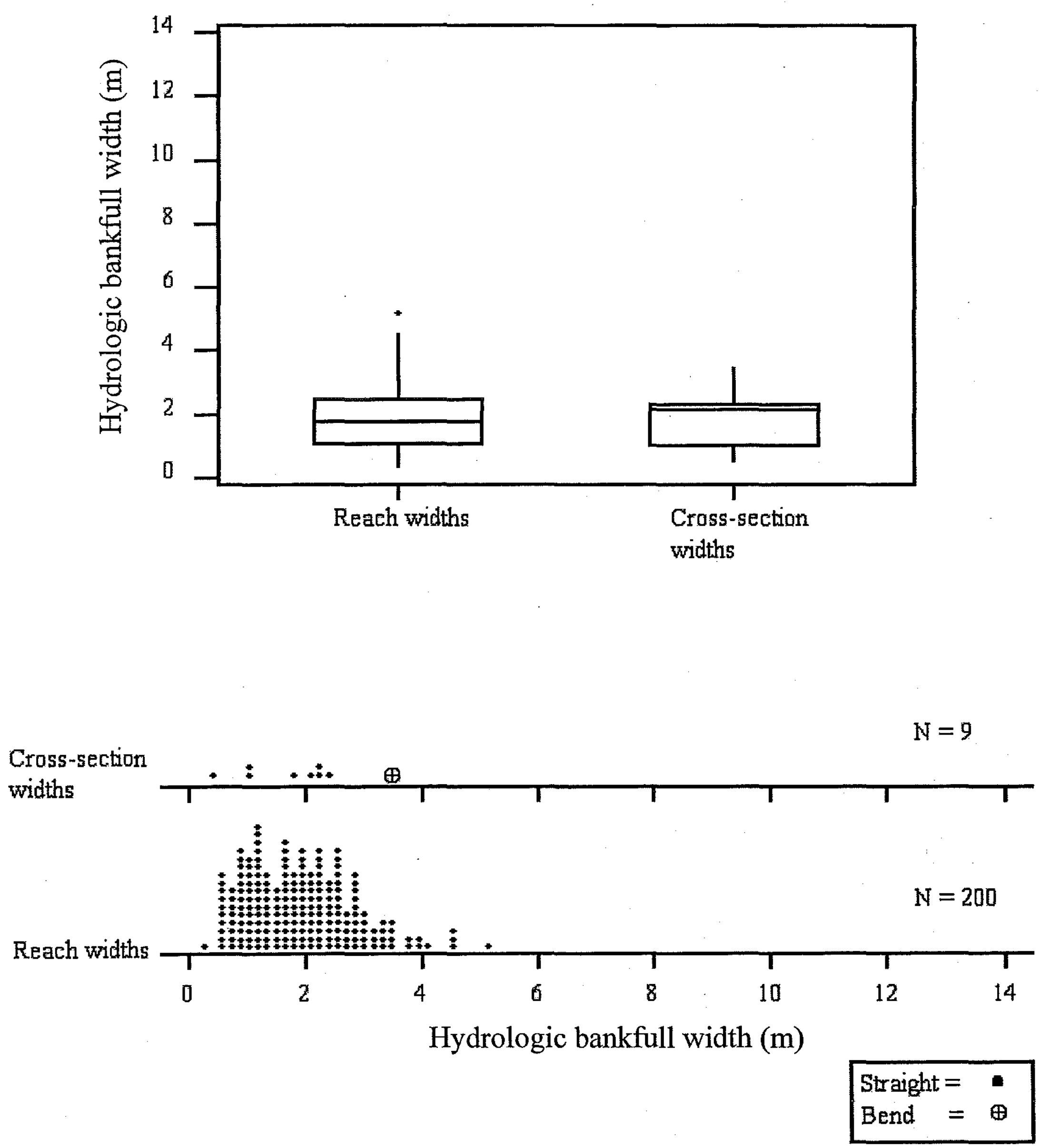


1993 Muddy Creek reach containing cross-sections 23 and 24.

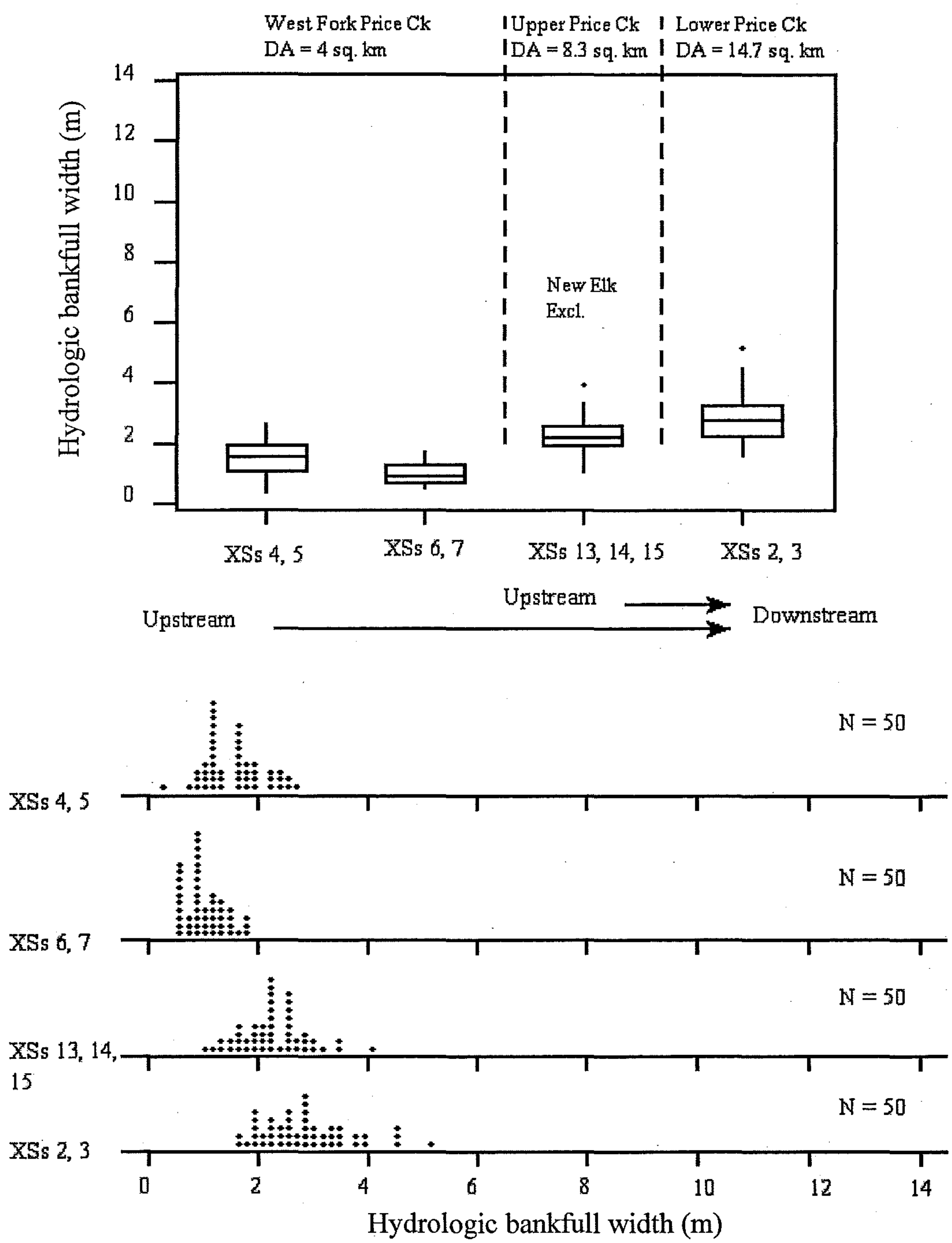




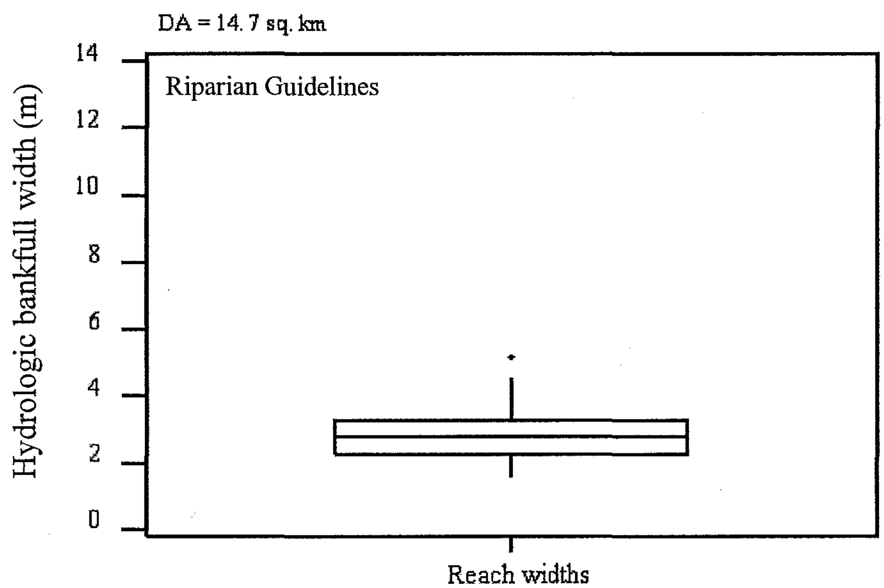
1994 Price Creek summary comparison of reach and cross-section widths and distributions.

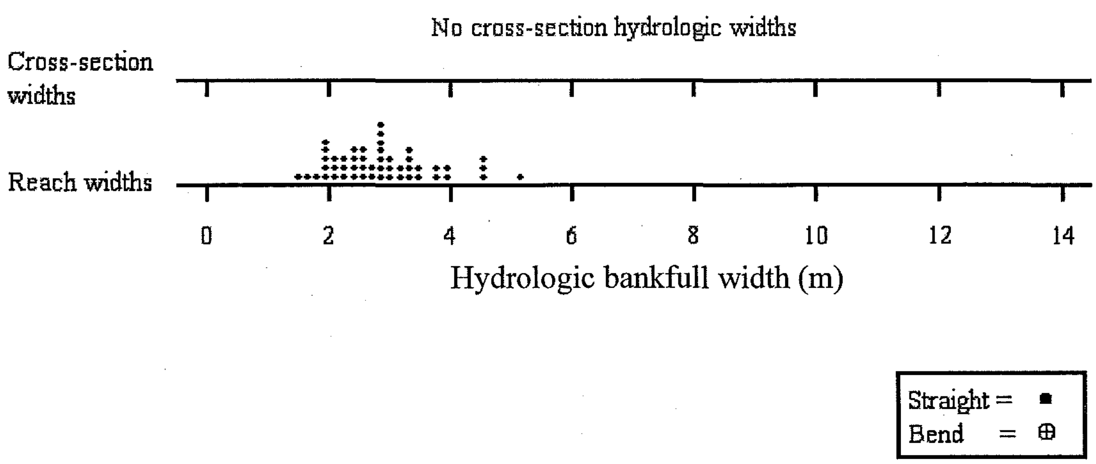


1994 Price Creek reach comparison of bankfull widths and distributions. Treatment = Riparian Guidelines unless otherwise noted.

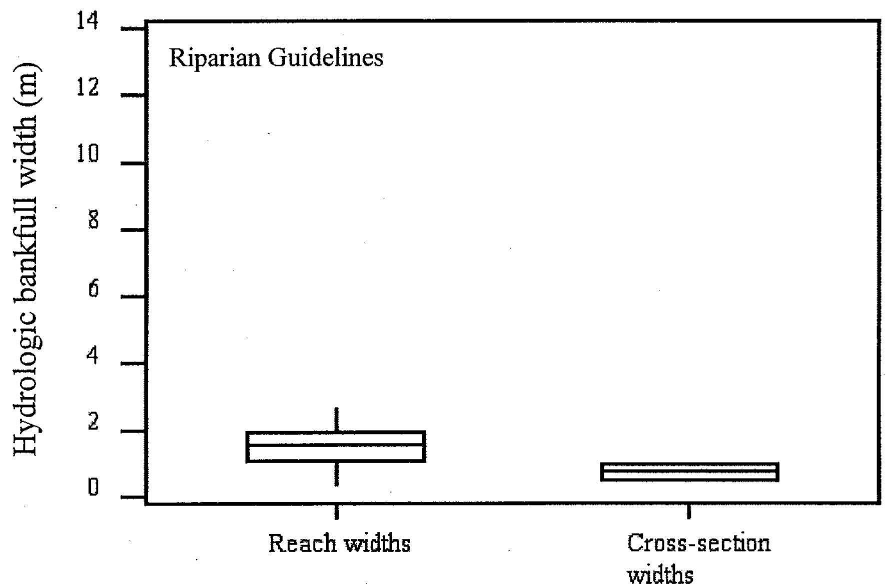


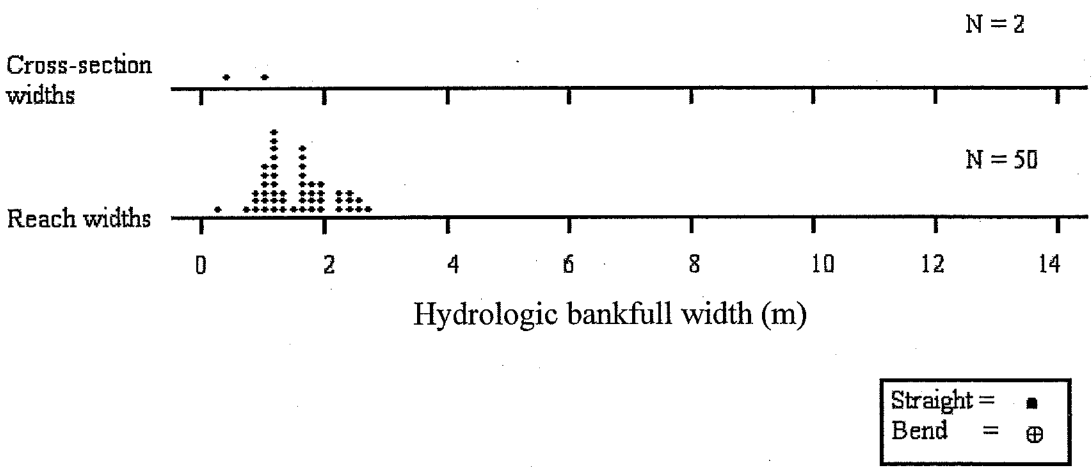
1994 Price Creek reach containing cross-sections 2 and 3.



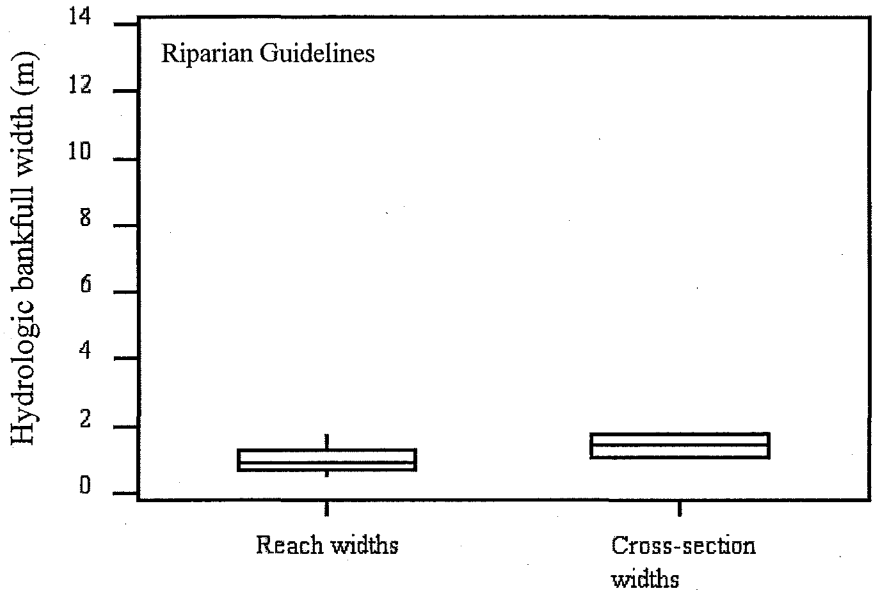


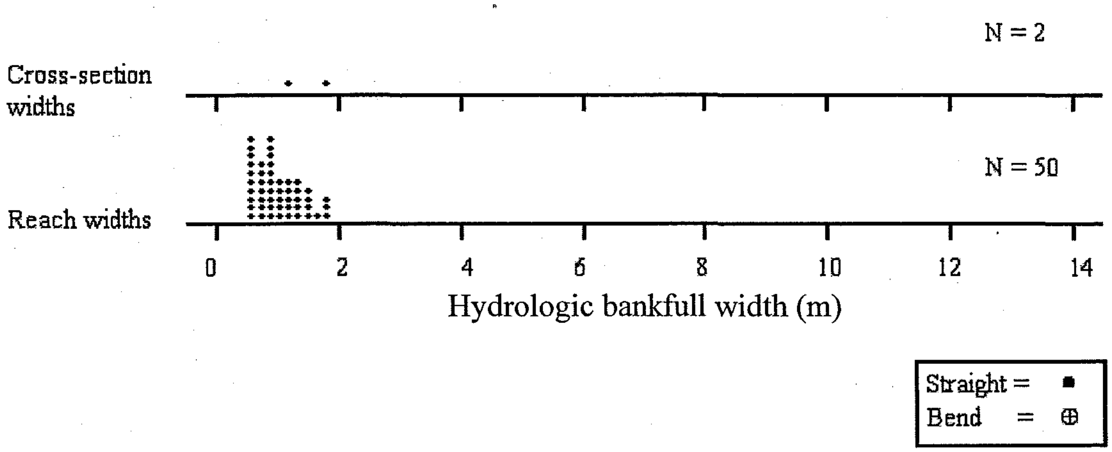
1994 Price Creek reach containing cross-sections 4 and 5.



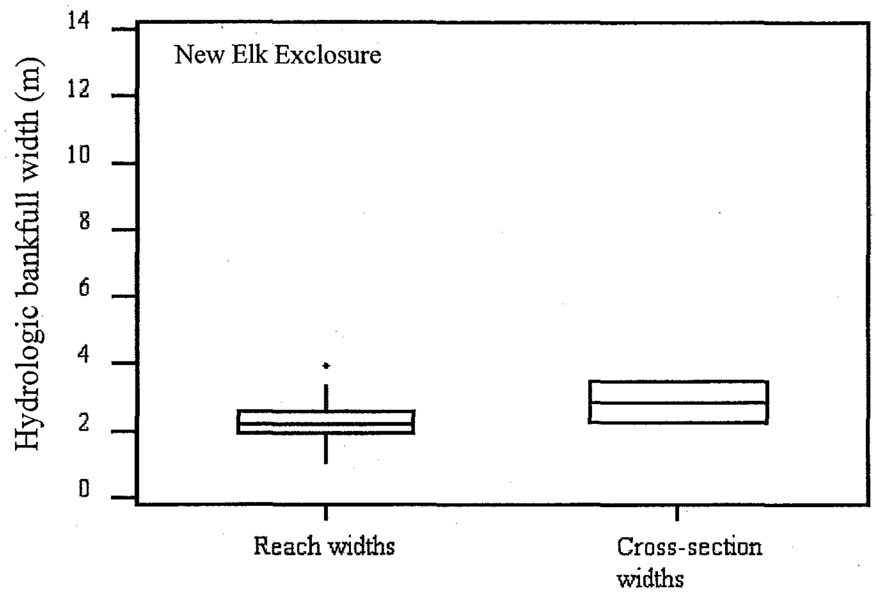


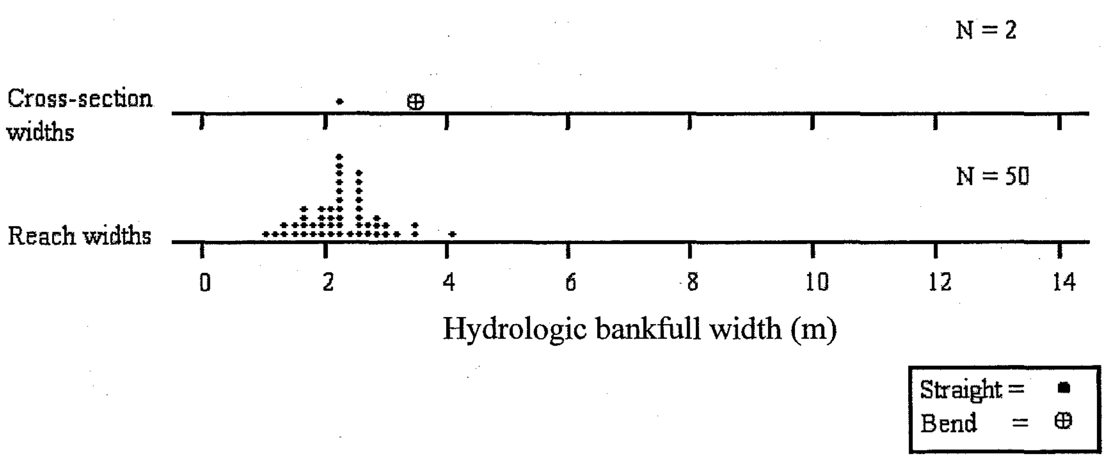
1994 Price Creek reach containing cross-sections 6 and 7.



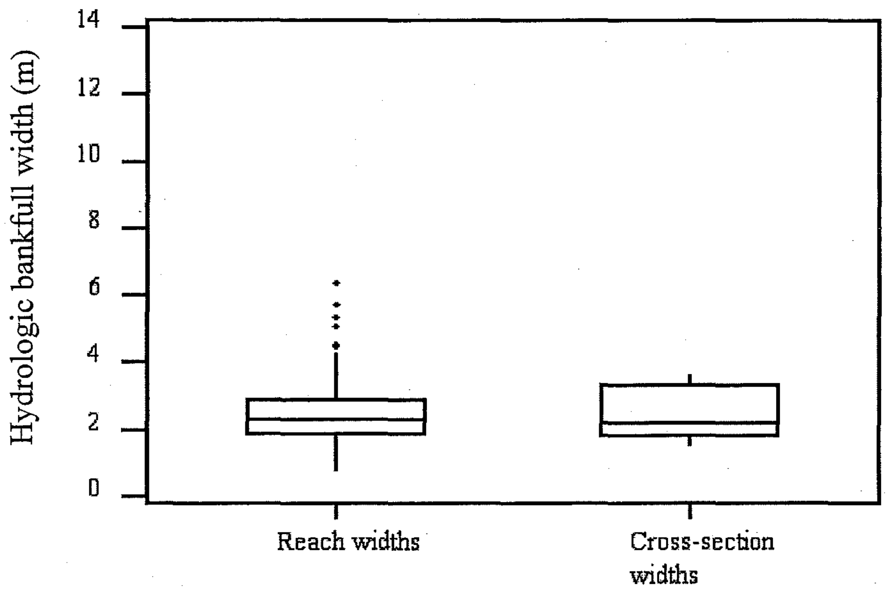


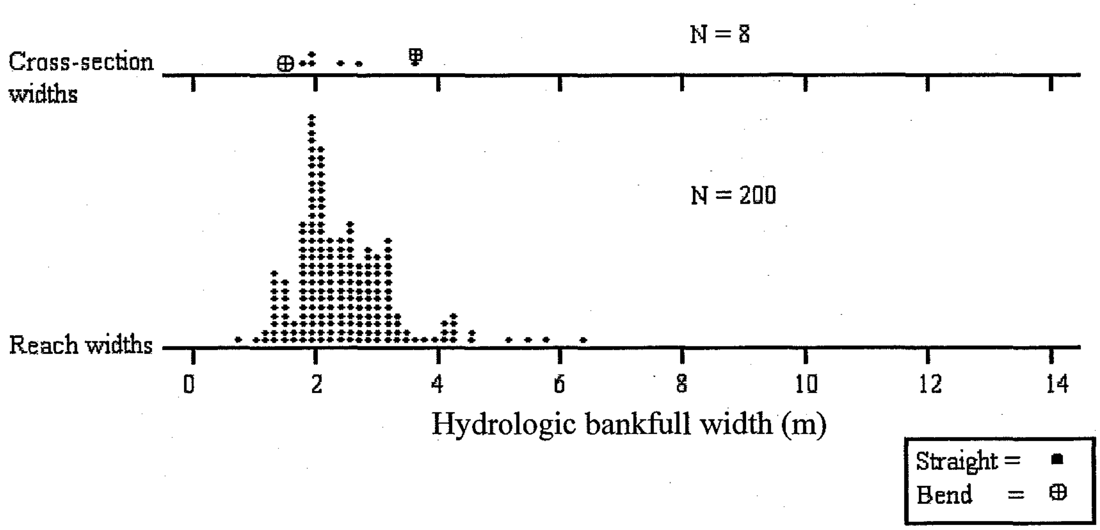
1994 Price Creek reach containing cross-sections 13, 14, and 15.



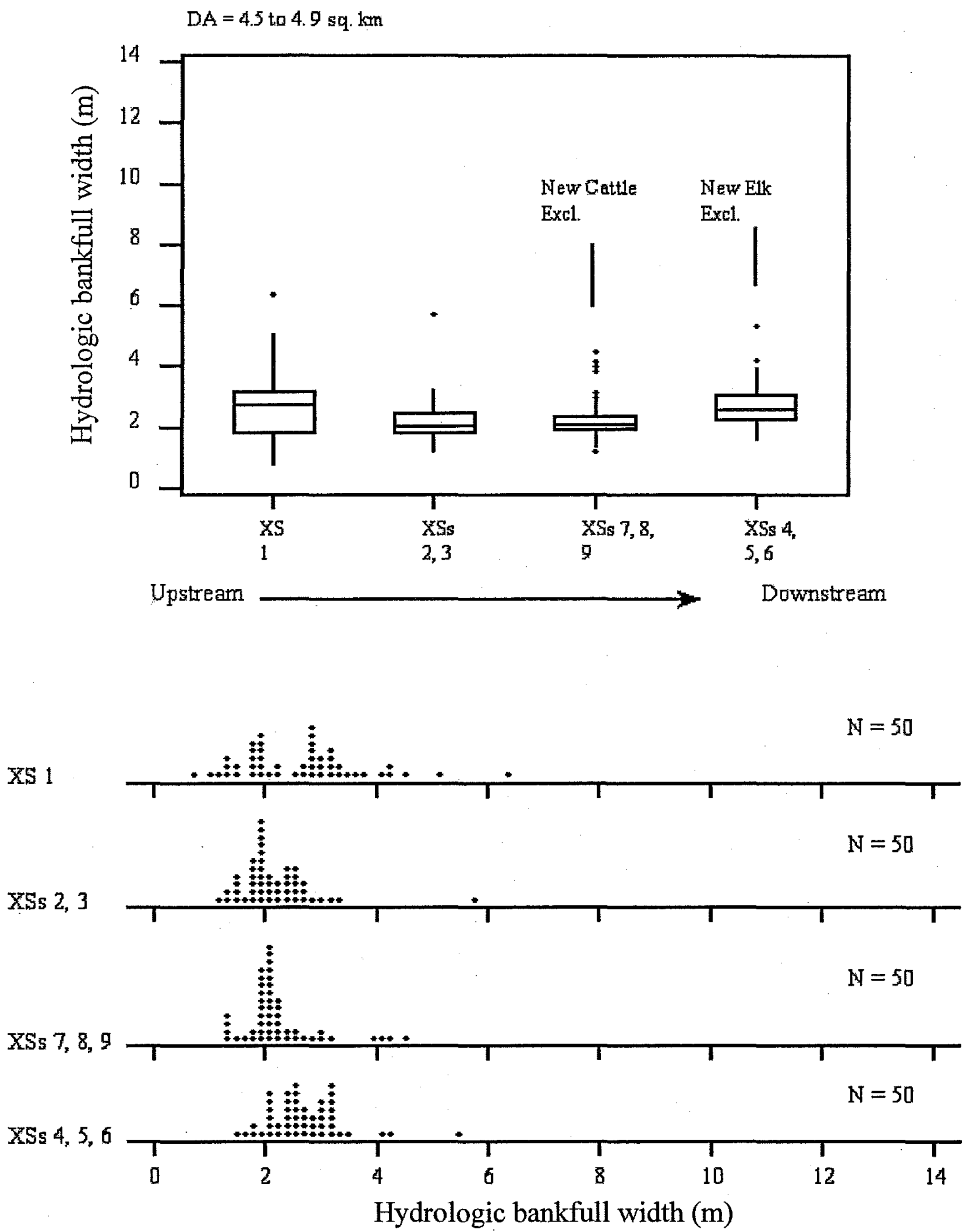


1997 Hay Creek summary comparison of reach and cross-section widths and distributions.

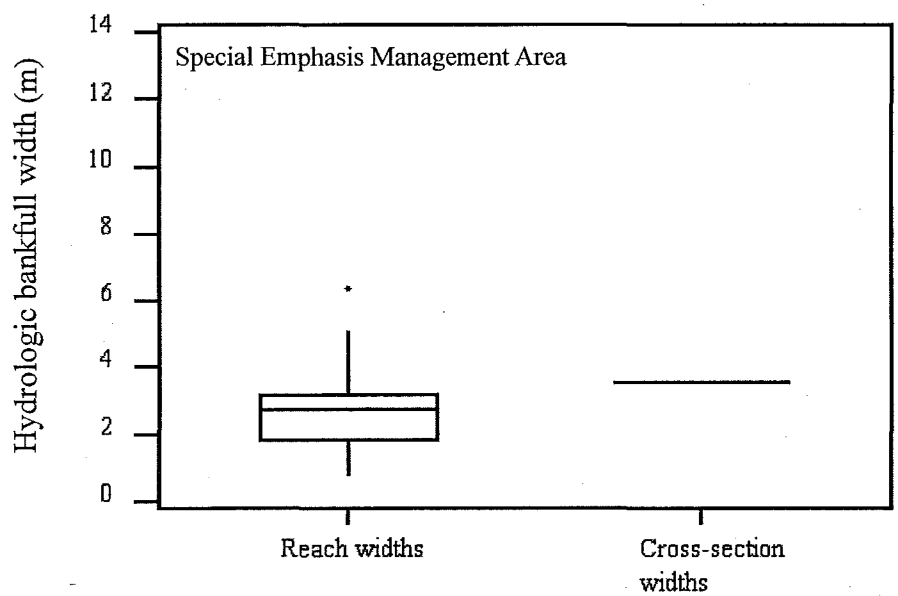


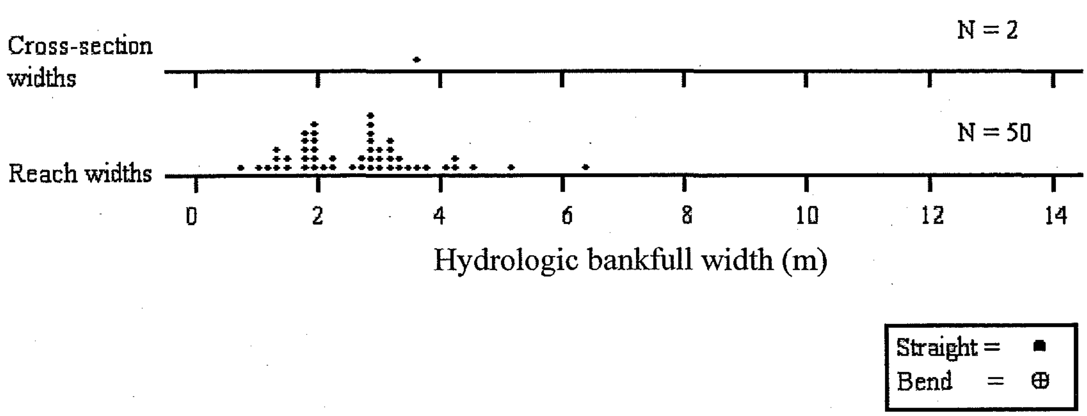


1997 Hay Creek reach comparison of bankfull widths and distributions. Treatment = Special Emphasis Management Area unless otherwise noted.

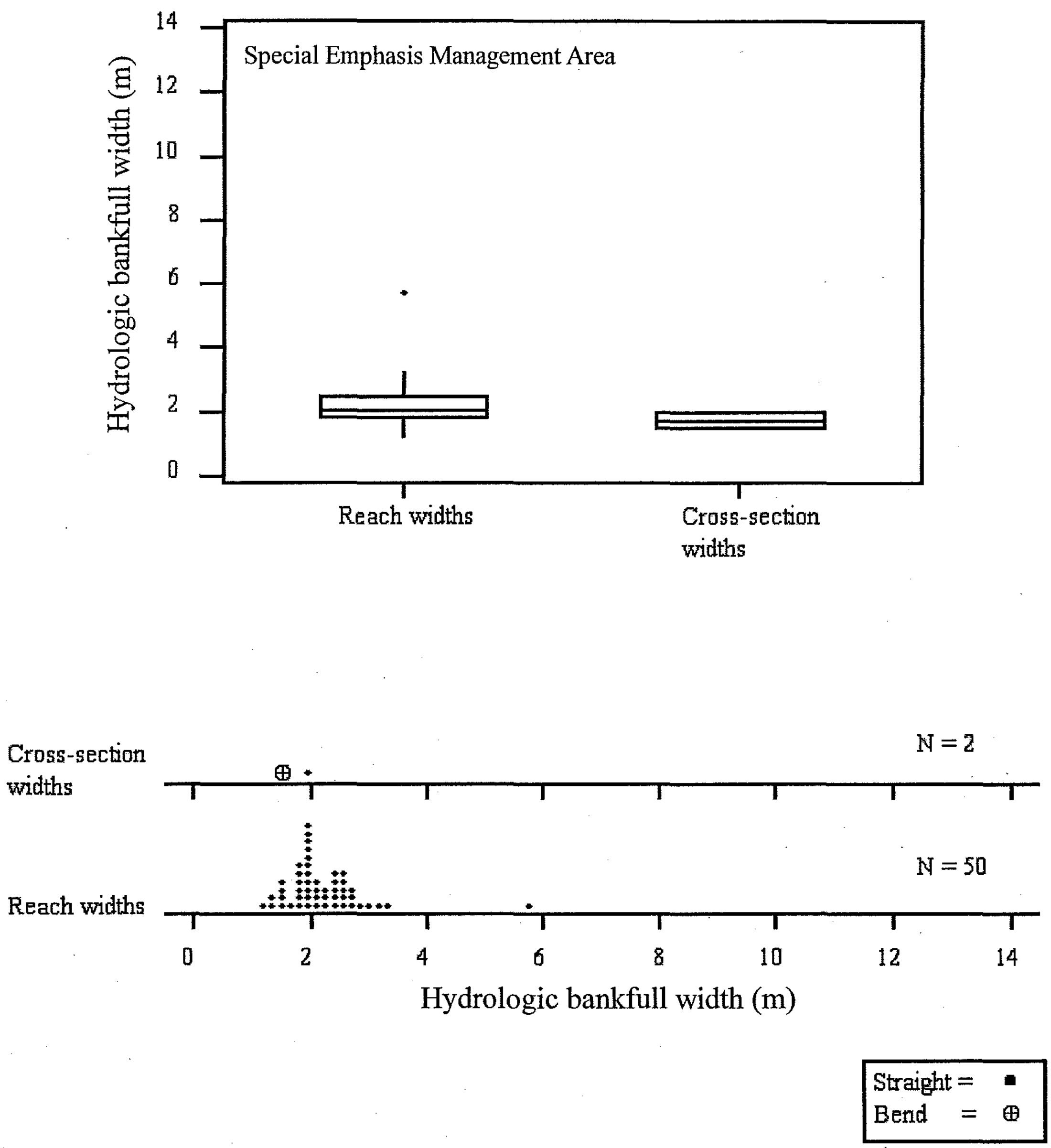


1997 Hay Creek reach containing cross-section 1.

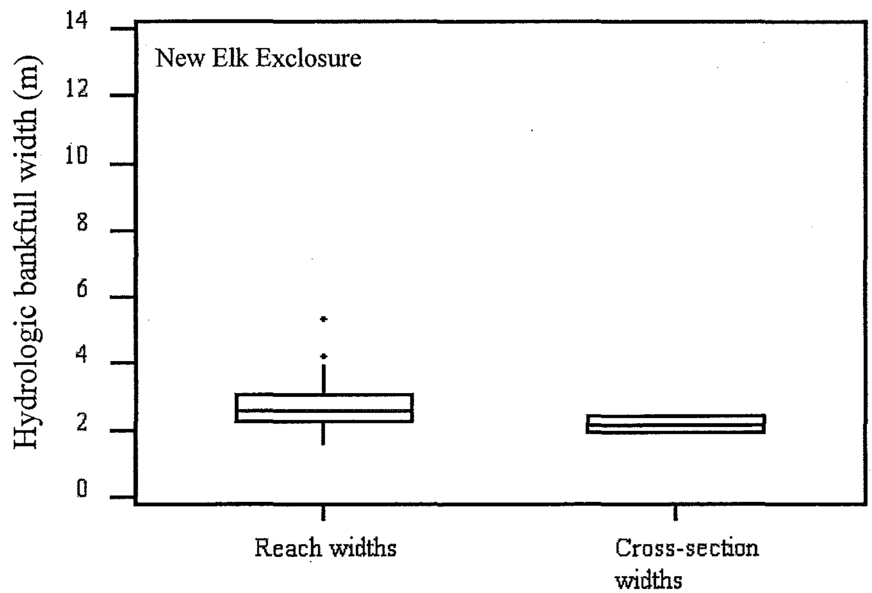


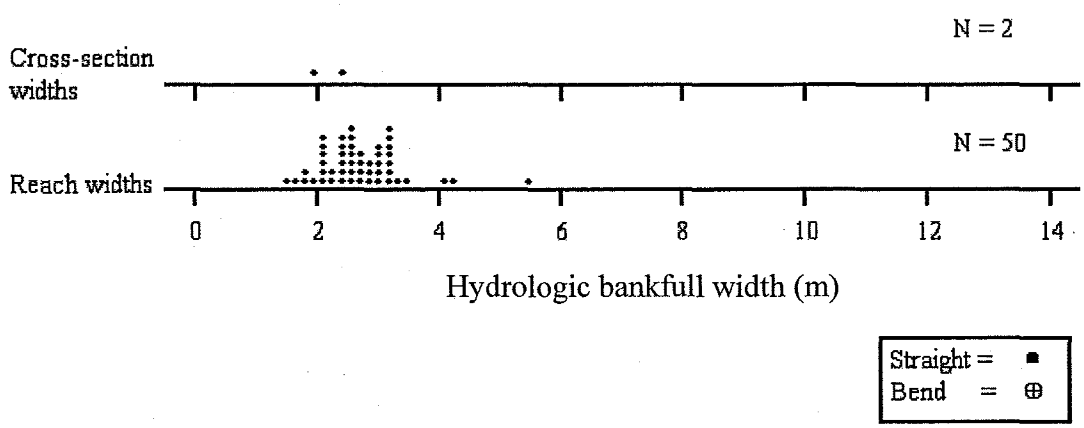


1997 Hay Creek reach containing cross-sections 2 and 3.

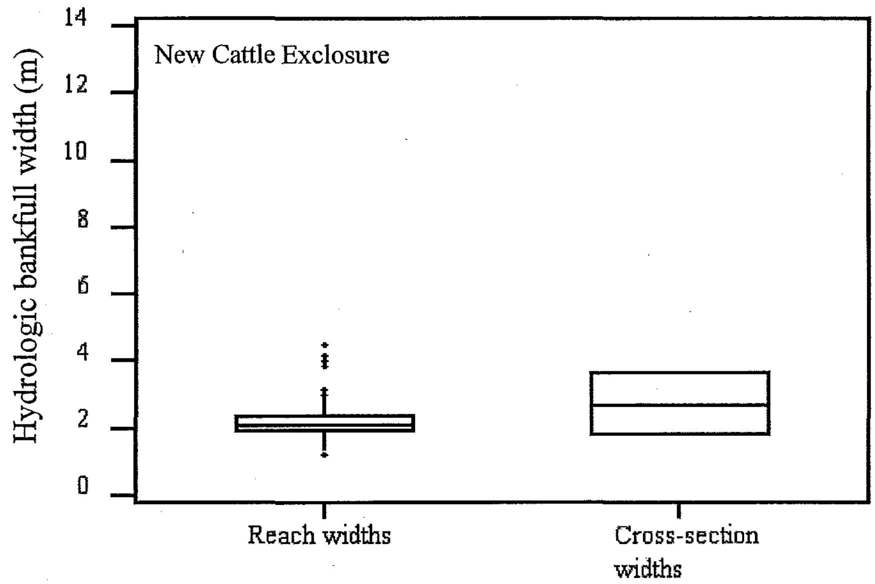


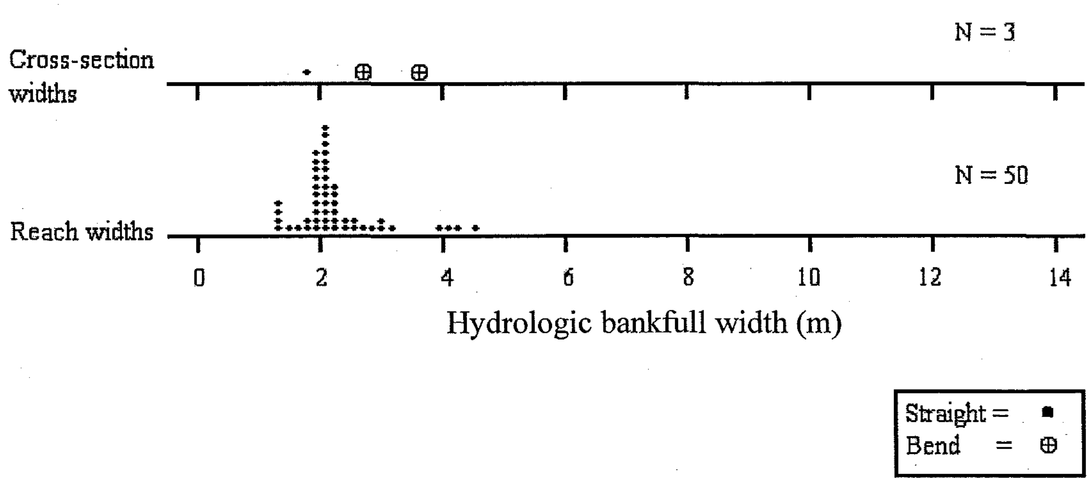
1997 Hay Creek reach containing cross-section 4, 5, and 6.



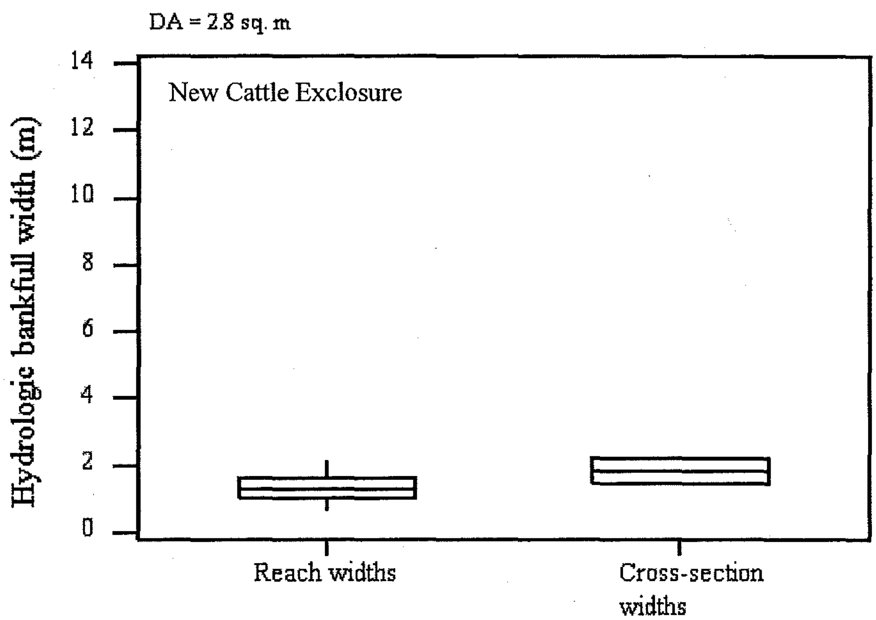


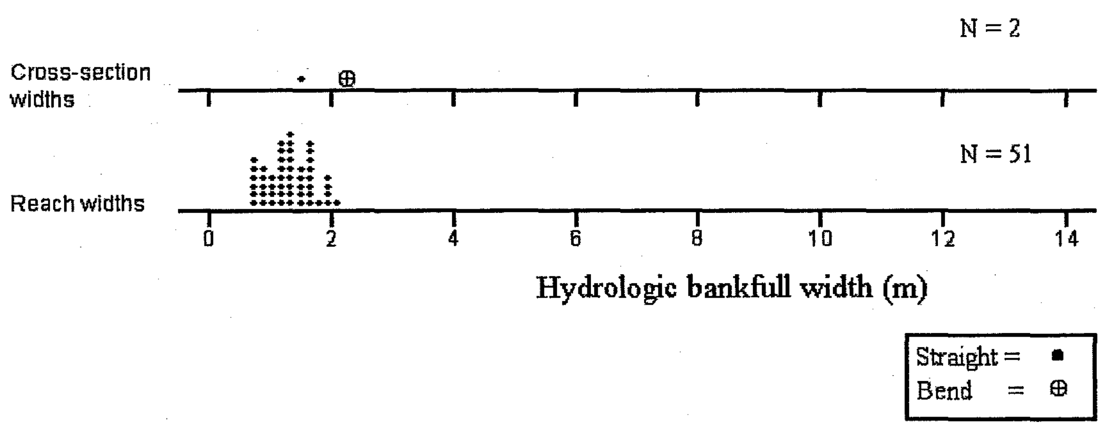
1997 Hay Creek reach containing cross-section 7, 8, and 9.



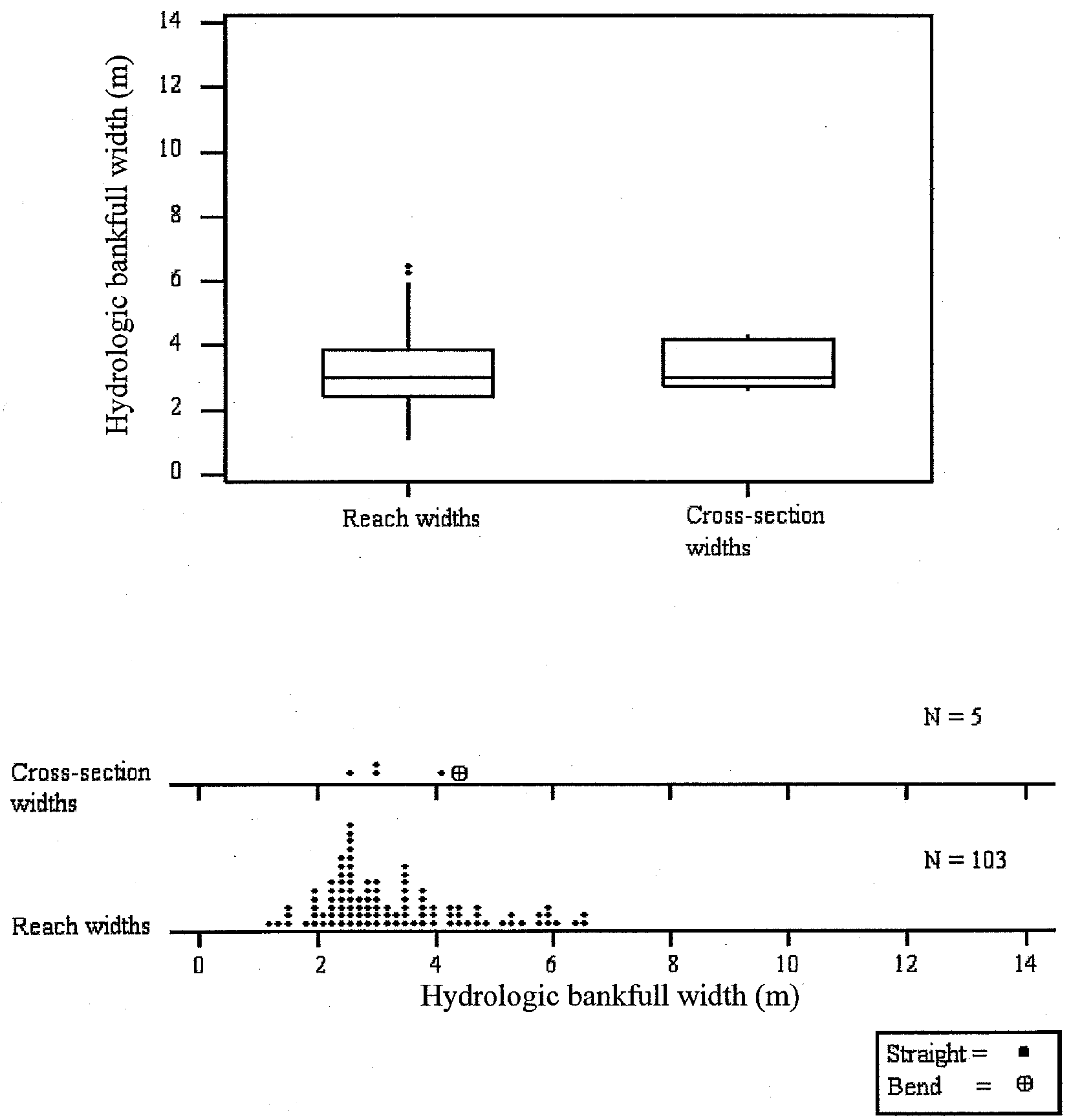


1997 Home Creek reach containing cross-sections 1 and 2.

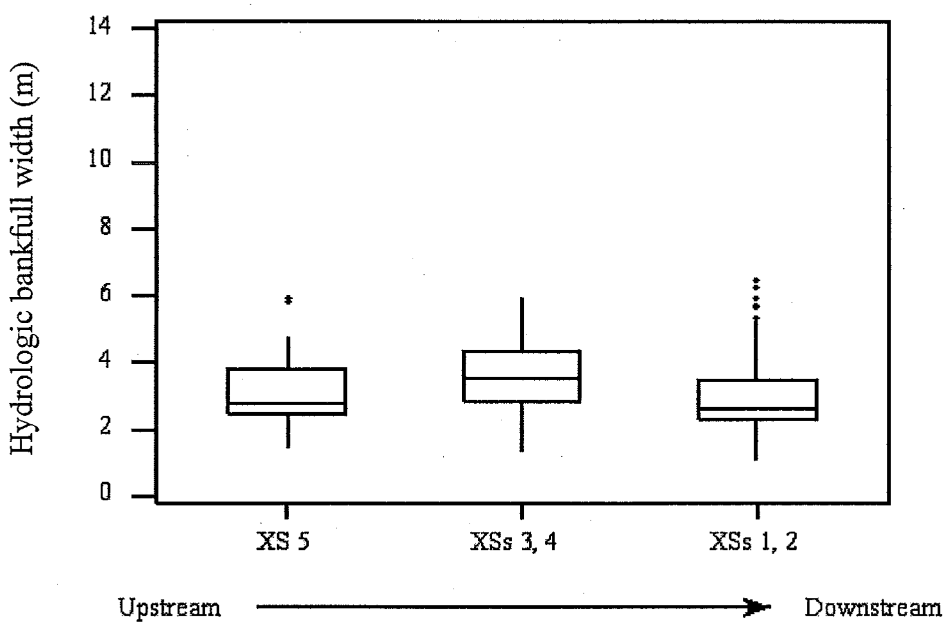


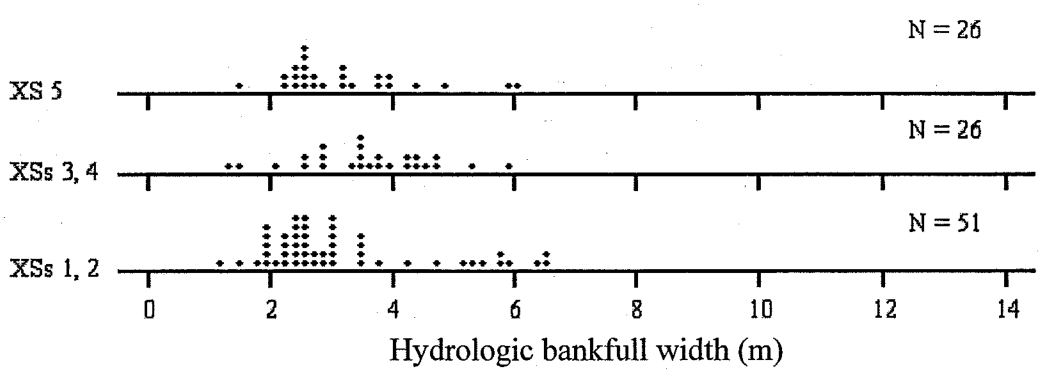


1997 Lower Burro Creek summary comparison of reach and cross-sections widths and distributions.

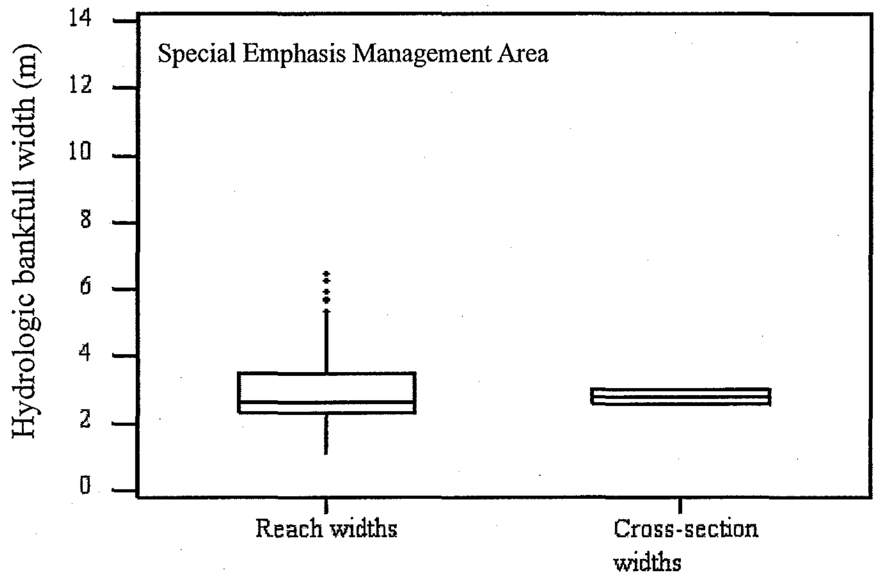


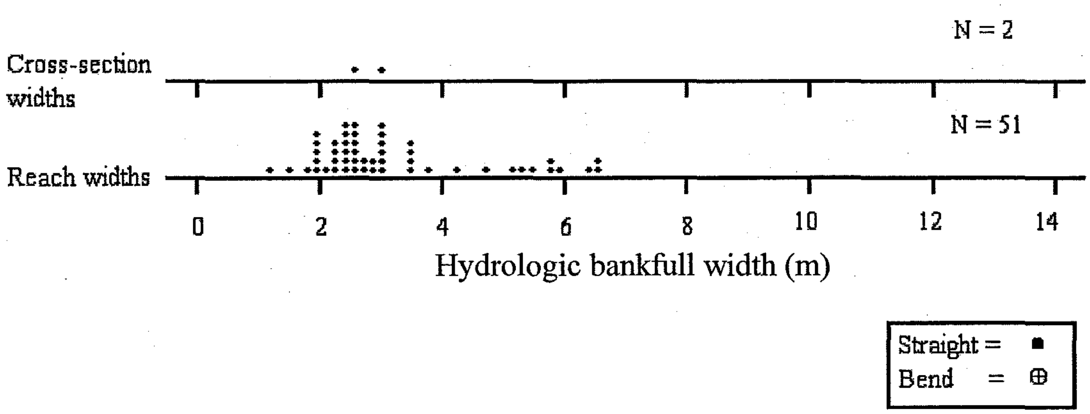
1997 Lower Burro Creek reach comparison of bankfull widths and distributions. Treatment = Special Emphasis Management Areas.



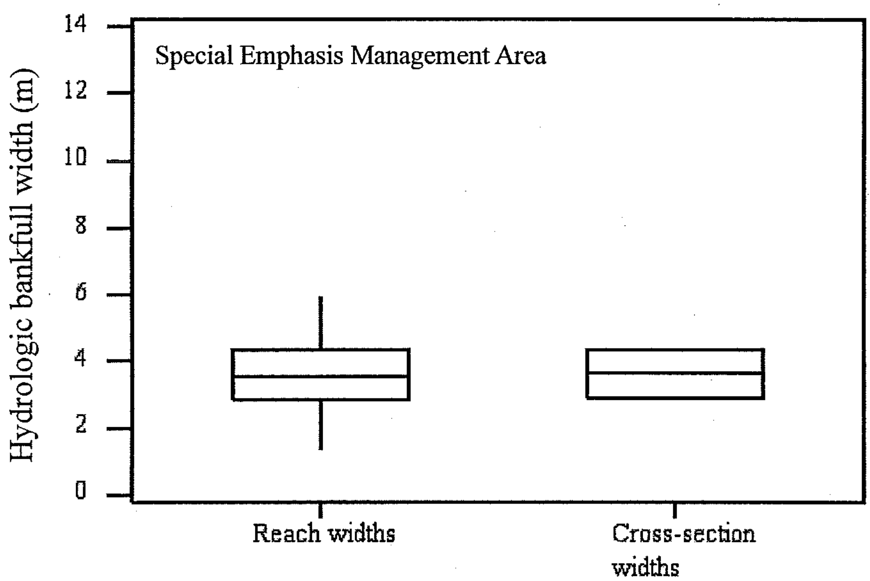


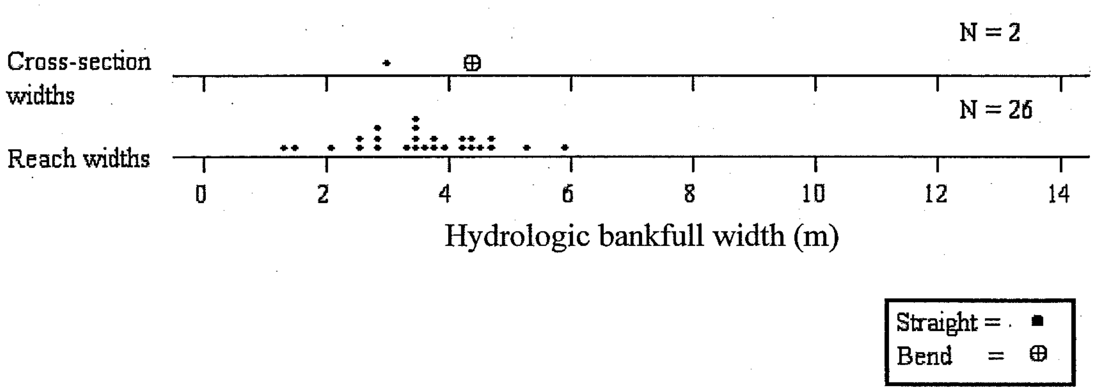
Lower Burro Creek reach containing cross-sections 1 and 2.



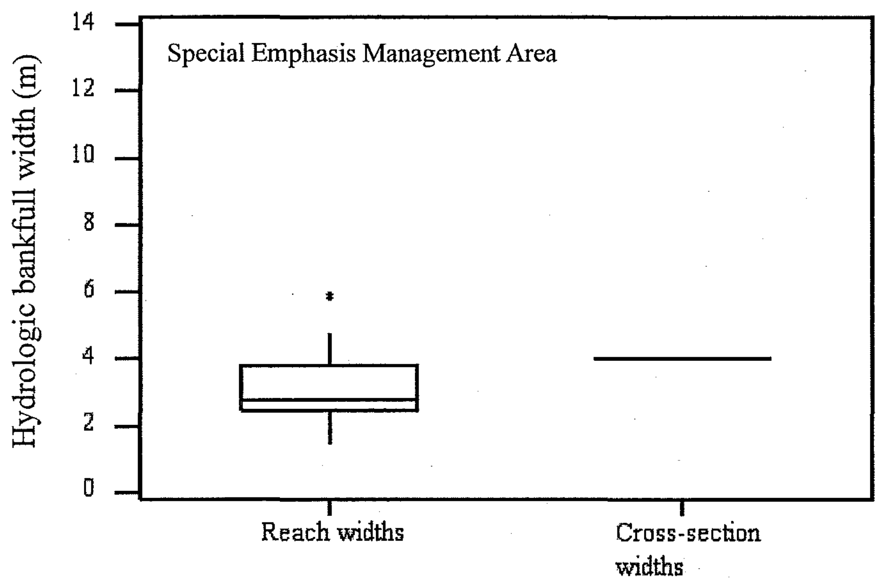


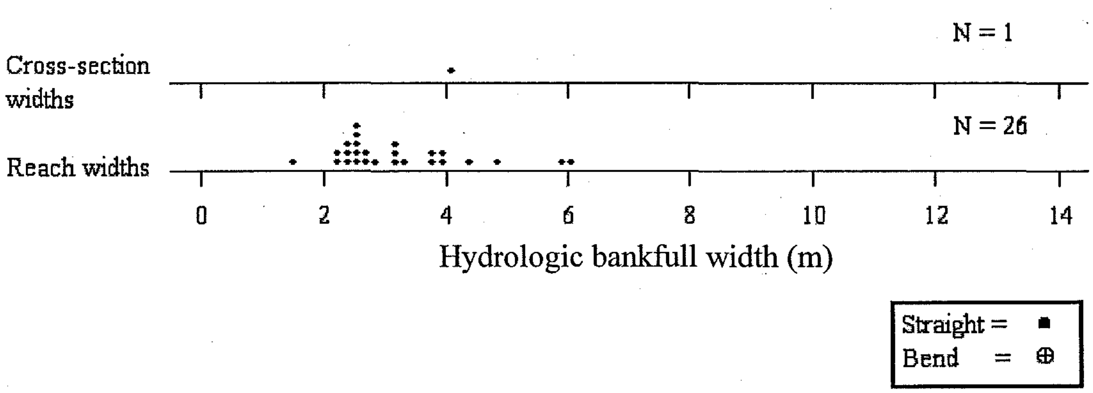
1997 Lower Burro Creek reach containing cross-sections 3 and 4.



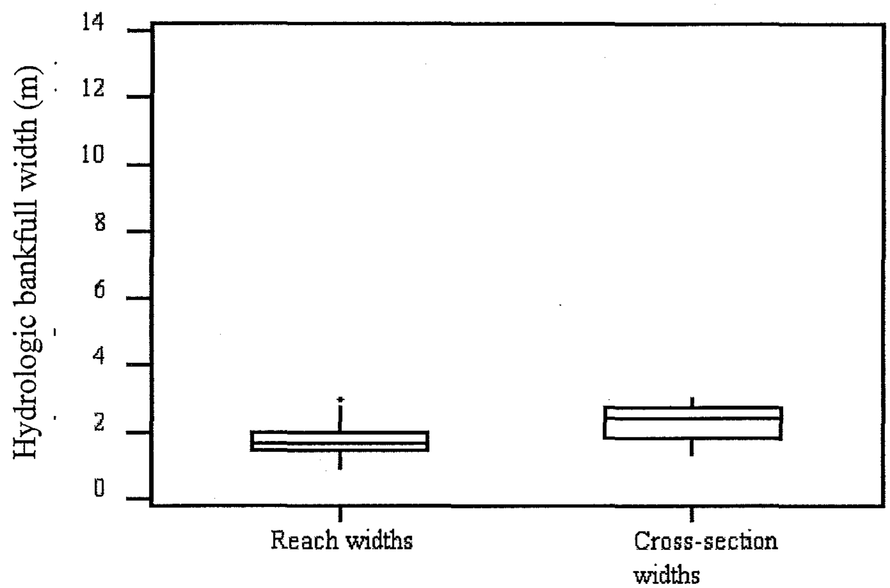


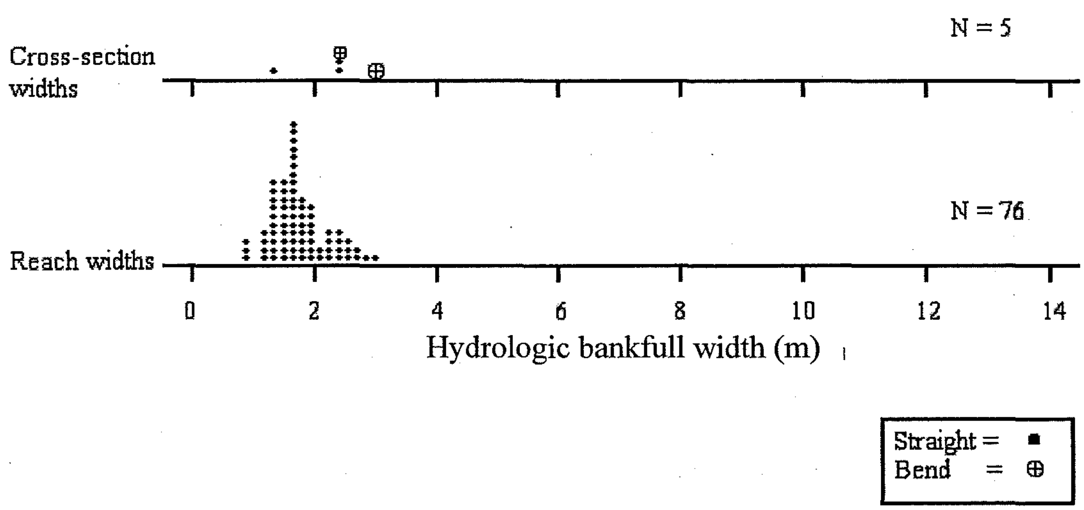
1997 Lower Burro Creek reach containing cross-section 5.



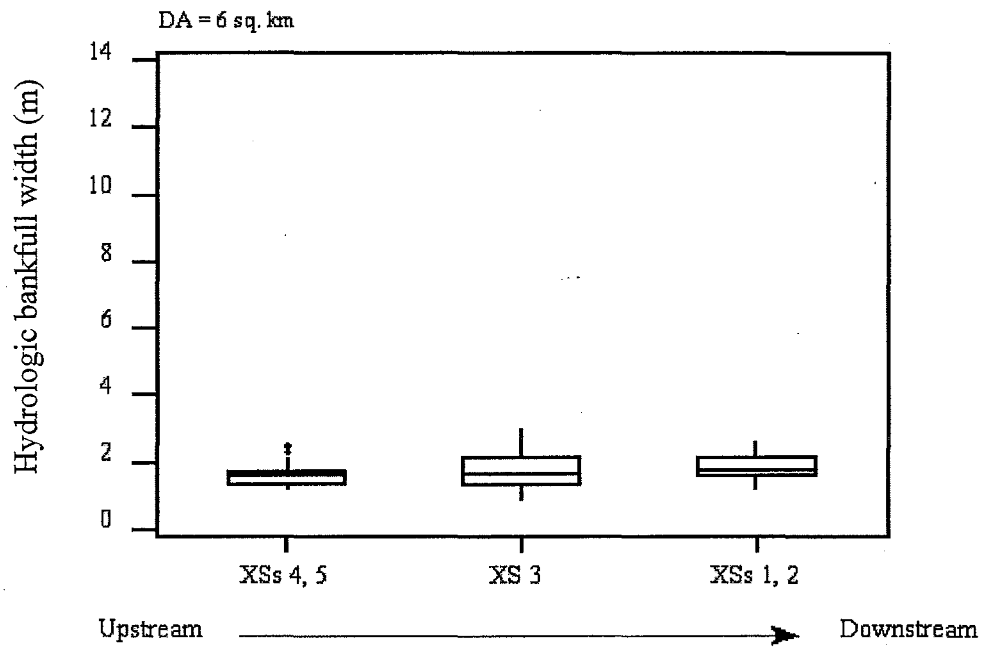


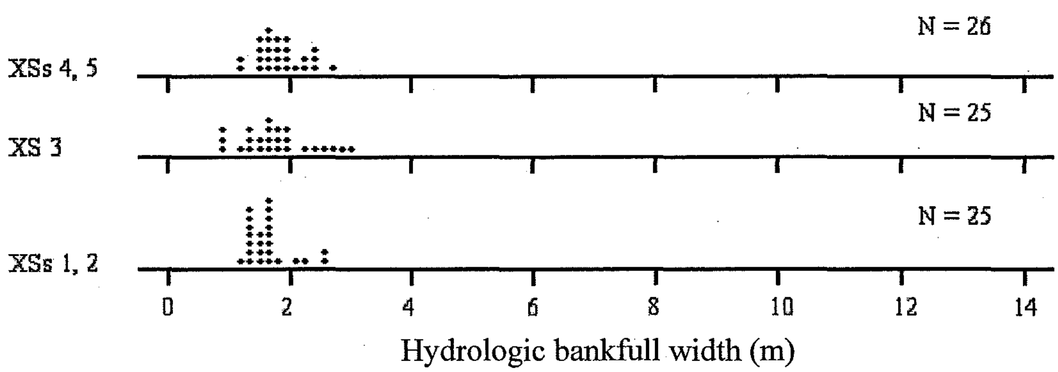
1997 Lower Stinky Creek summary comparison of reach and cross-section widths and distributions.



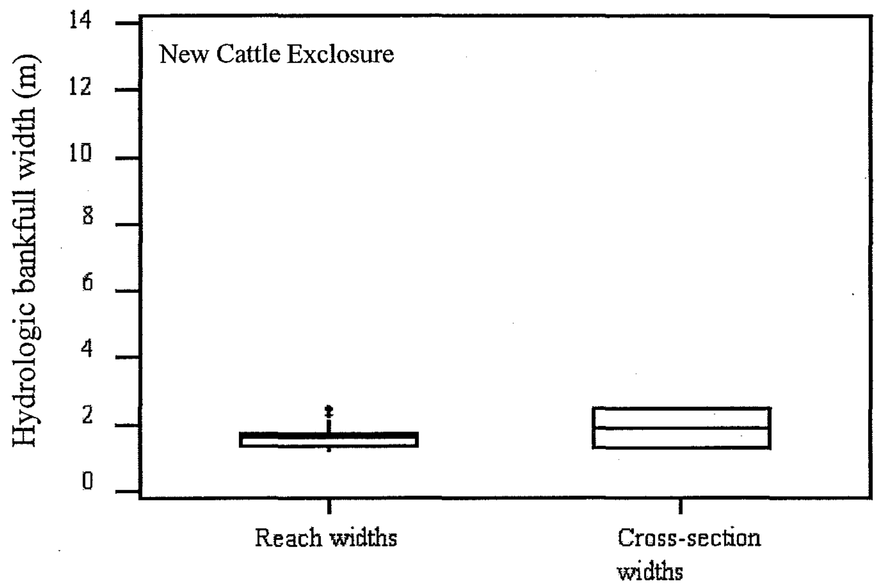


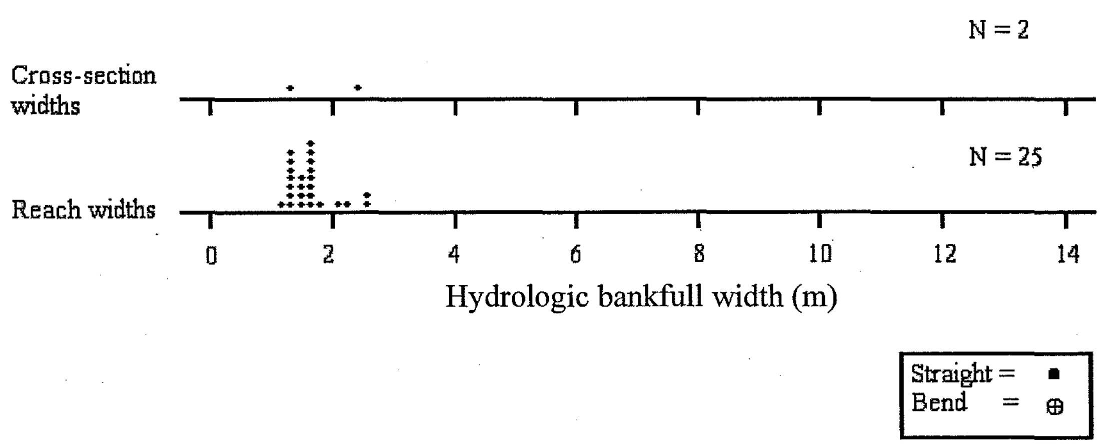
1997 Lower Stinky Creek reach comparisons of bankfull widths and distributions. Treatment = New Cattle Exclosure.



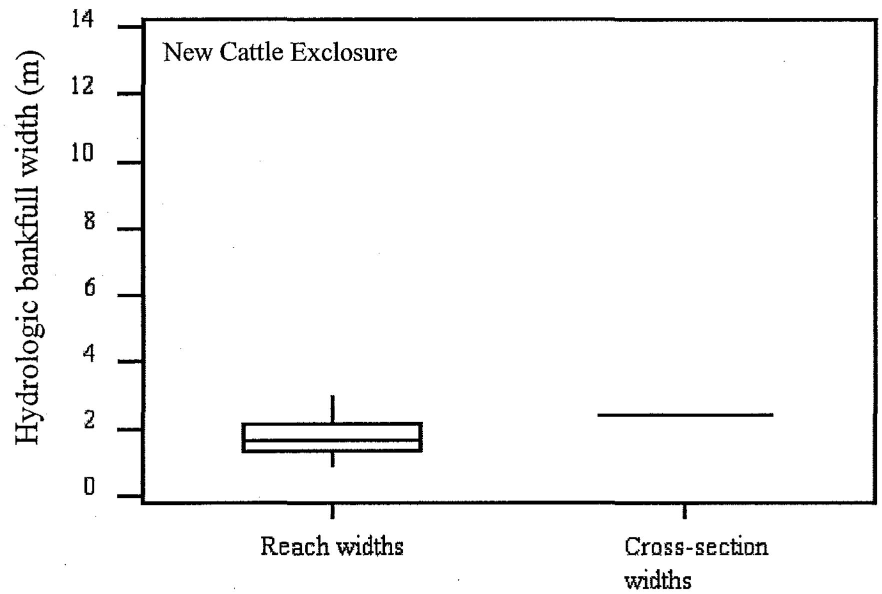


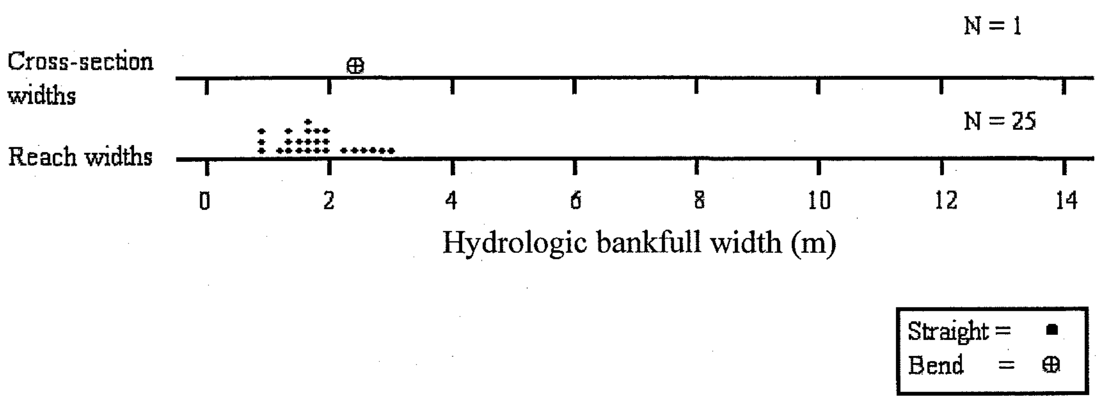
1997 Lower Stinky Creek reach containing cross-sections 1 and 2.



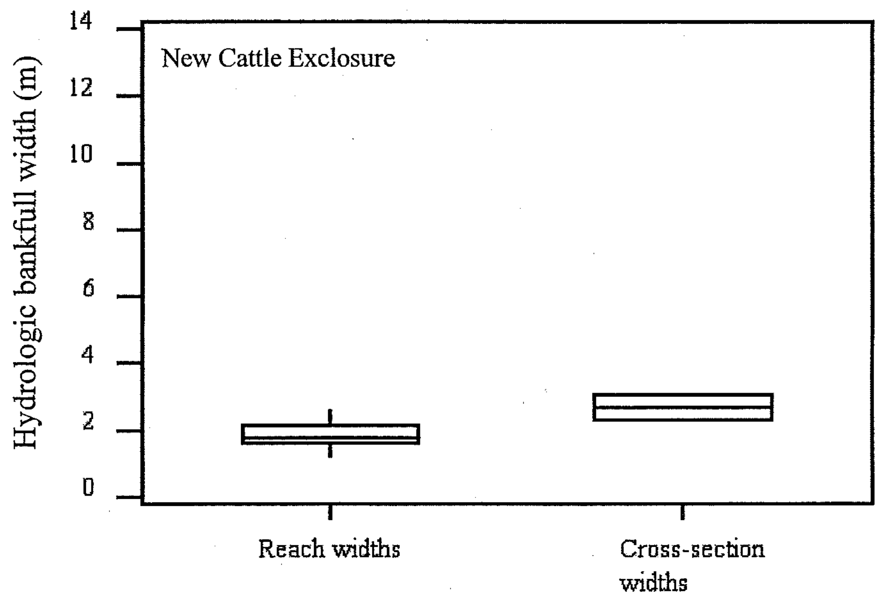


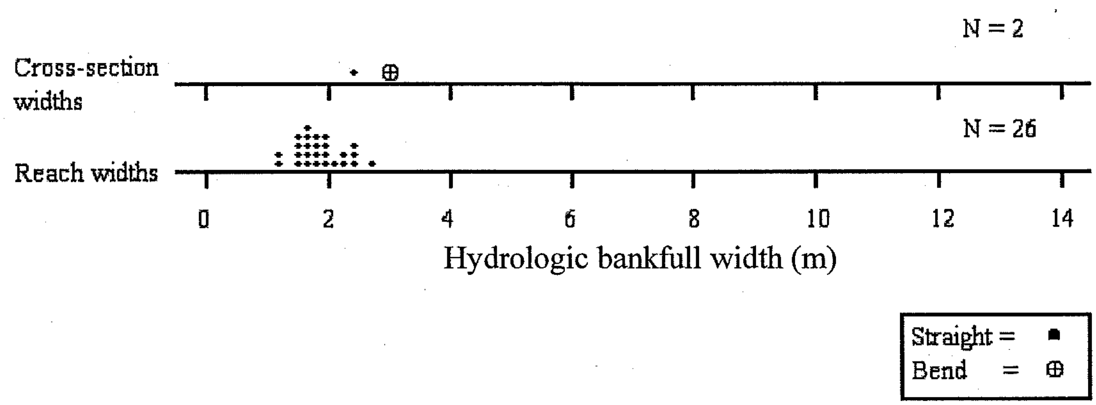
1997 Lower Stinky Creek reach containing cross-section 3.



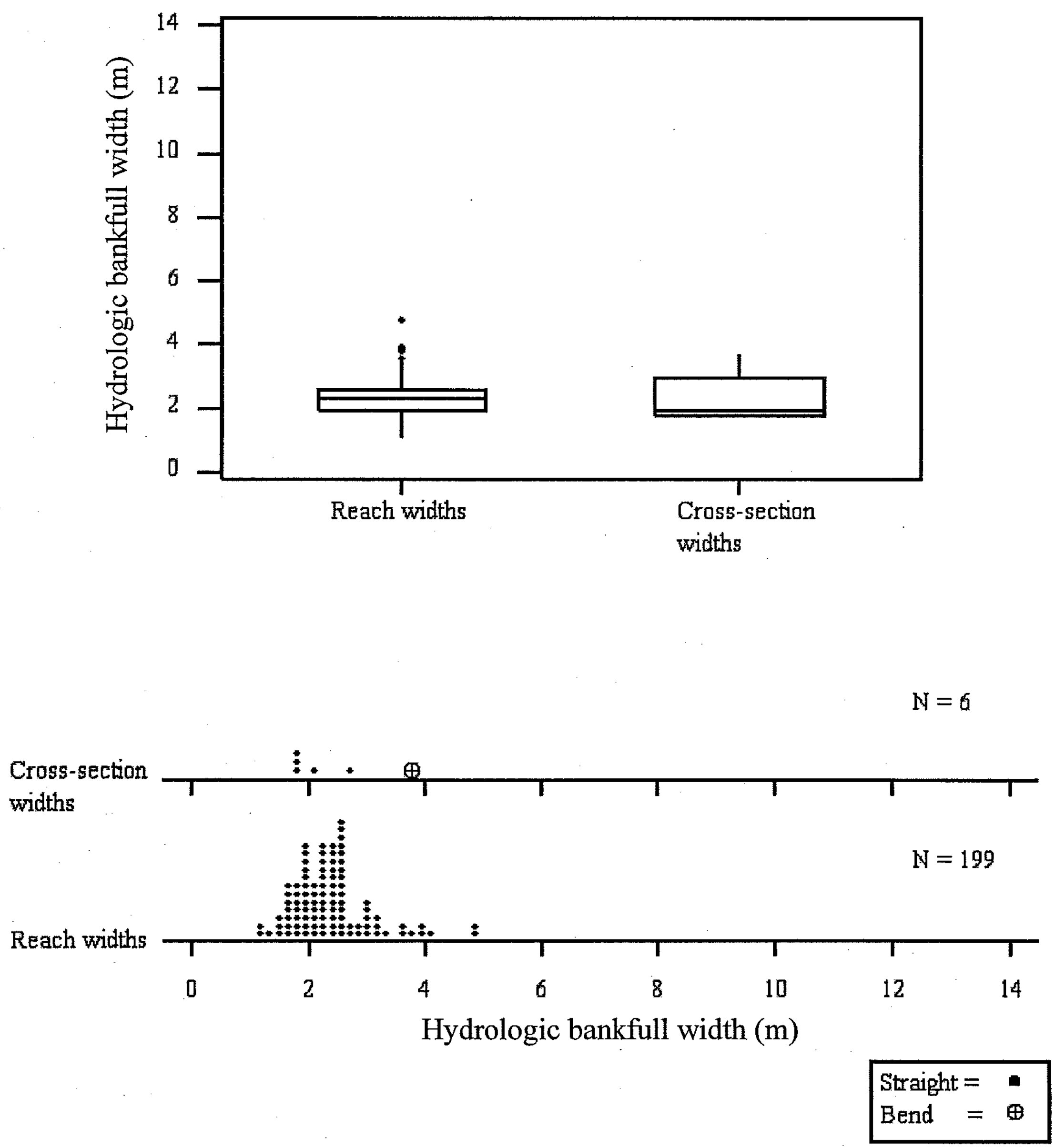


1997 Lower Stinky Creek reach containing cross-sections 4 and 5.

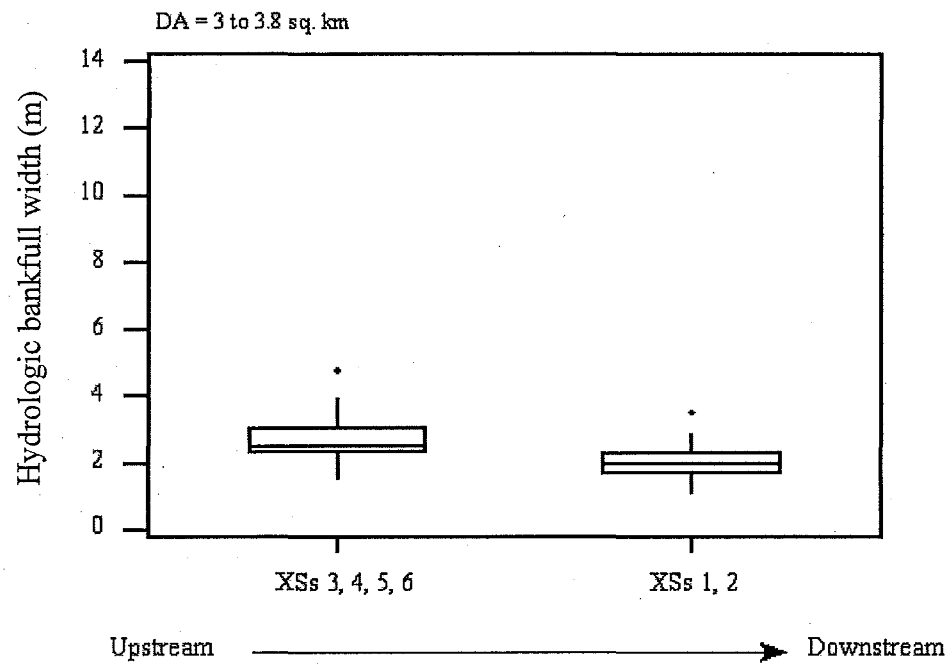


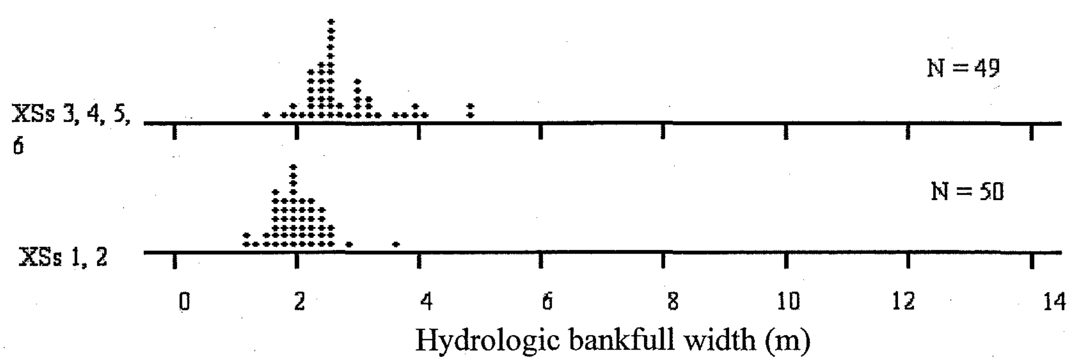


1997 Mandan Creek summary comparison of reach and cross-section widths and distributions.

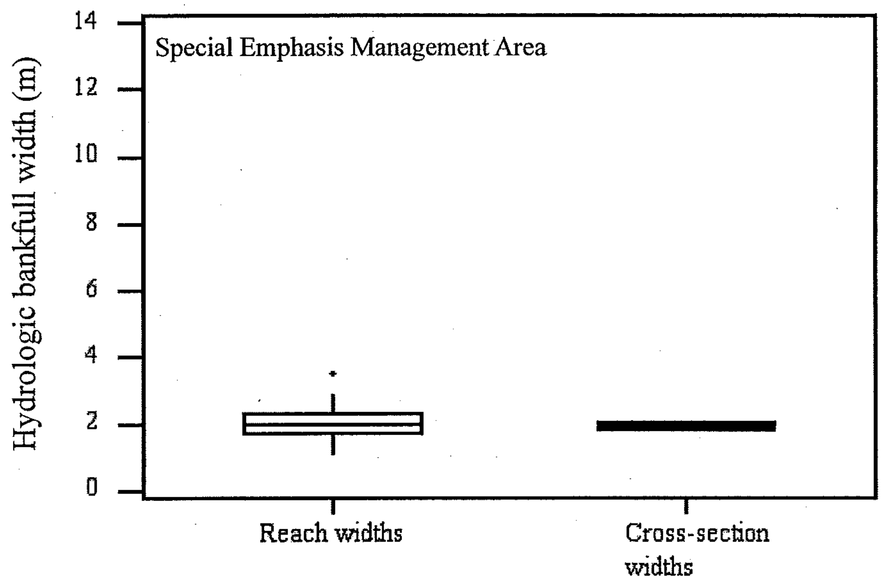


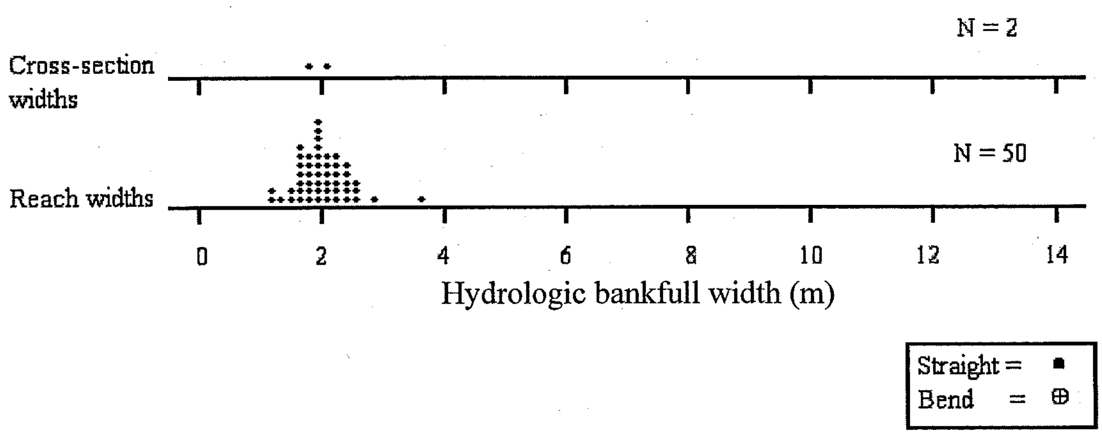
1997 Mandan Creek reach comparison of bankfull widths and distributions.
Treatment = Special Emphasis Management Area.



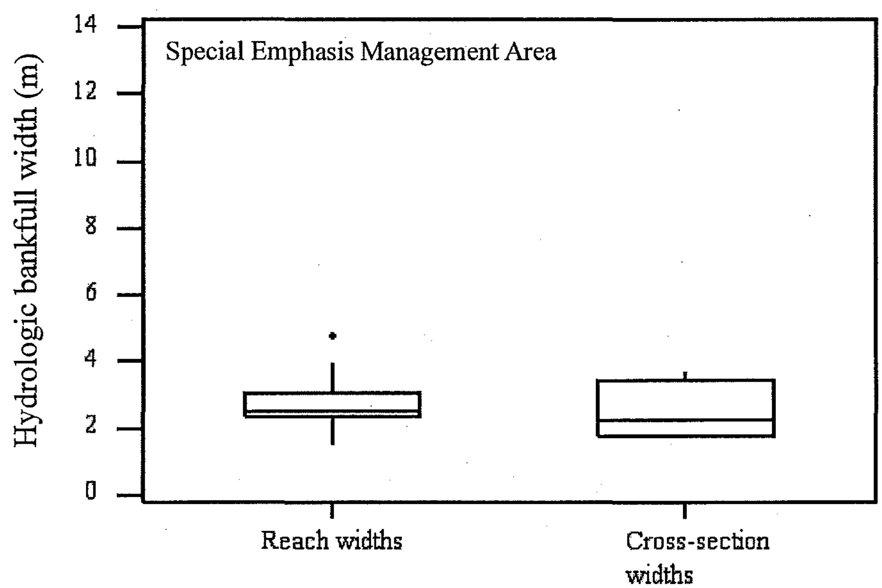


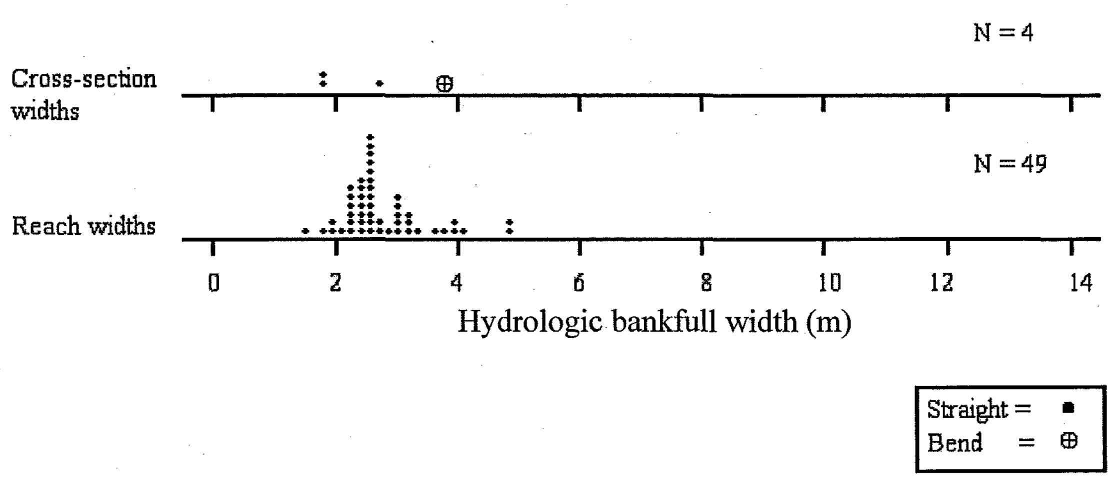
1997 Mandan Creek reach containing cross-sections 1 and 2.





1997 Mandan Creek reach containing cross-sections 3, 4, 5, and 6.





APPENDIX H

LINEAR REGRESSION RESULTS: TESTING FOR A RELATIONSHIP BETWEEN ANNUAL RATES OF CROSS-SECTION AREA AND DRAINAGE AREA AND ANNUAL RATES AND CHANNEL GEOMETRY

	Sample Size	Cross-section Area (sq. m)		Geomorphic Channel Width (m)		Geomorphic Channel Width/Average Depth Ratio		Drainage Area (sq. km)	
Creek									
All cross-sections		**r-sq percent**	**p-value**	**r-sq percent**	**p-value**	**r-sq percent**	**p-value**	**r-sq percent**	**p-value**
Basin	28	4.2	0.3	8.8	0.13	15.8	0.036	0.9	0.64
Muddy	27	3.5	0.35	0	0.32	16.4	0.036	0.9	0.64
Price	8	1.4	0.78	4.6	0.61	17.1	0.309	0.9	0.83
White Mts.	27	9.7	0.11	7.5	0.04	8.7	0.135	3.4	0.36
All	90	4	0.06	7.5	0.01	3.5	0.08	1.5	0.25
Straight sections only									
Basin	19	17.1	0.08	30.6	0.014	28	0.02	17.1	0.08
Muddy	15	1.8	0.63	0.2	0.86	10.8	0.23	20	0.1
Price	8	1.4	0.78	4.6	0.61	17.1	0.31	0.9	0.83
White Mts.	18	0.3	0.82	16.5	0.01	46.7	0.002	0.6	0.75
All	60	11.7	0.01	13.3	0.004	2.1	0.27	0.7	0.53
Bends only									
Basin	9	1.8	0.73	0.5	0.853	3	0.65	15	0.303
Muddy	12	3.5	0.56	6.2	0.434	44.3	0.018	18.6	0.162
White Mts.	9	22.9	0.192	12.7	0.346	5.1	0.558	10.9	0.386
All	30	0.8	0.633	4.4	0.266	5.7	0.203	2.4	0.415

	Sample Size	Cross-section Area (sq. m)		Geomorphic Channel Width (m)		Geomorphic Channel Width/Average Depth Ratio		Drainage Area (sq. km)	
Treatments									
All cross-sections		**r-sq percent**	**p-value**	**r-sq percent**	**p-value**	**r-sq percent**	**p-value**	**r-sq percent**	**p-value**
Old cattle exclosures	9	4.7	0.57	14.3	0.32	23.4	0.19	27	0.15
New elk exclosures	10	0	0.43	10	0.38	9.1	0.4	0.2	0.91
New cattle exclosures	18	29.8	0.02	23.9	0.04	0.1	0.92	0	0.94
Riparian guidelines	39	0.5	0.67	0.9	0.56	1	0.544	2.5	0.34
SEM area	14	11.1	0.24	3	0.55	0.6	0.79	7.2	0.35
Straight sections only									
Old cattle exclosures	6	31.8	0.24	28.1	0.28	21.6	0.35	4	0.71
New elk exclosures	7	6.9	0.57	4.5	0.65	3.3	0.7	0.1	0.96
New cattle exclosures	11	82	0	66	0.002	1.6	0.71	0.1	0.92
New cattle exclosures[1]	10	33	0.08	10	0.38	3.6	0.602	5.1	0.53
Riparian guidelines	25	9.6	0.13	6.7	0.21	0.4	0.76	8.8	0.15
SEM area	11	10.1	0.34	21.6	0.15	57	0.01	2.5	0.64

[1] Basin 9 removed. This point was an outlier both in terms of its valley bottom width and annual rate of cross-section area change when compared to the other cross-sections.

[2] H_0 = no relationship between annual rates of cross-section area change and control variable. Significance level is "alpha" = 0.05

APPENDIX I

VALUES USED TO DETERMINE THE GEOMORPHIC SIGNIFICANCE OF THE ANNUAL RATES OF CROSS-SECTION AREA CHANGE

Treatment[1]	Baseline Year[2]	Comp. years[3]	Creek	XS	Channel Segment	Drainage Area (sq. km)	Baseline Geomorphic Channel XS Area (sq. m)[4]	Est. Pre-disturbance Geomorphic Channel XS Area (sq. m)[5]	Geomorphic Channel Change from the Pre-disturbance area (sq. m)	Distance above Beaver Dam (m)
OCE	1993	9398	Muddy	2	Straight	75.98	3.91	0.53	3.38	N/A
OCE	1993	9398	Muddy	1	RB = inside	76	4.27	0.53	3.74	N/A
OCE	1995	9598	Muddy	26	Straight	76.01	1.04	0.53	0.51	N/A
OCE	1995	9598	Muddy	25	Straight	54.01	2.54	0.53	2.01	N/A
OCE	1996	9698	Muddy	32	Straight	75.99	3.45	0.53	2.92	N/A
OCE	1996	9698	Muddy	31	RB = inside	76.04	1	0.53	0.47	N/A
OCE	1996	9698	Muddy	30	Straight	76.03	0.53	0.53	0	N/A
OCE	1993	9398	Muddy	13	Straight	53.99	1.63	0.53	1.1	N/A
OCE	1993	9398	Muddy	12	RB = inside	54	2.58	0.53	2.05	N/A
NEE	1994	9497	Hayground	4	RB = inside	4.91	1.64	0.1	1.54	N/A
NEE	1995	9597	N. Basin	25	Straight	2.29	1.39	0.1	1.29	N/A
NEE	1995	9597	Main Basin	3	Straight	6.68	2.69	0.1	2.59	N/A
NEE	1995	9597	Main Basin	2	Straight	6.69	3.29	0.1	3.19	N/A
NEE	1995	9597	N. Basin	6	LB = inside	2.29	1.81	0.1	1.71	N/A
NEE	1995	9597	N. Basin	5	Straight	2.3	0.38	0.1	0.28	N/A
NEE	1995	9597	Main Basin	1	Straight	7	1.59	0.1	1.49	N/A
NEE	1995	9597	N. Basin	4	LB = inside	2.31	1.35	0.1	1.25	N/A
NEE	1994	9497	Hayground	6	Straight	4.9	2.62	0.1	2.52	N/A
NEE	1994	9497	Hayground	5	Straight	4.89	0.59	0.1	0.49	N/A
NCE	1995	9597	S. Basin	9	Straight	4.67	6.69	0.1	6.59	N/A
NCE	1995	9597	S. Basin	8	RB = inside	4.68	10.25	0.1	10.15	N/A
NCE	1993	9398	Muddy	22	Straight	10	1.13	0.1	1.03	N/A
NCE	1993	9398	Muddy	23	Straight	6	0.98	0.1	0.88	N/A

Treatment[1]	Baseline Year[2]	Comp. years[3]	Creek	XS	Channel Segment	Drainage Area (sq. km)	Baseline Geomorphic Channel XS Area (sq. m)[4]	Est. Pre-disturbance Geomorphic Channel XS Area (sq. m)[5]	Geomorphic Channel Change from the Pre-disturbance area (sq. m)	Distance above Beaver Dam (m)
NCE	1994	9497	L. Stinky	1	Straight	6.1	0.99	0.1	0.89	N/A
NCE	1994	9497	L. Stinky	4	LB = inside	6	1.56	0.1	1.46	N/A
NCE	1995	9597	S. Basin	7	Straight	4.7	1.39	0.1	1.29	N/A
NCE	1995	9597	S. Basin	23	Straight	4.71	1.97	0.1	1.87	N/A
NCE	1994	9497	Home	1	LB = inside	2.8	0.56	0.1	0.46	N/A
NCE	1994	9497	Home	2	Straight	2.79	0.495	0.1	0.4	N/A
NCE	1994	9497	Hayground	7	RB = inside	4.7	0.72	0.1	0.62	N/A
NCE	1994	9497	Hayground	9	Straight	4.71	0.58	0.1	0.48	N/A
NCE	1994	9497	L. Stinky	5	Straight	5.99	0.505	0.1	0.41	N/A
NCE	1993	9398	Muddy	24	Straight	5.99	0.14	0.1	0.04	N/A
NCE	1994	9497	L. Stinky	3	RB = inside	6.08	0.53	0.1	0.43	N/A
NCE	1994	9497	Hayground	8	RB = inside	4.69	0.66	0.1	0.56	N/A
NCE	1994	9497	L. Stinky	2	Straight	6.09	0.86	0.1	0.76	N/A
NCE	1995	9597	S. Basin	24	LB = inside	4.69	5.39	0.1	5.29	N/A
RG	1993	9398	Muddy	11	RB = inside	59.99	1.8	0.53	1.27	N/A
RG	1993	9398	Muddy	6	RB = inside	68.99	1.66	0.53	1.13	N/A
RG	1993	9398	Muddy	10	LB = inside	60	1.44	0.53	0.91	N/A
RG	1995	9398	N. Basin	26	LB = inside	2.11	3.19	0.1	3.09	N/A
RG	1993	9398	Muddy	18	Straight	51	1.37	0.53	0.84	N/A
RG	1995	9597	S. Basin	11	Straight	4.64	7.21	0.1	7.11	N/A
RG	1995	9597	Main Basin	14	RB = inside	7.1	5.57	0.1	5.47	N/A
RG	1993	9398	Muddy	15	Straight	52.99	0.76	0.53	0.23	N/A
RG	1993	9398	Muddy	4	LB = inside	69.99	1.29	0.53	0.76	N/A
RG	1993	9398	Muddy	14	RB = inside	53	1.02	0.53	0.49	N/A
RG	1993	9398	Muddy	9	Straight	60.98	1.21	0.53	0.68	N/A

Treatment[1]	Baseline Year[2]	Comp. years[3]	Creek	XS	Channel Segment	Drainage Area (sq. km)	Baseline Geomorphic Channel XS Area (sq. m)[4]	Est. Pre-disturbance Geomorphic Channel XS Area (sq. m)[5]	Geomorphic Channel Change from the Pre-disturbance area (sq. m)	Distance above Beaver Dam (m)
RG	1993	9398	Muddy	8	LB = inside	60.99	2	0.53	1.47	N/A
RG	1993	9398	Muddy	5	Straight	69	0.81	0.53	0.28	N/A
RG	1995	9597	Main Basin	15	Straight	7.09	3.12	0.1	3.02	N/A
RG	1995	9598	Muddy	3	Straight	70	1.96	0.53	1.43	N/A
RG	1995	9597	S. Basin	12	Straight	4.65	4.42	0.1	4.32	N/A
RG	1994	9498	W. Fk. Price	7	Straight	4.1	0.472	0.1	0.37	N/A
RG	1995	9597	Main Basin	16	LB = inside	7.08	3	0.1	2.9	N/A
RG	1994	9498	W. Fk Price	4	Straight	3.89	0.203	0.1	0.1	N/A
RG	1994	9498	W. Fk Price	6	Straight	4	0.465	0.1	0.37	N/A
RG	1995	9597	N. Basin	21	Straight	2.06	1.17	0.1	1.07	N/A
RG	1995	9598	Price	18	Straight	14.28	3.79	0.1	3.69	14
RG	1993	9398	Muddy	7	RB = inside	61	3.21	0.53	2.68	N/A
RG	1995	9597	N. Basin	22	Straight	2.05	1.37	0.1	1.27	N/A
RG	1995	9598	W. Fk. Price	32b	Straight	5.29	0.31	0.1	0.21	N/A
RG	1995	9597	Main Basin	27	Straight	7.2	1.91	0.1	1.81	N/A
RG	1995	9597	S. Basin	13	Straight	4.66	2.32	0.1	2.22	N/A
RG	1995	9597	N. Basin	20	Straight	2.07	2.35	0.1	2.25	N/A
RG	1995	9597	W. Fk Price	31	Straight	5.3	0.11	0.1	0.01	N/A
RG	1995	9598	Price	17e	Straight	14.29	6.9	0.1	6.8	N/A
RG	1995	9597	N. Basin	18	Straight	2.09	0.87	0.1	0.77	N/A
RG	1994	9498	W. Fk Price	5	Straight	3.9	0.745	0.1	0.65	N/A
RG	1993	9398	Muddy	16	Straight	52	2.18	0.53	1.65	N/A
RG	1995	9597	S. Basin	10	LB = inside	4.63	7.99	0.1	7.89	N/A
RG	1995	9597	N. Basin	19	Straight	2.08	1.08	0.1	0.98	N/A
RG	1995	9597	N. Basin	17	Straight	2.1	2.12	0.1	2.02	N/A
RG	1993	9398	Muddy	19	RB = inside	50.99	1.84	0.53	1.31	N/A

Treatment[1]	Baseline Year[2]	Comp. years[3]	Creek	XS	Channel Segment	Drainage Area (sq. km)	Baseline Geomorphic Channel XS Area (sq. m)[4]	Est. Pre-disturbance Geomorphic Channel XS Area (sq. m)[5]	Geomorphic Channel Change from the Pre-disturbance area (sq. m)	Distance above Beaver Dam (m)
RG	1995	9597	Main Basin	28	RB = inside	7.19	2.16	0.1	2.06	N/A
RG	1993	9398	Muddy	17	LB = inside	51.99	2.2	0.53	1.67	N/A
SEMA	1994	9497	Mandan	3	Straight	3.31	1.68	0.1	1.58	N/A
SEMA	1994	9497	L. Burro	4	RB = inside	12.69	2.02	0.1	1.92	N/A
SEMA	1994	9497	Hayground	3	RB = inside	4.51	1	0.1	0.9	N/A
SEMA	1994	9497	L. Burro	1	Straight	13.7	2.01	0.1	1.91	N/A
SEMA	1994	9497	Mandan	2	Straight	3.79	0.84	0.1	0.74	N/A
SEMA	1994	9497	Mandan	1	Straight	3.8	0.68	0.1	0.58	N/A
SEMA	1994	9497	L. Burro	2	Straight	13.69	1.086	0.1	0.99	N/A
SEMA	1994	9497	Hayground	2	Straight	4.5	0.93	0.1	0.83	N/A
SEMA	1994	9497	L. Burro	3	Straight	12.7	1.46	0.1	1.36	N/A
SEMA	1994	9497	Mandan	6	Straight	2.98	0.266	0.1	0.17	N/A
SEMA	1994	9497	Hayground	1	Straight	4.49	1.427	0.1	1.33	N/A
SEMA	1994	9497	Mandan	4	RB = inside	3	1.47	0.1	1.37	N/A
SEMA	1994	9497	L. Burro	5	Straight	9.8	1.395	0.1	1.3	N/A
SEMA	1994	9497	Mandan	5	Straight	2.99	1.1	0.1	1	N/A
IBD (NEE)	1994	9497	Price	15a	Straight	8.32	1.87	0.1	1.77	6
IBD (NCE)	1995	9597	Price	20a	RB = inside	8.7	3.07	0.1	2.97	9
IBD (NEE)	1994	9497	Price	13a	RB = inside	8.3	1.54	0.1	1.44	5
IBD (NEE)	1994	9497	Price	14a	Straight	8.31	1.35	0.1	1.25	15
IBD (NCE)	1995	9597	Price	27a	LB = inside	8.81	4.09	0.1	3.99	11
IBD (NCE)	1995	9597	Price	21a	Straight	8.69	2.09	0.1	1.99	12
IBD (NCE)	1995	9597	Price	26a	Straight	8.81	2.71	0.1	2.61	27
IBD (NCE)	1995	9597	Price	23a	Straight	8.78	1.68	0.1	1.58	15

Treatment[1]	Baseline Year[2]	Comp. years[3]	Creek	XS	Channel Segment	Drainage Area (sq. km)	Baseline Geomorphic Channel XS Area (sq. m)[4]	Est. Pre-disturbance Geomorphic Channel XS Area (sq. m)[5]	Geomorphic Channel Change from the Pre-disturbance area (sq. m)	Distance above Beaver Dam (m)
IBD (NCE)	1995	9597	Price	19a	Straight	8.71	1.23	0.1	1.13	35
IBD (NCE)	1995	9597	Price	22a	Straight	8.77	2.22	0.1	2.12	16
IBD (NCE)	1995	9597	Price	25a	Straight	8.8	1.6	0.1	1.5	19
FBD (RG)	1994	9495	Price	17a	Straight	14.29	6.9	0.1	6.8	N/A
FBD (NCE)	1997	9798	Price	25	Straight	8.8	1.64	0.1	1.54	19
FBD (NCE)	1997	9798	Price	19	Straight	8.71	1.19	0.1	1.09	35
FBD (NCE)	1997	9798	Price	22	Straight	8.77	2.25	0.1	2.15	16
FBD (NCE)	1995	9598	Price	28b	Straight	8.9	1.43	0.1	1.33	22
FBD (NEE)	1997	9798	Price	14b	Straight	8.31	0.72	0.1	0.62	36
FBD (RG)	1994	9495	Price	18a	Straight	14.28	3.63	0.1	3.53	14
FBD (NCE)	1997	9798	Price	21	Straight	8.69	1.81	0.1	1.71	12
FBD (NEE)	1997	9798	Price	13b	RB = inside	8.3	0.87	0.1	0.77	5
FBD (NCE)	1997	9798	Price	26	Straight	8.81	2.44	0.1	2.34	27
FBD (NCE)	1997	9798	Price	27	LB = inside	8.81	3.69	0.1	3.59	11
FBD (NEE)	1997	9798	Price	15b	Straight	8.32	0.12	0.1	0.02	6
FBD (NCE)	1997	9798	Price	23	Straight	8.78	1.49	0.1	1.39	15
FBD (RG)	1994	9498	Price	16	Straight	14.3	4.39	0.1	4.29	21
FBD (NCE)	1997	9798	Price	20	RB = inside	8.7	2.3	0.1	2.2	9
FBD (NEE)	1997	9798	Price	33	Straight	8.29	1.18	0.1	1.08	22
FBD (NCE)	1995	9598	Price	24b	Straight (at ar	8.79	2.39	0.1	2.29	3
FBD (NCE)	1995	9598	Price	29b	LB = inside	8.91	0.95	0.1	0.85	3
FBD (RG)	1994	9498	Price	2	RB = inside	14.7	4.66	0.1	4.56	13
FBD (NCE)	1995	9598	Price	30b	Straight	9	16.3	0.1	16.2	3

Treatment[1]	Comp. years[3]	Creek	XS	NET Change in Baseline XS Area (sq. m)[6]	ANNUAL Rate of Change in Baseline XS area (sq. m/yr)	TARGET Rate of Change in Baseline XS Area (sq. m/yr)[7]	ANNUAL % Change in Baseline XS Area	Geomorphic Significance
OCE	9398	Muddy	2	-0.05	-0.01	-0.34	0	No Sign. Change
OCE	9398	Muddy	1	-0.03	-0.01	-0.37	0	No Sign. Change
OCE	9598	Muddy	26	-0.02	-0.01	-0.05	-1	No Sign. Change
OCE	9598	Muddy	25	0	0.00	-0.2	0	No Sign. Change
OCE	9698	Muddy	32	0.01	0.01	-0.29	0	No Sign. Change
OCE	9698	Muddy	31	0.05	0.03	-0.05	3	No Sign. Change
OCE	9698	Muddy	30	0.1	0.05	0	9	Channel area increases
OCE	9398	Muddy	13	0.2	0.04	-0.11	2	Channel area increases
OCE	9398	Muddy	12	0.79	0.16	-0.21	6	Channel area increases
NEE	9497	Hayground	4	-0.3	-0.10	-0.15	-6	Positive channel area decr.
NEE	9597	N. Basin	25	-0.25	-0.13	-0.13	-9	Sign. channel area decr.
NEE	9597	Main Basin	3	-0.25	-0.13	-0.26	-5	Positive channel area decr.
NEE	9597	Main Basin	2	-0.25	-0.13	-0.32	-4	Positive channel area decr.
NEE	9597	N. Basin	6	-0.21	-0.11	-0.17	-6	Positive channel area decr.
NEE	9597	N. Basin	5	-0.19	-0.10	-0.03	-25	Sign. channel area decr.
NEE	9597	Main Basin	1	-0.14	-0.07	-0.15	-4	Positive channel area decr.
NEE	9597	N. Basin	4	-0.01	-0.01	-0.13	0	No Sign. Change
NEE	9497	Hayground	6	0.05	0.02	-0.25	1	No Sign. Change
NEE	9497	Hayground	5	0.09	0.03	-0.05	5	Channel area increases
NCE	9597	S. Basin	9	-0.36	-0.18	-0.66	-3	Positive channel area decr.
NCE	9597	S. Basin	8	-0.3	-0.15	-1.02	-1	Positive channel area decr.
NCE	9398	Muddy	22	-0.27	-0.05	-0.1	-5	Positive channel area decr.
NCE	9398	Muddy	23	-0.25	-0.05	-0.09	-5	Positive channel area decr.

Treatment[1]	Comp. years[3]	Creek	XS	NET Change in Baseline XS Area (sq. m)[6]	ANNUAL Rate of Change in Baseline XS area (sq. m/yr)	TARGET Rate of Change in Baseline XS Area (sq. m/yr)[7]	ANNUAL % Change in Baseline XS Area	Geomorphic Significance
NCE	9497	L. Stinky	1	-0.19	-0.06	-0.09	-6	Positive channel area decr.
NCE	9497	L. Stinky	4	-0.092	-0.03	-0.15	-2	Positive channel area decr.
NCE	9597	S. Basin	7	-0.09	-0.05	-0.13	-3	Positive channel area decr.
NCE	9597	S. Basin	23	-0.07	-0.04	-0.19	-2	Positive channel area decr.
NCE	9497	Home	1	-0.06	-0.02	-0.05	-4	Positive channel area decr.
NCE	9497	Home	2	-0.021	-0.01	-0.04	-1	No Sign. Change
NCE	9497	Hayground	7	-0.02	-0.01	-0.06	-1	No Sign. Change
NCE	9497	Hayground	9	-0.02	-0.01	-0.05	-1	No Sign. Change
NCE	9497	L. Stinky	5	0.003	0.00	-0.04	0	No Sign. Change
NCE	9398	Muddy	24	0.01	0.00	0	1	No Sign. Change
NCE	9497	L. Stinky	3	0.07	0.02	-0.04	4	Channel area increases
NCE	9497	Hayground	8	0.09	0.03	-0.06	5	Channel area increases
NCE	9497	L. Stinky	2	0.09	0.03	-0.08	3	Channel area increases
NCE	9597	S. Basin	24	0.2	0.10	-0.53	2	Channel area increases
RG	9398	Muddy	11	-0.29	-0.06	-0.13	-3	Positive channel area decr.
RG	9398	Muddy	6	-0.26	-0.05	-0.11	-3	Positive channel area decr.
RG	9398	Muddy	10	-0.23	-0.05	-0.09	-3	Positive channel area decr.
RG	9398	N. Basin	26	-0.21	-0.11	-0.31	-3	Positive channel area decr.
RG	9398	Muddy	18	-0.18	-0.04	-0.08	-3	Positive channel area decr.
RG	9597	S. Basin	11	-0.16	-0.08	-0.71	-1	Positive channel area decr.
RG	9597	Main Basin	14	-0.13	-0.07	-0.55	-1	Positive channel area decr.
RG	9398	Muddy	15	-0.13	-0.03	-0.02	-3	Sign. channel area decr.
RG	9398	Muddy	4	-0.1	-0.02	-0.08	-2	Positive channel area decr.
RG	9398	Muddy	14	-0.09	-0.02	-0.05	-2	Positive channel area decr.
RG	9398	Muddy	9	-0.09	-0.02	-0.07	-1	Positive channel area decr.

Treatment[1]	Comp. years[3]	Creek	XS	NET Change in Baseline XS Area (sq. m)[6]	ANNUAL Rate of Change in Baseline XS area (sq. m/yr)	TARGET Rate of Change in Baseline XS Area (sq. m/yr)[7]	ANNUAL % Change in Baseline XS Area	Geomorphic Significance
RG	9398	Muddy	8	-0.08	-0.02	-0.15	-1	Positive channel area decr.
RG	9398	Muddy	5	-0.07	-0.01	-0.03	-2	Positive channel area decr.
RG	9597	Main Basin	15	-0.05	-0.03	-0.3	-1	No Sign. Change
RG	9598	Muddy	3	-0.05	-0.02	-0.14	-1	No Sign. Change
RG	9597	S. Basin	12	-0.05	-0.02	-0.43	-1	No Sign. Change
RG	9498	W. Fk. Price	7	-0.048	-0.01	-0.04	-3	No Sign. Change
RG	9597	Main Basin	16	-0.04	-0.02	-0.29	-1	No Sign. Change
RG	9498	W. Fk Price	4	-0.028	-0.01	-0.01	-3	No Sign. Change
RG	9498	W. Fk Price	6	-0.025	-0.01	-0.04	-1	No Sign. Change
RG	9597	N. Basin	21	-0.02	-0.01	-0.11	-1	No Sign. Change
RG	9598	Price	18	-0.01	0.00	-0.37	0	No Sign. Change
RG	9398	Muddy	7	-0.01	0.00	-0.27	0	No Sign. Change
RG	9597	N. Basin	22	0.01	0.00	-0.13	0	No Sign. Change
RG	9598	W. Fk. Price	32b	0.01	0.00	-0.02	1	No Sign. Change
RG	9597	Main Basin	27	0.01	0.01	-0.18	0	No Sign. Change
RG	9597	S. Basin	13	0.02	0.01	-0.22	0	No Sign. Change
RG	9597	N. Basin	20	0.04	0.02	-0.23	1	No Sign. Change
RG	9597	W. Fk Price	31	0.06	0.03	0	27	Channel area increases
RG	9598	Price	17e	0.06	0.02	-0.68	0	Channel area increases
RG	9597	N. Basin	18	0.08	0.04	-0.08	5	Channel area increases
RG	9498	W. Fk Price	5	0.119	0.03	-0.06	4	Channel area increases
RG	9398	Muddy	16	0.14	0.03	-0.17	1	Channel area increases
RG	9597	S. Basin	10	0.17	0.09	-0.79	1	Channel area increases
RG	9597	N. Basin	19	0.18	0.09	-0.1	8	Channel area increases
RG	9597	N. Basin	17	0.21	0.11	-0.2	5	Channel area increases
RG	9398	Muddy	19	0.22	0.04	-0.13	2	Channel area increases

Treatment[1]	Comp. years[3]	Creek	XS	NET Change in Baseline XS Area (sq. m)[6]	ANNUAL Rate of Change in Baseline XS area (sq. m/yr)	TARGET Rate of Change in Baseline XS Area (sq. m/yr)[7]	ANNUAL % Change in Baseline XS Area	Geomorphic Significance
RG	9597	Main Basin	28	0.25	0.13	-0.21	6	Channel area increases
RG	9398	Muddy	17	0.95	0.19	-0.17	9	Channel area increases
SEMA	9497	Mandan	3	-0.15	-0.05	-0.16	-3	Positive channel area decr.
SEMA	9497	L. Burro	4	-0.135	-0.05	-0.19	-2	Positive channel area decr.
SEMA	9497	Hayground	3	-0.11	-0.04	-0.09	-4	Positive channel area decr.
SEMA	9497	L. Burro	1	-0.1	-0.03	-0.19	-2	Positive channel area decr.
SEMA	9497	Mandan	2	-0.016	-0.01	-0.07	-1	No Sign. Change
SEMA	9497	Mandan	1	-0.01	0.00	-0.06	0	No Sign. Change
SEMA	9497	L. Burro	2	0.034	0.01	-0.1	1	No Sign. Change
SEMA	9497	Hayground	2	0.05	0.02	-0.08	2	No Sign. Change
SEMA	9497	L. Burro	3	0.05	0.02	-0.14	1	No Sign. Change
SEMA	9497	Mandan	6	0.084	0.03	-0.02	11	Channel area increases
SEMA	9497	Hayground	1	0.093	0.03	-0.13	2	Channel area increases
SEMA	9497	Mandan	4	0.14	0.05	-0.14	3	Channel area increases
SEMA	9497	L. Burro	5	0.144	0.05	-0.13	3	Channel area increases
SEMA	9497	Mandan	5	0.29	0.10	-0.1	9	Channel area increases
IBD (NEE)	9497	Price	15a	-1.75	-0.58	-0.18	-31	Sign. channel area decr.
IBD (NCE)	9597	Price	20a	-0.77	-0.39	-0.3	-13	Sign. channel area decr.
IBD (NEE)	9497	Price	13a	-0.666	-0.22	-0.14	-14	Sign. channel area decr.
IBD (NEE)	9497	Price	14a	-0.63	-0.21	-0.13	-16	Sign. channel area decr.
IBD (NCE)	9597	Price	27a	-0.4	-0.20	-0.4	-5	Positive channel area decr.
IBD (NCE)	9597	Price	21a	-0.28	-0.14	-0.2	-7	Positive channel area decr.
IBD (NCE)	9597	Price	26a	-0.27	-0.14	-0.26	-5	Positive channel area decr.
IBD (NCE)	9597	Price	23a	-0.19	-0.10	-0.16	-6	Positive channel area decr.

Treatment[1]	Comp. years[3]	Creek	XS	NET Change in Baseline XS Area (sq. m)[6]	ANNUAL Rate of Change in Baseline XS area (sq. m/yr)	TARGET Rate of Change in Baseline XS Area (sq. m/yr)[7]	ANNUAL % Change in Baseline XS Area	Geomorphic Significance
IBD (NCE)	9597	Price	19a	-0.04	-0.02	-0.11	-2	No Sign. Change
IBD (NCE)	9597	Price	22a	0.03	0.02	-0.21	1	No Sign. Change
IBD (NCE)	9597	Price	25a	0.04	0.02	-0.15	1	No Sign. Change
FBD (RG)	9495	Price	17a	-0.06	-0.06	-0.68	-1	No Sign. Change
FBD (NCE)	9798	Price	25	-0.03	-0.03	-0.15	-2	No Sign. Change
FBD (NCE)	9798	Price	19	-0.02	-0.02	-0.11	-2	No Sign. Change
FBD (NCE)	9798	Price	22	0.04	0.04	-0.22	2	No Sign. Change
FBD (NCE)	9598	Price	28b	0.09	0.03	-0.13	2	Channel area increases
FBD (NEE)	9798	Price	14b	0.15	0.15	-0.06	21	Channel area increases
FBD (RG)	9495	Price	18a	0.16	0.16	-0.35	4	Channel area increases
FBD (NCE)	9798	Price	21	0.21	0.21	-0.17	12	Channel area increases
FBD (NEE)	9798	Price	13b	0.24	0.24	-0.08	28	Channel area increases
FBD (NCE)	9798	Price	26	0.27	0.27	-0.23	11	Channel area increases
FBD (NCE)	9798	Price	27	0.39	0.39	-0.36	11	Channel area increases
FBD (NEE)	9798	Price	15b	0.53	0.53	0	442	Channel area increases
FBD (NCE)	9798	Price	23	0.53	0.53	-0.14	36	Channel area increases
FBD (RG)	9498	Price	16	0.95	0.24	-0.43	5	Channel area increases
FBD (NCE)	9798	Price	20	1.06	1.06	-0.22	46	Channel area increases
FBD (NEE)	9798	Price	33	1.08	1.08	-0.11	92	Channel area increases
FBD (NCE)	9598	Price	24b	1.24	0.41	-0.23	17	Channel area increases
FBD (NCE)	9598	Price	29b	1.34	0.45	-0.09	47	Channel area increases
FBD (RG)	9498	Price	2	1.39	0.35	-0.46	7	Channel area increases
FBD (NCE)	9598	Price	30b	1.86	0.62	-1.62	4	Channel area increases

[1] OCE = Old Cattle Exclosure, NEE = New Elk Excl., NCE = New Cattle Exclosure, RG = Riparian Guidelines, SEMA = Special Emphasis Management Area, IBD (NCE) = Intact beaver dam inside a newcattle exclosure, IBD (NEE) = Intact beaver dam inside an new elk exclosure, FBD (NCE) = Failing beaver dam inside a new cattle exclosure, FBD (NEE) = Failing beaver dam inside a new elk exclosure. FBD (RG) = Failing beaver dam in a Riparian Guideline area.

[2] The first year a cross-section was surveyed for a given treatment. If a treatment changed during the study it was assigned a new baseline year.

[3] The years for which the baseline geomorphic channel cross-section area, annual rate of cross-section area change, and net change values refer to.

[4] Baseline geomorphic channel cross-section area for a given cross-section under a given treatment. If the treatment changes over the course of the study, a new baseline area was assigned to the cross-section reflecting the cross-section area at the initiation of the new treatment.

[5]Estimated Pre-disturbance channel cross-section area = the value based on the smallest cross-section area surveyed for a given drainage area size with adjustments made for tributary contributions.

[6]Net Change = Baseline geomorphic cross-section area - Final geomorphic cross-section area

[7]Target Rate = Annual rate of change required to reduce the geomorphic channel cross-section area to its estimated pre-disturbance cross-section area in 10 years.

APPENDIX J

VALUES USED TO DETERMINE PERCENT REDUCTION IN THE GEOMORPHIC CHANNEL CAPACITY

Survey Year	Creek	XS	Geomorphic Channel Cross-section Area (sq. m)	Water-Filled Cross-section Area (sq. m)	Percent Reduction in Geomorphic Channel Capacity due to Water	Beaver Dam Condition
1995	Basin	1	1.59	0.28	18	N/A
1995	Basin	2	3.29	0.45	14	N/A
1995	Basin	3	2.69	0.47	17	N/A
1995	Basin	4	1.35	0.07	5	N/A
1995	Basin	5	0.38	0.19	50	N/A
1995	Basin	6	1.81	0.11	6	N/A
1995	Basin	7	1.35	0.23	17	N/A
1995	Basin	8	10.25	0.31	3	N/A
1995	Basin	9	6.69	0.37	6	N/A
1995	Basin	10	7.99	0.14	2	N/A
1995	Basin	11	7.21	0.14	2	N/A
1995	Basin	12	4.42	0.41	9	N/A
1995	Basin	13	2.32	0.14	6	N/A
1995	Basin	14	5.57	0.47	8	N/A
1995	Basin	15	3.12	0.25	8	N/A
1995	Basin	16	3	0.74	25	N/A
1995	Basin	17	2.12	0.05	2	N/A
1995	Basin	18	0.87	0.05	6	N/A
1995	Basin	19	1.08	0.09	8	N/A
1995	Basin	20	2.35	0.05	2	N/A
1995	Basin	21	1.17	0.02	2	N/A
1995	Basin	22	1.37	0.1	7	N/A
1995	Basin	23	1.97	0.08	4	N/A
1995	Basin	24	5.39	0.09	2	N/A
1995	Basin	25	1.36	0.03	2	N/A
1995	Basin	26	3.19	0.04	1	N/A
1995	Basin	27	1.91	0.13	7	N/A
1995	Basin	28	2.16	0.08	4	N/A
1995	Muddy	1	4.23	0.21	5	N/A

Survey Year	Creek	XS	Geomorphic Channel Cross-section Area (sq. m)	Water-Filled Cross-section Area (sq. m)	Percent Reduction in Geomorphic Channel Capacity due to Water	Beaver Dam Condition
1995	Muddy	2	4.05	0.41	10	N/A
1995	Muddy	3	1.96	0.28	14	N/A
1995	Muddy	4	1.33	0.46	35	N/A
1995	Muddy	5	0.72	0.26	36	N/A
1995	Muddy	6	1.55	0.37	24	N/A
1995	Muddy	12	3.20	0.43	13	N/A
1995	Muddy	13	1.77	0.22	12	N/A
1995	Muddy	14	0.95	0.27	28	N/A
1995	Muddy	15	0.69	0.14	20	N/A
1995	Muddy	16	2.26	0.5	22	N/A
1995	Muddy	17	2.50	0.65	26	N/A
1995	Muddy	22	1.08	0.11	10	N/A
1995	Muddy	23	0.75	0.08	11	N/A
1995	Muddy	24	0.18	0.08	44	N/A
1995	Muddy	25	2.54	0.43	17	N/A
1995	Muddy	26	1.04	0.26	25	N/A
1998	Muddy	1	4.24	0.22	5	N/A
1998	Muddy	2	3.86	0.34	9	N/A
1998	Muddy	3	1.91	0.21	11	N/A
1998	Muddy	4	1.19	0.37	31	N/A
1998	Muddy	5	0.74	0.2	27	N/A
1998	Muddy	6	1.40	0.35	25	N/A
1998	Muddy	12	3.37	0.45	13	N/A
1998	Muddy	13	1.84	0.25	14	N/A
1998	Muddy	14	0.93	0.29	31	N/A
1998	Muddy	15	0.63	0.17	27	N/A
1998	Muddy	16	2.32	0.61	26	N/A
1998	Muddy	17	3.15	0.9	29	N/A
1998	Muddy	22	0.85	0.11	13	N/A
1998	Muddy	23	0.73	0.05	7	N/A
1998	Muddy	24	0.15	0.04	27	N/A
1998	Muddy	25	2.54	0.56	22	N/A
1998	Muddy	26	1.02	0.24	24	N/A
1995	Price	17	6.84	0.38	6	N/A
1995	Price	18	3.79	0.49	13	Remnant beaver dam
1995	Price	19	1.23	1.23	100	Intact beaver dam
1995	Price	20	3.07	3.5	114	Intact beaver dam
1995	Price	21	2.09	1.29	62	Intact beaver dam
1995	Price	22	2.22	1.35	61	Intact beaver dam
1995	Price	23	1.68	1.39	83	Intact beaver dam

Survey Year	Creek	XS	Geomorphic Channel Cross-section Area (sq. m)	Water-Filled Cross-section Area (sq. m)	Percent Reduction in Geomorphic Channel Capacity due to Water	Beaver Dam Condition
1995	Price	24	2.39	1.76	74	Intact beaver dam
1995	Price	25	1.6	0.54	34	Intact beaver dam
1995	Price	26	2.71	1.01	37	Intact beaver dam
1995	Price	27	4.09	2.65	65	Intact beaver dam
1995	Price	28	1.43	0.55	38	Intact beaver dam
1995	Price	29	0.95	0.36	38	Intact beaver dam
1995	Price	30	1.63	0.5	31	Intact beaver dam
1998	Price	17	6.9	0.39	6	N/A
1998	Price	18	3.78	0.42	11	N/A
1998	Price	19	1.17	0.36	31	Failing beaver dam
1998	Price	20	3.36	0.54	16	Failing beaver dam
1998	Price	21	2.02	0.38	19	Failing beaver dam
1998	Price	22	2.29	0.21	9	Failing beaver dam
1998	Price	23	2.02	0.64	32	Failing beaver dam
1998	Price	24	3.63	1.01	28	Failing beaver dam
1998	Price	25	1.61	0.26	16	Failing beaver dam
1998	Price	26	2.71	0.53	20	Failing beaver dam
1998	Price	27	4.08	1.17	29	Failing beaver dam
1998	Price	28	1.52	0.25	16	Failing beaver dam
1998	Price	29	2.29	0.14	6	Failing beaver dam
1998	Price	30	3.49	0.18	5	Failing beaver dam

APPENDIX K

ESTIMATED AMOUNT OF SEDIMENT REQUIRED TO DECREASE THE GEOMORPHIC CHANNEL TO ITS PRE-DISTURBANCE CROSS-SECTION AREA

Creek	Cross-sections	Reach Length (m)	Av. Channel enlargement in a given reach (sq. m)	Total Sed. Require per Reach (cu. m) [1]
Basin	1, 2 and 3	69	2.42	167
Basin	4, 5, 6 and 25	100	1.13	113
Basin	7, 8, 9, 23 and 24	142	5.04	716
Basin	10, 11, 12 and 13	163	5.39	879
Basin	14, 15 and 16	150	3.77	566
Basin	17, 18 and 26	100	1.96	196
Basin	19, 20, 21, 22	150	1.4	210
Basin	27 and 28	100	1.91	191
Basin TOTAL		974	2.88	3038
Muddy	1, 2, 26, 30, 31, 32	200	1.84	368
Muddy	3, 4	210	1.1	231
Muddy	5, 6	150	0.71	107
Muddy	7, 8, 9	68	1.61	109
Muddy	10, 11	149	1.09	162
Muddy	12, 13, 25	152	1.72	261
Muddy	14, 15	149	0.36	54
Muddy	16, 17	149	1.66	247
Muddy	18, 19	149	1.08	161
Muddy	22	107	1.03	110
Muddy	23, 24	149	0.46	69
Muddy TOTAL		1632	1.29	1879
Price Creek	2	152	4.3	654
Price Creek	13, 14, 15, 33	115	1.39	160
Price Creek	16, 17, 18	100	4.81	481
Price Creek	19, 20, 21	100	2.03	203
Price Creek	22 - 27	200	2.35	470
Price Creek	28, 29	100	1.09	109
Price Creek	30	100	1.53	153
Price Creek (W. Fk)	4, 5	152	0.37	56
Price Creek (W. Fk)	6, 7	152	0.37	56
Price Creek (W. Fk)	31, 32	100	0.11	11
Price TOTAL		1271	1.835	2353
Hayground	1	150	1.33	200
Hayground	2, 3	150	0.87	131
Hayground	4, 5, 6	115	1.52	175

Creek	Cross-sections	Reach Length (m)	Av. Channel enlargement in a given reach (sq. m)	Total Sed. Require per Reach (cu. m) [1]
Hayground	7, 8, 9	115	0.55	63
Home	1, 2	113	0.43	49
Lower Burro	1, 2	100	1.45	145
Lower Burro	3, 4	114	1.64	187
Lower Burro	5	137	1.3	178
Lower Stinky	1, 2	57	0.825	47
Lower Stinky	3	57	0.43	25
Lower Stinky	4, 5	152	0.93	141
Mandan	1, 2	152	0.66	100
Mandan	3, 4, 5, 6	150	1.03	155
White Mts TOTAL		1562	1.00	1596
[1] Total sediment required = (average geomorphic channel enlargement for a given reach) x reach length.				
Foot ball field = 110 m x 49 m = 5390 sq. m				

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