ANALYSIS OF BANK EROSION ON THE ILLINOIS RIVER IN NORTHEAST OKLAHOMA

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CHAPTER ONE

INTRODUCTION

Streambank erosion is recognized as a major natural resource management problem. Streambank erosion causes damage to adjacent land and to downstream land, structures, and water bodies. Streambank erosion results in the loss of productive agricultural land and damages or destroys roads, bridges, and other structures (Hooke 1979, Grissinger and Bowie 1982). Accelerated streambank erosion contributes increased sediment loads to water bodies, thus magnifying such problems as reservoir and navigable waterway sedimentation (both of which require dredging or other maintenance), recreational opportunity decrease, commercial fishing harvest decrease, water treatment cost increase, and aquatic ecosystem damage (Ribaudo 1986).

Riparian zones, the ecological interfaces between upland and aquatic ecosystems generally defined as areas of trees and/or other vegetation located adjacent to and upgradient from surface water bodies (Welsch 1991, Anderson and Masters), have been shown to be effective in streambank stabilization (Rosgen 1993a, Shields et al. 1995, USDA-SCS 1985, Madej et al. 1994). Natural and restored riparian zones can reduce streambank erosion rates by several orders of magnitude (Rosgen 1993a) if their associated vegetation is both healthy and well-established. Riparian vegetation protects streambanks by decreasing water velocity and its erosive force, by creating a physical barrier between the water and the bank materials, and by binding bank materials with its root system (Cooper et al. 1990).

Under natural conditions, as streams migrate within their floodplains, they erode bank material and deposit an approximately equivalent amount on point bars and other areas where sediment loads exceed transport capacity (Leopold et al. 1964, Madej et al. 1994, USDA-SCS 1985). Thus, under natural conditions, streams maintain a dynamic, yet stable, channel condition (Kondolf and Micheli 1995). Streambank erosion is a natural process. However, human activities, such as removal of natural riparian vegetation, have accelerated streambank erosion rates by reducing the ability of streambanks to resist erosion. The stabilization of streambanks is an important function of riparian zone vegetation as unprotected streambanks contribute large amounts of sediment. Several recent studies have reported that streambank erosion contributes a large portion of the total sediment load in streams. Rosgen (1993a) concluded that accelerated streambank erosion caused by human activity contributes greater than 50% of total sediment produced in large Western watersheds. Bowie (1982, 1987) reported that stream channel erosion contributes up to 55% of total sediment yield in a northern Mississippi watershed. Odgaard (1987) cited a US Army Corp of Engineers study (1983) that reported streambank erosion contributed 59% of the total sediment load in the Sacramento River Basin in California.

Rosgen (1988) states that there is a need for and a slow-moving trend toward restoring the natural stability and function of river systems, as opposed to the imposed and often failed attempts of traditional "controls," such as channel straightening. Restoring and maintaining riparian zones is a step in that direction. Riparian vegetation helps streams maintain their natural, dynamic stable form in the presence of human disturbance.

With increased streambank erosion and its contribution to increased sediment loads in streams creating many detrimental impacts, data on streambank erosion is needed. Quantification of streambank erosion is vital to assessing bank erosion's contribution to negative agricultural, environmental, recreational, and economic impacts. This quantification is especially important on areas such as the Upper Illinois Basin in northeast Oklahoma (figure 1) that directly benefit from water-based recreation.

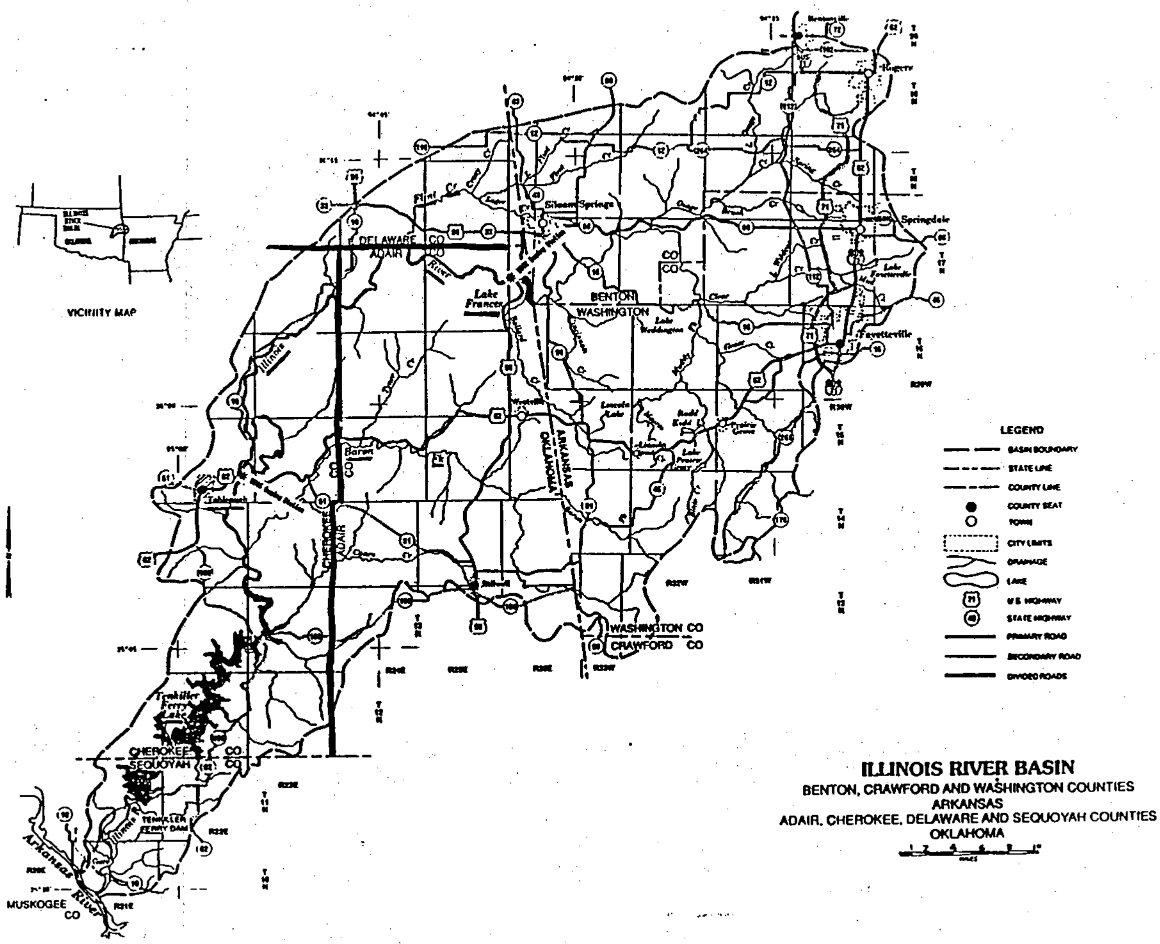

Figure 1: Map of Illinois River Basin (adapted from USDA-SCS 1991)

This research focused on bank erosion on the Upper Illinois River, a 63-mile section between Lake Frances and Lake Tenkiller (figure 1). This portion of the river, designated as an Oklahoma Scenic River, is an important recreational and economic resource. The importance of recreation is illustrated by the $1.6 million spent in the area by 114,000 canoeists in 1991. In recent years water quality degradation in parts of the Illinois River Basin has become apparent (USDA-SCS 1991). Water quality samples indicate that nutrients, bacteria, and turbidity often exceed standards for beneficial uses. Public concerns about decreased water quality may have already had a negative impact on recreation in the river basin. A sharp decline in recreational float trips on the Illinois from 1984 to 1990 has been attributed to negative reports of water quality problems in the river.

The specific objectives of this research on the Upper Illinois River in northeast Oklahoma are:

- to use bank pins and cross-sectional surveys to measure short-term bank erosion for selected bank sites with a range of physical, vegetative, and hydraulic conditions,
- to measure long-term erosion from 1958 to 1991 with aerial photographs,
- to evaluate the impact of riparian vegetation on short- and long-term erosion,
- to compare the short-term results of this study to similar work by D.L. Rosgen in the western US on bank erosion rates as a function of near bank stress (hydraulic factors) and bank erodibility (physical factors), and
- to estimate the contribution of bank erosion along the Illinois River to the sedimentation of Lake Tenkiller.

CHAPTER TWO

LITERATURE REVIEW

In an analysis of bank erosion and the influence of riparian vegetation on bank erosion along the Illinois River in northeast Oklahoma, several important aspects needed attention. Comparisons between natural erosion rates (dynamic stability of natural rivers) and accelerated bank erosion due to human influences were made. Methods of streambank erosion measurement, reported erosion rates, and the importance of riparian vegetation and of the stream classification context were also reviewed. A study site description of the Upper Illinois River Basin is also included.

Natural and Accelerated Bank Erosion

In natural, dynamic equilibrium, as streams migrate within their floodplains, they erode bank material from the outside of meander bends. Bank erosion can also occur along straight reaches but occurs most frequently slightly downstream from the axes of meander bends (Leopold et al. 1964). In stable streams, this erosion is balanced by deposition of an approximately equivalent amount of sediment on point bars and other areas where sediment loads exceed transport capacity (Madej et al. 1994, USDA-SCS 1985). Thus, under natural conditions, streams maintain a dynamic, yet stable, channel condition (Kondolf and Micheli 1995).

Erosion of streambank materials can occur by two mechanisms: 1) removal of bank material as flow contacts the streambank or "fluvial entrainment" and 2) mass movement of material due to gravity (Bowie 1982, Thorne 1982). The rate of bank erosion due to flow contact with bank materials depends on the relationship between the flow's force acting on the bank and on the bank's resistance to erosion or bank erodibility (Morisawa 1985, Thorne 1981). Flow in stream channels generates a shear stress, proportional to the boundary velocity gradient, on the channel bank and bed. To remain in equilibrium, the bank and bed materials must supply an equal and opposite shear resistance. If the flow shear stress exceeds the internal resistance of the material, bank and/or bed particles become entrained in the flow (Thorne 1982).

The mass movement of bank material by sloughing or sliding results from reduction in the upper bank's internal strength due to saturation, to undermining, or to foundation deterioration caused by seepage. Subsurface drainage toward the channel after the passage of high flow events, especially during rapid draw down, creates a force toward the channel and can also cause sloughing of bank materials (Leopold 1994, Thorne 1982). The rate of bank erosion due to mass failure depends on the relationship between gravitational forces, subsurface pressure, and the bank's resistance to mass failure, referred to as internal shear strength (Bowie 1982, Thorne 1981). Mass movement of bank material presents the next high flow event with easily available sediment (Leopold 1994).

River stability is defined by Rosgen (1996b) as the ability over time to transport detritus, sediment, and other material produced by the watershed, and flow in such a manner that the stream neither aggrades or degrades and maintains its dimension, pattern, and profile. Aggradation is defined as widespread deposition that increases the elevation of a channel bed, and degradation is the downcutting of a channel bed (Leopold 1994).

When a stream is stable, in this natural dynamic equilibrium, no net deposition or erosion occurs because the sediment supply from upstream is balanced by the flow's capacity to transport sediment (Willis 1981). A river's stability can be affected by significant changes in its watershed. If a river's sediment load input decreases significantly due to large-scale changes in watershed management, for example, and its discharge does not change; net bed scour and bank erosion may increase. Also, if a river's sediment load input increases significantly, bed aggradation may occur as sediment is deposited in the channel (Madej et al. 1994). The formation of these in-channel depositional features, referred to as midchannel bars, diverts flow which increases stress on banks and increases bank erosion rates (Leopold et al. 1964, Madej et al. 1994, Rosgen 1993a).

Streambank erosion is a natural process occurring as water flows from uplands to water bodies and within water bodies; however, man's activities have accelerated streambank erosion rates. Man's activities, including channelization, municipal storm drain construction, wetland conversion, and riparian vegetation destruction, all increase the frequency and magnitude of floods, and therefore, accelerate bank erosion rates (Rosgen 1993a, USDA-SCS 1985, Evans et al. 1992, Karr and Schlosser 1978, De Laney 1995, Anderson and Masters).

Channelization (levee construction, channel lining, and river straightening) reduces flow lengths, decreases channel infiltration rates, and decreases energy dissipation in the natural pool/riffle sequence (USDA-SCS 1985, Rosgen 1993b). The adverse impacts of river straightening, which include increased bank erosion, have been known for some time as evidenced by Gottschalk and Jones (1955).

In traditionally designed channels, all of the flow occurs in one channel. In natural alluvial channels, however, flow occurs in the three channels: the baseflow channel, the bankfull channel, and the floodplain, depending on flow magnitude (Rosgen 1993b). The baseflow channel or thalweg, the thread of the deepest portion of a stream channel (Leopold 1994), contains low flows. The bankfull channel contains intermediate flows. The floodplain contains high flows by allowing these flows to spread over a large area.

In order to contain the range of flows encountered, constructed channels are built overwidth. These overwidth channels do not allow natural floodplain flow during high flow events. Overwidth channels can lead to aggradation which occurs due to reduced stream energy. Once sediment deposition occurs and bar features form, pressure on banks increases and lateral migration occurs (Rosgen 1993b). Lined channels obviously do not erode, but upon outlet, they place tremendous pressure on unlined downstream banks. Municipal storm drains cause similar flow alteration because they circumvent normal flow routing processes thus decreasing lag times and discharging higher peak flows and higher flow velocities (Rosgen 1993a, Leopold 1994).

Wetland conversion and riparian vegetation destruction also increase the frequency and magnitude of floods, and therefore, accelerate bank erosion rates. Wetlands function as flow detention basins by reducing flow velocity and flow volume (De Laney 1995). Well-vegetated riparian zones, in both near bank regions and floodplains, have high infiltration rates (unless saturated during flood events) and convert rapid overland flow to subsurface flow that is released slowly (Anderson and Masters).

Measurement of Bank Erosion

In measuring bank erosion, remote sensing or intensive field study techniques can be used (Thorne 1981). The use of remote sensing data from maps or aerial photographs allows erosion to be examined over long channel lengths and long time periods. The use of intensive field studies, with erosion pins and/or surveys, provides valuable, detailed information (Lawler 1993).

A technique of analyzing bank erosion with the use of sequential aerial photographs is described in Brice (1982). The technique involves comparing enlarged, sequential photographs by superimposing sequential tracing of bank lines. A river bank tracing from one photograph can be superimposed over the river bank on another photograph or a river bank tracing from one photograph can be superimposed over a river bank tracing from another photograph. Areas in which the most recent bank line extends beyond the previous bank line are shaded. Second, the centerlines of the most recent channel are drawn with tick marks at intervals of two channel widths. At each tick mark, the linear distance of bank erosion (shortest distance between the sequential bank lines) is measured with a millimeter scale to the nearest half-millimeter. Linear distances are then determined according to map scale.

The use of surveys and bank pins are the most widely accepted methods of measuring bank erosion in the field. Surveys of bank edge profiles allow measurement of erosion over larger areas, and cross-sectional surveys allow measurement of erosion and deposition on the entire stream cross section. This technique requires establishment of permanent survey base points and requires more time than measurement of erosion with bank pins (Lawler 1993).

Bank pins can be installed and effectively used in alluvial material (Thorne 1981, Hooke 1979). Erosion pins allow accurate measurements of small amounts of erosion (0.01ft) quickly and easily because of their simplicity (Lawler 1993). The presence of pins does not seem to alter erosion in alluvial material but can possibly reinforce the soil and inhibit mass failure erosion. The use of bank pins in gravel deposits is not recommended because gravel deposits rely on frictional forces related to packing density and imbrication (overlapping) for strength (Hooke 1979, Thorne 1981). Installation of pins in gravel banks causes local weakness and increased erosion. In such gravel banks, spray painting of bank material can give indications of removal and deposition (Thorne 1981).

In a review of bank erosion studies, Lawler (1993) suggests that the smallest diameter pins possible (0.08 - 0.24 in) be used to limit public visibility and bank material disruption. Thorne (1981) suggests the use of 1.0 - 1.6 ft length, 0.25 in diameter reinforcing rods as bank pins, but Hooke (1979) suggests longer pins (at least 2.6 ft) to avoid loss of pins in actively eroding banks. Rosgen (1991) suggests the use of 4.0 - 5.0 ft length, 0.3 - 0.5 in diameter smooth rods as bank pins. Thorne (1981) prefers shorter bank pins to reduce the pins effect on cantilever stability. In previous research, Thorne (1978) noted that in the use of 3.3 ft pins, cantilever widths of 2.0 - 2.6 ft developed; however, natural cantilevers seldom exceeded 1.0 - 1.6 ft in width.

Reported Bank Erosion Rates

Bank erosion studies have been conducted for many years, with a majority in the last 30 years, by researchers from many disciplines. Lawler (1993) gives an extensive review of bank erosion studies, including techniques used and rates reported. Other research not reported by Lawler (1993) includes work by Brice (1982) and Odgaard (1987). Brice (1982) used the aerial technique to measure erosion rates on a number of US rivers and presented results from each of the sites studied. Measured erosion rates presented ranged from 0.12 - 9 m/yr, but no erosion was detected at several of the sites. One Oklahoma river, the North Canadian River near Guymon, was analyzed by Brice to have a median erosion rate of 4.5 m/yr during the study period.

Odgaard (1987) measured average erosion rates of 2 - 4 m/yr on bends of the East Nishnabotna and Des Moines Rivers of Iowa over 9 and 37 years, respectively. Odgaard used the sequential aerial photograph analysis procedure developed by Brice (1982). For the Des Moines River during the 37 year period, 0.56 ac of land per mile of river length was lost annually to erosion. Additional information on selected bank erosion studies is presented in table 1.

Riparian Vegetation Influence

Streambank stabilization is an important function of riparian zone vegetation as unprotected streambanks can contribute large amounts of sediment. Healthy riparian zones can reduce this streambank erosion rate by several orders of magnitude (Rosgen 1993a). Research by Dickinson and Scott (1979) showed that as agricultural activity in

Table 1: Information on Selected Bank Erosion Studies

study	stream	location	erosion	method
Brice (1982)	N. Canandian River	near Guymon, OK	median = 14.8 ft/yr	sequential aerial photographs
	White River	near Gregory, AR	median = 2.4 ft/yr	sequential aerial photographs
comments:	median of measurements taken at intervals of two channel widths			
Odgaard (1987)	E. Nishnabotna River	SW Iowa	mean = 9.2 ft/yr range = 3.3 - 23 ft/yr	sequential aerial photographs
	Des Moines River	SE Iowa	range = 7.9 - 12 ft/yr	sequential aerial photographs
comments:	rates determined by dividing the area by the length of the eroding bank only bends with centerline curve > 20 degrees were analyzed			
Rosgen (1996b)	various streams	Colorado	range = 0.02 - 3 ft/yr	bank pins
	various streams	Yellowstone National Park	range = 0.02 - 2.5 ft/yr	bank pins
comments:	only one year of erosion data was collected			
Hooke (1977 and 1979)	various streams	Devon, UK	range = 0.3 - 3.9 ft/yr	bank pins
comments:	342 pins used on meanders with alluvial material, 46 - 81% silt and clay			
Lawler (1984)	River Ilston	South Wales	0.1 - 1.0 ft/yr	bank pins
comments:	230 pins used on meander bend sites of gravel bed rivers with cohesive materials, 20 - 84% silt and clay			
Pizzuto (1994)	Powder River	Montana	mean = 36 ft median = 9.2 ft	cross-section surveys
comments:	12 sites analyzed for a 1978 flood			
	Powder River	Montana	mean = 10.2 ft median = 3.9 ft	cross-section surveys
comments:	12 sites analyzed from after the 1978 flood to 1991			

the riparian zone increases (vegetative cover decreases), bank erosion becomes sensitive to soil erodibility. However, when riparian areas are well-vegetated, even highly erodible banks remain relatively stable.

In another study, Beeson and Doyle (1996) used aerial photographs to test the hypothesis that riparian vegetation reduces lateral migration of small alluvial gravel streams (mean annual discharge 57 - 187 cfs) in Southern British Columbia, Canada. In this study Beeson and Doyle did not measure actual erosion rates but tested 748 bends on four streams for the presence of significant erosion (detectable from aerial photographs) caused by a 1990 flood (25 - 200 yr return interval on the four streams). Each bend was classified as vegetated, semi-vegetated, or non-vegetated. Their results indicated that non-vegetated banks were nearly five times more likely to undergo significant erosion than vegetated banks. They also found that major erosion (>147 ft) was 30 times more prevalent on non-vegetated banks than on vegetated banks.

Riparian vegetation protects streambanks by decreasing water velocity and its erosive force, by creating a physical barrier between the water and the bank materials, and by binding soil with its root system (Cooper et al. 1990). Riparian zone vegetation slows flow velocity in stream channels during average flows and in associated flood plains during high flows. Riparian zone vegetation thus reduces the detachment capability and transport capacity of stream flow by increasing the channel boundary roughness (Hickin 1984). Adamus and Stockwell (1983) cited a previous study that reported "scrub-shrub" (brush) vegetation reduced flow velocity at a vegetated bank by as much as 50%.

Riparian vegetation also protects streambanks by creating a physical barrier between the water and bank. Plants that cover a large portion of the soil surface area or flatten during flow are especially effective. In a hypothesized ranking of wetland systems for protecting shorelines from erosion, forested and "scrub-shrub" (brush) systems were rated the highest (Adamus and Stockwell 1983). These high rankings were attributed to tree and shrub's deep roots, good layering ability, high regenerative capacity, and long life span.

The root system of riparian vegetation binds soil particles together, and thus contributes to streambank stability by mechanically reinforcing soil. A thorough discussion on the role of vegetation in the stability and protection of slopes appears in Gray and Leiser (1982). Specifically, in regards to riparian zone vegetation, the diversity of plant species (grasses, shrubs, and trees) present in native and healthy restored riparian zones produce a combination of woody and fibrous roots that effectively promotes stable stream banks (Elmore 1992). The degree of protection increases with increasing root depth and with increasing root mass density (Rosgen 1993a). In restored riparian zones, the degree of protection increases with time as plants grow and establish root networks (Kondolf and Micheli 1995). Also, restored riparian zone vegetation may establish and mature more quickly than naturally invading vegetation (Shields et al. 1995). Even in degraded channels, healthy riparian zones have been shown to give bank soils additional strength, thus preventing bank collapse under a new channel disturbance (Shields et al. 1995).

On small to intermediate streams (approximately less than 4th order) riparian vegetation exerts significant bank and channel control (Meehan et al. 1977) and can dominate channel morphology in very small streams (Hickin 1984). In larger streams and rivers, however, riparian vegetation has much less, but possibly significant, impact on bank and channel control because of the large magnitude of hydraulic forces involved (Hickin 1984).

As well as stabilizing streambanks, riparian zone vegetation also provides other well-documented and accepted benefits. Healthy riparian zones offer water quality protection by: 1) reducing flood heights through increased infiltration, storage, and slow release of runoff water (this function is performed when upland riparian areas detain water and reduce downstream floods); 2) reducing flow velocities and detachment from banks and floodplains; 3) providing large woody debris and organic matter to streams which improves wildlife habitat; 4) filtering sediments and associated pollutants from surface flow; and 5) increasing infiltration, thereby trapping sediment, nutrients, and chemicals. If managed properly, riparian zones can provide these water quality benefits and provide important wildlife habitat, shade streams providing improved aquatic habitat, support productive forests which can be harvested periodically, and provide productive livestock pasture (Anderson and Masters, NCDEHNR-DEM 1991, Rosgen 1993a, USDA-SCS 1985, Snyder and Snyder 1994, Ice 1995, Kuenzler 1988).

Rosgen's River Classification System

Many previous efforts have been made at classifying streams and rivers, but currently the most widely accepted manner of describing channels is the Rosgen system (Leopold 1994). Rosgen (1994) lists the following objectives of his work to categorize river systems by channel morphology: 1) to predict a river's behavior from its appearance, 2) to develop specific hydraulic and sediment relations for a given morphological channel type and state, 3) to provide a mechanism to extrapolate site-specific data collected on a given stream reach to reaches of similar character, and 4) to provide a consistent and reproducible frame of reference of communication for those working with river systems in a variety of disciplines.

This classification system developed by David L. Rosgen describes individual reaches, short lengths of channel, on the basis on channel dimension, pattern, and profile. The current physical appearance (dimension, pattern, and profile) of rivers results from a complex combination of variables relating the adjustment of river boundaries to current streamflow conditions and sediment regime (Rosgen 1994). As stated by Leopold et al. (1964), stream pattern morphology is directly influenced by channel width, depth, and hydraulic roughness, water surface slope, discharge velocity and volume, and sediment load and size. Similarly stated by Morisawa (1985), at each stream reach, morphology is determined by flow velocity, discharge and shear, by channel width, depth, slope, and pattern (of the reach and directly upstream), by load size and amount, and by bed and bank material. A change in any of these variables causes a channel adjustment which affects the other variables and results in a change in channel form (Rosgen 1994, Morisawa 1985).

The related, quantifiable variables are included in the Rosgen classification system (Rosgen 1994). These variables include: entrenchment ratio, width to depth ratio, channel sinuosity, channel slope, and channel material size.

Entrenchment ratio is the ratio of the width of the flood-prone area to the bankfull width of the channel. Bankfull discharge is the flow which just fills the channel to flood stage (Rosgen et al. 1986). The bankfull discharge is a flow that has a return period of one to two years or approximately 1.5 years for most streams (Leopold et al. 1964, Rosgen et al. 1986, Morisawa 1985). The width of the flood-prone area is the width measured at the depth that is twice the maximum depth at bankfull discharge. *Width to depth ratio* is the ratio of the bankfull channel width to the average bankfull depth. The average bankfull depth can be calculated by averaging the bankfull depths taken at equal intervals or by dividing the cross-sectional area by the bankfull width. *Sinuosity* is the ratio of stream thalweg length to valley length or equivalently the ratio of valley slope to stream thalweg slope, but only if the change in valley elevation equals the change in stream elevation. *Water surface slope* is the change in water surface elevation per unit stream length. *Channel material size*, determined by a pebble count, is reported as the D_{50} particle size. If the D_{50} particle is not present in the channel, the dominant particle size is used. The dominant particle size is the size that was sampled most frequently in the pebble count. Possible channel material types are bedrock, boulder, cobble, gravel, sand, and silt/clay.

Entrenchment ratio and width to depth ratio, two of the variable discussed above, depend on bankfull discharge measurements. Bankfull discharge has morphologic and hydrologic significance as bankfull discharge is considered to be the channel-forming or effective discharge, the discharge that carries the largest amount of sediment (Leopold 1994, Morisawa 1985). Because large floods rarely occur and because low flows transport small amounts of sediment, frequent intermediate discharges transport the largest long-term amounts of sediment (Leopold 1994, Morisawa 1985). Studies by Andrews (1980) showed that the effective discharge is approximately equal to the bankfull discharge.

The Rosgen stream reach classification system consists of four levels in a hierarchical system (Rosgen 1996b):

1) Level I classification, a broad, geomorphic characterization, can be made with channel slope, shape, and pattern observations from topographic maps and aerial photographs;

2) With knowledge of channel pattern (single thread or multiple thread) along with data on the entrenchment ratio, width to depth ratio, sinuosity, slope, and bed material size, a stream reach can be classified to the Rosgen Level II;

3) Rosgen Level III classification, an assessment of stream condition, includes: 1) Rosgen Level II stream classification - based on the entrenchment and width/depth ratios, sinuosity, slope, and dominant channel material; 2) bank erosion potential (BEP) and near bank stress (NBS) ratings; 3) additional information such as organic debris in the active channel, riparian vegetation, flow regimen, depositional features, and meander patterns; and 4) a Pfankuch Stream Reach Inventory and Channel Stability Evaluation (Pfankuch 1975). The Pfankuch evaluation uses fifteen parameters including landform slope, vegetative bank protection, channel capacity, bank rock content, and consolidation of channel particles to estimate channel stability (Pfankuch 1975); and

4) Level IV classification consists of measurements on sediment transport and size distribution, on streamflow conditions, and on bank and channel stability. Level IV is the field data verification, monitoring, and prediction step.

Study Site Description

A 1991 report by the USDA-SCS presents a good general description of the Illinois River Basin located in northwest Arkansas and northeast Oklahoma (figure 1). The headwaters of the Illinois River begin in Arkansas' Ozark region. The Illinois meanders westerly through Arkansas and into Lake Frances on the Oklahoma/Arkansas border. In Oklahoma, the Illinois meanders westerly for approximately 14 miles below the Lake Frances dam then southwesterly another 49 miles to Lake Tenkiller (also referred to as Tenkiller Ferry Lake and Tenkiller Reservoir). Below the Lake Tenkiller dam, the river flows approximately 8 miles to its confluence with the Arkansas River. This study focuses on the 63-mile portion of the Illinois River in Oklahoma from the dam on Lake Frances to Horseshoe Bend on the head waters of Lake Tenkiller.

In the study area, the United States Geological Survey (USGS) currently operates four gage stations (Blazs, et al. 1997). The two gages on the river, the Watts gage station, 0.5 miles below the Lake Frances Dam, and the Tahlequah gage station, approximately 52 miles below the Frances Dam, have contributing drainage areas of 635 and 959 miles^2, respectively. The gage stations on two major tributaries, Flint Creek and Baron Fork, have contributing drainage areas of 110 and 307 miles^2, respectively. The total drainage area of the basin is 1671 miles^2 (USDA-SCS 1991).

The Illinois River maintains a perennial flow, as subsurface flow provides flow even in extended periods with no surface runoff (USDA-SCS 1991). Flow in the Illinois is generally highest in March, April, and May and lowest in July, August, and September

(Blazs, et al. 1997). For the Tahlequah gage station, the average annual flow is 935 cfs and the average annual runoff is 13.24 in (Blazs, et al. 1997).

The average annual precipitation in the Illinois River Basin ranges from 40 to 54 in, but most of the basin receives an average of 40 to 46 in (USDA-SCS 1991). The heaviest rains are generally associated with frontal passage in the spring and fall. Rainfall amounts are generally greatest in April through June and least in December through February.

Lake Tenkiller, located in Cherokee and Sequoyah counties of Oklahoma, is the only major active reservoir on the Illinois River. Lake Tenkiller, a U.S. Army Corps of Engineers structure, began full flood control operation in 1953 (USDA-SCS 1991). Prior to 1990, Lake Frances also influenced flow in the Illinois River. In 1990, however, as a result of decreased flood storage due to sediment accumulation, much of the Lake Frances dam was destroyed in a large flow event. Today Lake Frances is little more than a shallow swamp.

The dominant soil associations in the Oklahoma portion of the basin are the Waben-Midco-Razort, which occurs on bottomlands and terraces, and the Clarkesville-Nixa-Noark, which occurs on uplands (USDA-SCS 1991). The Waben-Midco-Razort association consists of very deep, well-drained, moderate to rapidly permeable, gravelly soils on gentle to flat slopes. The Clarkesville-Nixa-Noark association consists of well-drained, moderate to very slowly permeable, soils on gentle to very steep slopes.

Two important groundwater formations, the Boone Chert formation and the Roubidoux formation, underlie the Illinois River Basin (USDA-SCS 1991). Terrace and alluvial deposits along the Illinois River also provide some groundwater supplies. The

Boone Chert formation is recharged from local percolation through the highly permeable overlying cherty soil and through numerous fractures in rock outcrops. This formation produces many springs that provide baseflow to streams in the basin. The Roubidoux formation, a deeper sandstone and sandy/cherty dolomite formation, is recharged from precipitation on its outcrop area in southwest Missouri.

Land use in the Illinois River Basin is dominated by grassland and forest land (USDA-SCS 1991). Grassland covers 45% of the watershed and forest land covers 44%. Other land uses include cropland (2%), orchards and vineyards (1%), urban areas (6%), and other land uses such as confined animal feeding operations and roads (2%).

A 1991 USDA-SCS and a 1994 Oklahoma Cooperative Extension Service (OCES) report list negative water quality impacts caused by point and nonpoint source pollution in the basin. The impacts listed include increased eutrophication, alteration of fish communities, increased turbidity causing "murky water," increased river width and decreased depth, and decreased recreational and aesthetic value.

The 1991 USDA-SCS report lists potential point and nonpoint source pollution sources for the Illinois River. These sources include sewage effluent, industrial discharges, soil erosion, commercial nursery runoff, gravel removal, road construction, recreation, irrigation return, uncontrolled solid waste disposal, fertilizer and pesticides, land application of animal wastes, and improper disposal of dead animals. This extensive list does not include bank erosion as a significant source of pollution. This exclusion may be due to the lack of data on bank erosion.

The 1994 OCES report and a cooperative report produced by Oklahoma State University and the University of Arkansas (1991) list many of these same pollution sources as contributing to water quality degradation in the Illinois River. These reports, however, do include accelerated bank erosion and several of its probable causes, including riparian vegetation destruction and unmanaged cattle access to streambanks, as contributors to water quality degradation in the river. Because of the potential for bank erosion to degrade water quality and because no data exists on bank erosion on the Illinois River, bank erosion and its contribution to the pollution problems of the Illinois River need to be studied.

CHAPTER THREE

METHODS

Research for this project was conducted in several steps. First, in July 1996, a bank characterization trip on the Upper Illinois River was made to gather physical, vegetative, and hydrologic data on eroding and stable banks. Characterized banks were grouped according to bank physical and vegetative conditions and hydrologic influence. At least one bank from each group was selected for detailed field study. Erosion was measured using bank pins and cross-sectional surveys from August/September 1996 through July 1997. Bank erosion was also measured from aerial photographs using a method modified slightly from Brice (1982).

Initial Bank Characterization

A canoe trip down the Illinois River from below the Lake Frances dam to Horseshoe Bend on the upper portion of Lake Tenkiller was made during July 1996 to characterize bank conditions of eroding banks. Several stable banks were also characterized to provide a comparison with eroding banks. Eroding banks, especially those eroding by mass wasting or sloughing, are indicated by high banks, steep slopes, and limited vegetation and/or limited roots in the lower half of the banks (USDA 1996). The photographs of site 065b in Appendix A illustrate these eroding bank characteristics. The boundaries of eroding banks were delineated by a change from the properties listed above to well-vegetated and/or gently sloping areas. Banks with significantly different characteristics along their length of the bank were broken into homogeneous segments.

In an effort to measure only significant eroding banks, only banks exceeding a minimum area criteria were measured. This criteria was adjusted during the bank characterization trip as knowledge of the sizes of eroding banks was gained. Most eroding banks were judged significant for characterization if their area, length times height above water, exceeded approximately 1000 ft^2; however, several sites less than 1000 ft^2 were characterized.

The length, height above water, angle, river position, location, material, vegetation type and percent cover, root depth and density, maximum water depth, bankfull discharge depth, and percent flow in the near bank region under bankfull flow conditions was recorded for each eroding bank meeting a minimum criteria based on area and for several stable banks. Figure 2 illustrates the bank height, bank angle, and bankfull discharge depths measurements.

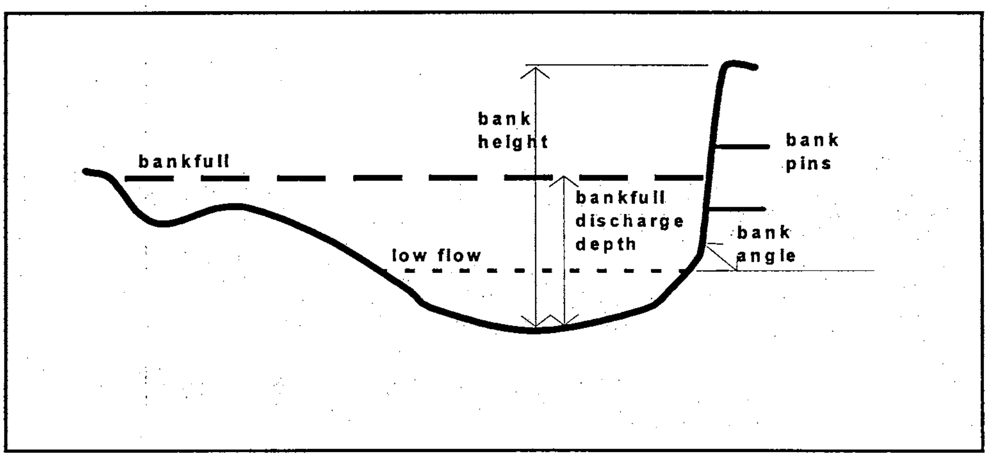

Figure 2: Cross Section of Site 015 Illustrating Bank Measurements Made in the Field

The length of each bank was measured along the edge of the water with a range finder or hip chain. The bank height, defined for this study as the vertical distance from the bottom of the channel thalweg to the top of the bank, and maximum water depth were measured with a survey rod. The bank angle, inclination of the bank from horizontal, was estimated visually. The river position represents the side of the river based on the downstream view and the position in a bend or straight. The location of each bank, recorded in Universal Transverse Mercator (UTM) coordinates, was determined with a Global Positioning Satellite (GPS) receiver with +/- 100 ft accuracy. Each eroding bank was plotted on a 1:24,000 scale topographic map. Bank material, dominant vegetation type and percent cover, and root depth and density were estimated visually. Root density was estimated as percent of the bank, within the rooting depth, covered by exposed roots.

The percent flow in the near bank region at bankfull flow was estimated from water depth measurements and visual bankfull indicators. The near bank region is defined as the third of the bankfull channel nearest the bank of interest (Rosgen 1996b). Specifically, the bankfull level was estimated based on the presence of bankfull indicators such as the tops of point bars, changes in vegetation type or bank material size distribution, and breaks in topography (Leopold 1994). Then, water depth measurements were taken to estimate the cross-sectional area of the near bank region and the total cross-sectional area. With an estimate of the relative cross-sectional areas of the near bank region and of the entire cross-section, an estimate of the percent flow in the near bank region under bankfull flow conditions was made. The assumption that flow is proportional to area, used in Rosgen's NBS calculation technique, was also used in this research to follow his procedure (Rosgen 1996a).

Selection of Banks for Detailed Study

After the bank characterization trip, data on exposed banks gathered on the bank characterization trip were analyzed to select banks for detailed erosion study. First, a bank erosion potential (BEP) developed by Rosgen (1996b) as part of Level III classification was assigned to each characterized bank. Five parameters are needed to calculate the BEP. These parameters are: 1) ratio of bank height to bankfull discharge depth near the bank, 2) ratio of root depth to bank height, 3) root density, 4) bank angle, and 5) percent bank surface protection (the percent of the bank covered by vegetation). Each parameter value corresponds to a numerical index. Once the numerical index value for each parameter was determined, the index values were added. This sum was then adjusted based on bank materials and stratification. Gravel banks were given a 5 point adjustment upward, banks with a mixture of silt and gravel were adjusted 10 points upward, and stratified banks were adjusted 10 points upward. From this numerical index, a bank erosion potential rating of extreme (> 45), very high (40 - 45), high (30 - 39.5), moderate (20 - 29.5), low (10 - 19.5), or very low (5 - 9.5) was assigned to each bank. An example of the BEP rating calculation appears in table 2a. Data used in this example appears in tables 3a and 3b.

A near bank stress estimate developed as part of Level III classification (Rosgen 1996a) was also assigned to each bank. The estimates, made in the initial bank characterization trip, were assigned according to estimates of the percent flow in the near bank region under bankfull conditions. Adjustments were also made for extreme hydraulic conditions in areas such as sharp bends and islands where the near bank stress

Table 2a: Bank Erosion Potential Calculation Example

site	010
bank height above water (ft)	7
water depth (ft)	6
bankfull discharge depth (ft)	8
root depth (ft)	4
root density (%)	50
bank angle (deg)	80
surface protection (%)	80

parameter	value	value range	corresponding index range	numerical index
bank height/bankfull height	1.62	1.6 - 2.0	6.0 - 7.9	6.10
root depth/bank height	0.31	.30 - .49	5.9 - 4.0	5.82
root density (%)	50	30 - 54	5.9 - 4.0	4.32
bank angle (deg)	80	61 - 80	4.0 - 5.9	5.90
surface protection (%)	80	80 - 100	1.9 - 1.0	1.90
			sum =	24.04
			adjustments:	
			bank material =	0
			stratification =	0
			bank erosion potential =	24.04
			rating =	moderate

Table 2b: Bank Erosion Potential (from Rosgen 1996b)

BANK EROSION POTENTIAL

CRITERIA	VERY LOW		LOW		MODERATE		HIGH		VERY HIGH		EXTREME	
	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX	VALUE	INDEX
Bank Ht/Bkf Ht	1.0-1.1	1.0-1.9	1.1-1.19	2.0-3.9	1.2-1.5	4.0-5.9	1.6-2.0	6.0-7.9	2.1-2.8	8.0-9.0	>2.8	10
Root Depth/Bank Ht	1.0-0.9	1.0-1.9	0.89-0.50	2.0-3.9	0.49-0.30	4.0-5.9	0.29-1.15	6.0-7.9	0.14-.05	8.0-9.0	<.05	10
Root Density (%)	80-100	1.0-1.9	55-79	2.0-3.9	30-54	4.0-5.9	15-29	6.0-7.9	5-14	8.0-9.0	<5.0	10
Bank Angle (Degrees)	0-20	1.0-1.9	21-60	2.0-3.9	61-80	4.0-5.9	81-90	6.0-7.9	91-119	8.0-9.0	>119	10
Surface Prot. (%)	80-100	1.0-1.9	55-79	2.0-3.9	30-54	4.0-5.9	15-29	6.0-7.9	10-15	8.0-9.0	<10	10
TOTALS												
		5-9.5		10-19.5		20-29.5		30-39.5		40-45		46-50
Numerical Adjustments												

Table 3a: Bank Characterization Data

site	length (ft)	height* (ft)	angle (deg)	side**	position	location UTM (east)	location UTM (north)	bank material***	root depth (ft)	root cover (%)
001	443	10	50	left	outside bend	359048	3999109	silt	1	50
002	230	13	70	right	straight	358426	3999369	silt and gravel	2	70
003	410	7	80	right	straight	358144	3999356	silt and gravel	4	50
004a	115	12	80	left	straight	357874	3999456	silt and gravel	6	70
004b	128	9	80	left	straight	357874	3999456	silt and gravel	8	40
005	246	6	80	right	outside slight bend	357464	3999352	silt/gravel	2	80
006	394	12	75	right	straight	356922	3998858	silt and gravel	3.5	60
007	394	6	55	right	inside bend	356669	3998445	gravel	2	50
008	1132	13	80	right	straight	356652	3998528	silt and gravel	2	70
009	476	5	65	right	outside bend	355929	3999324	gravel	3	60
010	755	7	80	right	straight	355338	4000154	silt	4	50
011	919	8	75	right	straight	355335	4000178	silt/gravel	2	30
012	262	6	80	left	outside bend	354576	4000240	gravel	1	25
013	361	4	85	right	outside slight bend	354493	4000340	gravel	1.5	40
014	345	10	70	left	straight	353856	4000552	silt and gravel	3	60
015	656	14	85	right	outside bend	353398	4000331	silt/gravel/silt/gravel	0.5	30
016a	197	13	75	right	outside bend	352622	3999767	silt and gravel/gravel	2	60
016b	787	10	65	right	outside bend	352622	3999767	silt and gravel/gravel	5	20
016c	459	6	75	right	outside bend	352622	3999767	silt and gravel/gravel	3	40
017	295	10	70	left	outside bend	352126	3999427	gravel	3	60
018	820	12	70	left	outside bend	351868	3999355	silt/gravel	5	30
019a	394	4	80	right	outside bend	351542	3999892	silt/gravel	3	60
019b	361	8	80	right	outside bend	351542	3999892	silt/gravel/bedrock	4	30
020a	394	3	75	right	outside bend	351029	4000119	silt/gravel	3	40
020b	459	6	75	right	outside bend	351029	4000119	silt and gravel	3	40
021	673	7	75	left	outside slight bend	350788	4000139	silt/gravel	2	50
022	98	4	50	left	inside bend	349890	4000910	gravel	1	60
023	249	4	70	right	straight	349600	4000095	silt/gravel	1	60
024	312	4	85	right	straight	349450	4001412	silt/silt and gravel	1.5	60
025	1116	7	80	left	outside slight bend	349044	4001781	silt and gravel	1	25
026a	148	12	70	right	outside bend	348672	4001960	silt	0.5	30
026b	131	12	45	right	outside bend	348672	4001960	silt/bedrock	0.5	30
026c	1558	8	70	right	outside bend	348672	4001960	silt	0.5	30
027	476	5	60	left	outside bend	348205	4002076	gravel	2	50
028	279	11	70	left	inside bend	347511	4002011	silt	5	50
029	328	3	45	right	straight	347418	4001816	gravel	1.5	50
030	246	4	60	left	inside bend	347170	4001751	gravel	1	55
031	492	10	70	right	outside bend	347170	4001751	gravel	1	50
032	584	4	50	left	outside slight bend	346555	4001120	gravel	0.5	50
033	820	7	90	right	outside bend	346584	4001997	silt and gravel/gravel	2	70
034	377	4	75	left	outside bend	345927	4001758	gravel	1.5	50
035a	1421	10	85	right	straight	345989	4001900	silt and gravel/gravel	3	70
035b	220	8	80	right	outside bend	345989	4001900	silt and gravel/gravel	2	30
036a	361	6	85	left	outside bend	346080	4002418	silt and gravel/gravel	5	15
036b	312	10	90	left	outside bend	346080	4002418	silt and gravel/gravel	5	15
037	98	9	85	right	outside bend	346250	4002714	silt w/ cobbles	2	40
038	213	3	60	right	straight	345797	4003070	gravel	0.5	15
039	210	6	70	right	outside bend	345343	4003502	gravel	1	40
040a	394	8	80	left	outside bend	345343	4003502	silt/gravel	3	60
040b	345	8	85	left	outside bend	345343	4003502	silt/gravel	3	60
040c	243	5	85	left	outside bend	345343	4003502	silt	3	60
041a	328	5	80	right	outside bend	345316	4004069	silt/gravel	2	50
041b	755	8	80	right	outside bend	345316	4004069	silt/gravel	2.5	50
042a	459	10	80	right	outside bend	345311	4004354	silt and gravel/gravel	0.5	20
042b	269	6	70	right	outside bend	345311	4004354	silt and gravel/gravel	1	70
043	230	7	85	left	outside bend	344830	4003851	silt and gravel/gravel	1.5	30
044	459	4	40	right	straight	344836	4003793	gravel	0.5	10
045a	525	8	80	left	outside bend	344755	4003602	silt/gravel	2	50
045b	541	8	85	left	outside bend	344755	4003602	silt/gravel	4	30
046	623	4	60	left	outside bend	343907	4002579	silt/gravel	1	60
047	361	4	80	right	straight	343869	4002282	gravel	0.5	30
048	262	3	50	right	inside bend	343680	4002208	gravel	2	40
049	853	7	85	right	straight	343118	4002014	silt	4	70
050a	607	4	60	left	straight	342426	4000824	gravel	4	70
050b	1017	5	80	left	straight	342426	4000824	gravel	4	20
051a	902	7	85	left	outside bend	342209	4000229	silt/gravel	6	40
051b	295	7	85	left	outside bend	342209	4000229	silt/gravel	3	15
052	236	5	65	right	outside slight bend	341615	3999447	gravel	1	40
053	558	8	80	left	outside slight bend	341631	3999416	silt/gravel	1	50
054	748	10	70	left	outside slight bend	340654	3998251	silt/gravel	3	60
055	361	3	85	right	straight	339432	3996645	gravel	0.5	10

056	951	5	85	left	outside bend	339432	3996645	silt/gravel	1	50
057	525	8	85	left	outside bend	338705	3996434	gravel	4	35
058	276	8	85	left	outside bend	338391	3996730	silt and gravel	3	60
059	492	6	70	left	outside bend	338149	3996857	silt/gravel	2	70
060a	459	12	80	right	inside slight bend	337540	3999314	silt/gravel	2	30
060b	722	10	80	right	inside slight bend	337540	3999314	silt/gravel	1	70
060c	361	8	85	right	inside slight bend	337540	3999314	silt/gravel	0.5	20
061	262	6	60	left	outside slight bend	337505	3997370	gravel	0.5	10
062a	459	7	60	right	outside bend	337340	3997982	gravel/silt	2	30
062b	230	10	85	right	outside bend	337340	3997982	silt/gravel	1.5	20
063	459	8	50	left	outside bend	337028	3997888	gravel	3	80
064	738	6	60	right	outside bend	336555	3997302	gravel	0.5	30
065a	459	9	70	right	outside bend	336508	3996788	silt/gravel	0.5	40
065b	190	11	90	right	outside bend	336508	3996788	silt/gravel	0.25	40
066a	115	7	75	right	straight	336150	3996360	silt	0.5	30
066b	262	6	65	right	straight	336150	3996360	silt	2	35
067	295	6	70	right	straight	335762	3996255	silt	0.5	45
068	738	5	85	right	outside bend	335762	3996255	gravel	0.5	35
069a	230	7	60	left	outside slight bend	335048	3995451	silt	2	40
069b	328	5	60	left	outside slight bend	335048	3995451	gravel	2	40
070a	459	8	80	right	outside bend	334822	3995337	silt/gravel	3	50
070b	361	6	70	right	outside bend	334822	3995337	silt/gravel	0.5	60
071	312	4	60	left	straight	334643	3995061	silt/gravel	1	50
072a	459	9	80	right	outside bend	333769	3994281	silt/silt and gravel	3	60
072b	820	10	85	right	outside bend	333769	3994281	silt/silt and gravel	1	20
073	755	6	75	right	outside bend	333439	3993833	gravel	2	30
074a	705	21	65	left	outside bend	333429	3993602	silt and gravel	2	40
074b	427	6	85	left	outside bend	333429	3993602	silt	1	30
075	1050	9	85	left	outside bend	332800	3993378	silt/gravel/silt/gravel	1.5	60
076	656	7	60	right	outside bend	332065	3993162	silt/gravel/silt/gravel	2	20
077	459	9	65	right	outside slight bend	331687	3993071	silt/gravel	1.5	20
078	722	12	60	right	outside bend	300928	3993065	silt w/ gravel and cobbles	2	70
079	410	9	85	right	outside bend	330250	3992000	silt/gravel	2.5	60
080	1198	8	80	left	outside bend	329100	3991000	silt/gravel	3	80
081	276	12	90	right	outside bend	329000	3991310	gravel	0.5	20
082	262	4	45	right	outside bend	328320	3990860	gravel	2	35
083	722	7	70	left	outside bend	328400	3990620	silt/gravel	1	60
084a	312	5	70	left	outside bend	328480	3990210	silt	1	30
084b	492	5	65	left	outside bend	328480	3990210	gravel	1	30
085	656	14	85	right	outside bend	328554	3989706	silt and gravel	1	30
086	722	6	80	left	outside bend	328635	3989409	silt and gravel	3	30
087	722	5	55	right	straight	327701	3988943	silt and gravel	1.5	30
088a	656	13	90	left	outside bend	327048	3988183	silt/gravel	2	40
088b	525	18	80	left	outside bend	327048	3988183	silt/gravel	2	70
088c	472	17	90	left	outside bend	327048	3988183	silt/gravel	2	70
089a	459	7	85	right	outside bend	326648	3986230	silt and gravel	2.5	70
089b	236	7	85	right	outside bend	326648	3986230	silt and gravel	2.5	70
089c	295	6	90	right	outside bend	326648	3986230	silt	4	30
090	295	9	70	right	straight	326822	3985774	silt/gravel	3	80
091	653	6	85	right	outside slight bend	327026	3985172	silt/gravel	2	80
092	243	6	90	right	outside bend	327227	3984951	silt	4	40
093a	197	2	90	left	outside bend	327266	3985011	silt/gravel	0.5	30
093b	295	5	90	left	outside bend	327266	3985011	silt/gravel/silt/gravel	0.5	30
094	312	3	90	right	outside bend	327273	3984091	silt/gravel	0.5	40
095	509	9	80	left	outside bend	327309	3982510	silt	2	40
096	345	8	75	left	outside bend	327869	3981718	silt	0.5	20
097	295	9	80	left	outside bend	328337	3982554	silt/gravel	2	45
098	276	11	80	left	outside bend	328298	3983272	silt	3	80
099	289	4	70	left	outside bend	328476	3984294	gravel	1	60
100	430	5	90	left	outside bend	330018	3983650	silt and gravel	0.5	20
101	361	3	60	left	straight	331089	3982230	gravel	0.5	30
102	820	7	50	left	outside slight bend	331147	3981680	silt	0.5	30
103a	328	9	60	right	straight	331396	3980447	silt and gravel	1	70
103b	558	10	90	right	outside bend	331396	3980447	silt and gravel	1	60
103c	623	10	65	right	outside bend	331396	3980447	silt and gravel	1	60
104	656	6	70	left	outside bend	331338	3980112	silt and gravel	2	70
105	656	7	70	right	outside slight bend	331237	3979820	silt and gravel	2	50
106a	525	7	80	left	outside bend	331160	3979728	silt/gravel	1	70
106b	394	8	90	left	outside bend	331160	3979728	silt/gravel	1	70
107	246	5	90	left	outside bend	330796	3979585	silt	0.5	20
108	591	7	70	right	outside bend	330627	3979542	silt/gravel	1	50
109	1982	9	85	right	outside bend	328520	3979822	silt/gravel	1	60
110	197	6	40	left	inside bend	328520	3979822	gravel	0.5	10
111	427	2	50	left	outside bend	329319	3979846	silt/gravel	0.5	40

112	951	7	70	left	outside slight bend	329283	3978853	silt/gravel	3	55
113a	1887	7	80	left	outside bend	329711	3978227	silt/gravel	3	80
113b	2067	8	80	left	outside bend	329711	3978227	silt/gravel	3	50
114	656	18	80	right	outside bend	329301	3978321	silt and gravel	2	45
115	951	7	60	left	outside bend	328827	3977788	gravel	0.5	30
116	1181	6	85	right	outside bend	328622	3977908	silt and gravel	3	60
117	394	2.5	90	left	outside bend	328336	3977765	gravel	0.25	20
118a	459	6	90	left	outside bend	328277	3977740	silt	3	60
118b	295	8	90	left	outside bend	328277	3977740	silt	2	30
119	295	7	80	left	outside bend	328047	3977872	silt and gravel	1	40
120	820	5	70	left	outside bend	327873	3977869	silt	2	45
121	755	8	90	left	outside bend	327867	3978186	silt and gravel	3	40
122	623	7	85	right	outside bend	327744	3978529	silt/gravel	2	65
123a	755	3	90	left	outside bend	327613	3978674	silt and gravel	2	20
123b	984	5	80	left	outside bend	327613	3978674	gravel	2	50
124	509	18	75	right	outside bend	327418	3979144	silt/gravel/silt/gravel	2	55
125	755	18	85	right	outside bend	327006	3978956	silt	1	70
126	164	10	80	right	inside bend	327271	3978800	silt	1	60
127	1673	5	60	left	outside bend	327137	3978497	gravel	1	50
128a	919	6	80	right	outside slight bend	326555	3978461	silt	2	70
128b	1837	6	85	right	outside bend	326555	3978461	silt/gravel	1	50
129	525	5	90	right	outside bend	326283	3977983	silt/gravel	0.5	40
130	738	4	90	right	outside slight bend	326379	3977522	silt/gravel	1	40
131	853	5	70	left	outside bend	325966	3974876	silt and gravel/gravel	0.5	50
132	289	4	85	left	outside slight bend	326014	3974480	silt	2	5
133	640	6	90	left	outside bend	325720	3974397	gravel/silt	6	10
134	951	5	85	right	outside bend	325572	3974544	silt and gravel	2.5	50
135	722	3	90	left	outside slight bend	325160	3973876	silt	3	30
136	427	5	95	left	outside bend	325111	3973631	silt	0.5	40
137	820	4	85	right	outside bend	324926	3973507	silt	3	40
138a	607	7	80	left	outside bend	325039	3973155	silt	1	60
138b	492	7	80	left	outside bend	325039	3973155	silt	2	80
138c	853	8	90	left	outside bend	325039	3973155	silt/gravel	1	65
139	591	9	70	right	outside bend	326269	3970388	silt/gravel	2	70
140	712	6	80	left	outside bend	326806	3969485	silt/gravel	2	50
141	755	5	80	left	outside slight bend	326887	3969320	silt	3	50
142	492	4	55	left	outside bend	327069	3968669	gravel	0.5	20
143	377	6	90	right	outside bend	326909	3968417	silt and gravel	1	10
144	1260	7	70	left	outside bend	326842	3968327	silt/gravel	2	40
145	262	5	70	right	outside slight bend	326535	3967859	silt and gravel	3	60
146	755	5	90	left	straight	326605	3967565	silt	2	30
147	525	7	75	left	outside bend	326753	3967250	silt/gravel	2	20
148	1050	5	85	right	outside bend	326809	3966882	silt	1	20
149a	820	6	70	left	outside slight bend	328146	3966636	silt	3	20
149b	361	5	85	left	outside bend	328146	3966636	silt	0.5	15
149c	345	5	70	left	outside bend	328146	3966636	silt	0.5	15
149d	345	5	85	left	outside bend	328146	3966636	silt	0.5	15
149e	591	3	85	left	outside bend	328146	3966636	silt	3	15

* bank height above water

** based on downstream view

*** "silt" indicates material smaller than gravel but not necessarily silt sized particles.
"and" indicates a mixture of materials
" / " indicates layers of materials

Table 3b: Bank Characterization Data, Continued

site	vegetation on bank (type)	vegetation (% cover)	vegetation on top of bank (type)	max water depth (ft)	BF discharge depth (ft)	flow in NBR* (%)
001	grass and shrubs	60	trees, grass, and shrubs	7	8	70
002	trees, grass, and shrubs	80	trees, grass, and shrubs	5	7	50
003	trees, grass, and shrubs	70	trees, grass, and shrubs	6.5	7.5	50
004a	shrubs and trees	90	trees then grass	8	10	50
004b	grass	5	trees then grass	10	12	50
005	grass and small trees	90	trees then grass	3	5	33
006	grass and a few shrubs and trees	60	grass	7	8	50
007	grass and a few trees	50	trees, grass, and shrubs	3	5	30
008	trees, grass, and shrubs	65	trees then grass	5	8	50
009	bare	0	trees, grass, and shrubs	3	6	60
010	trees, grass, and shrubs	80	trees, grass, and shrubs	6	8	50
011	trees, grass, and shrubs	70	trees, grass, and shrubs	2	4	40
012	grass	5	trees, grass, and shrubs	2	4	40
013	trees, grass, and shrubs	40	trees, grass, and shrubs	2	5	60
014	trees, grass, and shrubs	5	trees, grass, and shrubs	2	5	30
015	bare	0	grass	5	8	60
016a	grass	80	trees, grass, and shrubs	4	6	60
016b	grass and a few shrubs	10	grass	5	7	60
016c	trees	60	trees, grass, and shrubs	2	4	50
017	trees, grass, and shrubs	30	trees, grass, and shrubs	0.5	3	33
018	few shrubs	10	trees, grass, and shrubs	3	6	60
019a	bare	0	grass, trees, and shrubs	3	7	60
019b	shrubs	5	trees, grass, and shrubs	5	8.5	70
020a	grass, shrubs, and a few trees	50	trees, grass, and shrubs	3	5.5	60
020b	grass, shrubs, and a few trees	50	trees, grass, and shrubs	3	5.5	60
021	grass and trees	75	trees, grass, and shrubs	3	5	40
022	grass and a few trees	60	grass	2	4	40
023	grass	40	trees, grass, and shrubs	1	3	33
024	grass and a few trees	70	trees, grass, and shrubs	3	5	40
025	shrubs and trees	70	trees, grass, and shrubs	4	6	50
026a	bare	0	grass	1	5	30
026b	bare	0	grass	3	6	70
026c	bare	0	grass	2	5	40
027	trees, grass, and shrubs	40	trees, grass, and shrubs	3	6	50
028	trees, shrubs, grass	90	trees, grass, and shrubs	3	4.5	40
029	trees, grass, and shrubs	50	trees, grass, and shrubs	6	9	40
030	grass and trees	40	trees, grass, and shrubs	7	11	33
031	grass	40	grass and trees	3	4	60
032	trees, grass, and shrubs	40	trees, grass, and shrubs	2	3	60
033	grass	10	trees, grass, and shrubs	2	5	70
034	grass	35	trees, grass, and shrubs	3.5	5	60
035a	grass and shrubs	20	trees, grass, and shrubs	5	9	70
035b	trees, grass, and shrubs	60	trees, grass, and shrubs	6	9	70
036a	trees, grass, and shrubs	20	trees, grass, and shrubs	4	8	70
036b	trees, grass, and shrubs	20	trees, grass, and shrubs	4	8	70
037	trees, grass, and shrubs	65	trees, grass, and shrubs	8	10	80
038	bare	0	trees, grass, and shrubs	0.5	3	30
039	grass	20	trees, grass, and shrubs	2.5	4.5	40
040a	trees, grass, and shrubs	90	trees, grass, and shrubs	3	6	40
040b	trees, grass, and shrubs	40	trees, grass, and shrubs	3	6	60
040c	trees, grass, and shrubs	60	trees, grass, and shrubs	3	6	70
041a	shrubs, grass, trees	80	grass	3	5	40
041b	shrubs, grass, trees	50	trees, grass, and shrubs	3	6	60
042a	grass and a few trees	15	grass and a few trees	6	8	70
042b	grass	5	grass and a few trees	4	6	70
043	grass	5	grass and a few trees and shrubs	3	5	60
044	grass	15	grass then trees	4	6	33
045a	grass	80	grass and trees	0.5	3	40
045b	grass	5	grass and trees then grass	7	10	70
046	grass	60	grass and a few trees	2	4	60
047	bare	0	trees, grass and shrubs	1	4	40
048	shrubs, trees, and grass	60	trees, grass, and shrubs	4	6	20
049	trees, grass, and shrubs	75	trees, grass, and shrubs	1.5	4	33
050a	grass, shrubs, trees	75	trees, grass, and shrubs	1	3	33
050b	grass, shrubs, trees	60	trees, grass, and shrubs	2.5	4.5	40
051a	grass	5	grass	1	3	50
051b	grass	30	trees, grass, and shrubs	4	6	60
052	grass	5	trees, grass, and shrubs	1.5	3.5	60
053	trees, grass, shrubs	60	trees, grass, and shrubs	2.5	4.5	60
054	trees, grass, shrubs	75	trees, grass, and shrubs	3	5	60
055	bare	0	grass then trees	1.5	4.5	40

056	grass	10	mowed grass and a few trees	3	7	50
057	grass	5	trees, grass, and shrubs	4	7	70
058	trees, grass, and shrubs	60	trees, grass, and shrubs	2.5	5	70
059	trees, grass, shrubs	75	trees, grass, and shrubs	2.5	5.5	60
060a	trees and shrubs	40	grass	2	4	33
060b	grass, shrubs, and a few trees	80	grass	4	7	30
060c	grass	40	grass	3	6	50
061	trees, grass, and shrubs	80	trees, grass, and shrubs	3	6	40
062a	trees, grass, and shrubs	50	trees, grass, and shrubs	2.5	5.5	40
062b	grass and a few shrubs	10	grass	5	8	70
063	grass, trees, and shrubs	75	trees, grass, and shrubs	3.5	6.5	60
064	trees, grass, and shrubs	30	trees, grass, and shrubs	3	6	50
065a	grass and a few shrubs	25	grass	1	4	40
065b	bare	0	trees, grass, and shrubs	2.5	5	70
066a	grass	20	grass	7.5	10.5	40
066b	grass and trees	75	grass	1	4	40
067	grass and a few shrubs	90	trees, grass, and shrubs	2.5	5.5	33
068	grass	5	grass and a few trees	5.5	7.5	70
069a	trees, grass, shrubs	70	trees, grass, and shrubs	3	5	40
069b	trees, grass, shrubs	70	trees, grass, and shrubs	3	5	40
070a	trees, grass, shrubs	60	trees, grass, and shrubs	5	7	50
070b	grass	10	grass	5	7	50
071	grass	40	grass	2.5	4.5	50
072a	trees, grass, shrubs	70	trees, grass, and shrubs	3.5	6.5	70
072b	grass and a few shrubs	5	grass and a few shrubs	5	7.5	60
073	grass and a few trees	50	trees, grass, and shrubs	3	6	60
074a	grass	30	grass, shrubs, and a few trees	4	7	70
074b	trees, grass, and shrubs	70	trees, grass, and shrubs	6	8.5	70
075	bare	0	grass	5	8	50
076	grass	15	grass and a few trees	4	6	40
077	grass and a few trees	25	grass	2.5	5	40
078	trees, grass, and shrubs	90	trees, grass, and shrubs	5	8	40
079	grass	20	trees, grass, and shrubs	4	7	70
080	grass and a few trees	40	trees, grass, and shrubs	3.5	6.5	60
081	grass and shrubs	15	grass and a few trees	7	9.5	70
082	grass	10	trees, grass, and shrubs	1	3	50
083	grass	35	grass and a few trees	4.5	7	60
084a	shrubs and grass	15	trees, grass, and shrubs	2.5	5	50
084b	shrubs and grass	15	trees, grass, and shrubs	2.5	5	50
085	grass	10	trees, grass, and shrubs	2.5	6	50
086	grass and a few shrubs	25	trees, grass, and shrubs	3	6	60
087	grass and a few trees	50	mowed grass and a few trees	3	5	40
088a	bare	0	grass and a few trees	2	5	30
088b	grass, trees, and shrubs	60	grass and a few trees	2	5	30
088c	bare	0	grass and a few trees	2	5	30
089a	trees, grass, and shrubs	55	trees, grass, and shrubs	3	6	60
089b	trees, grass, and shrubs	95	trees, grass, and shrubs	3	6	60
089c	grass and shrubs	10	trees, grass, and shrubs	4	6	60
090	trees, grass, and shrubs	80	trees, grass, and shrubs	2.5	5.5	40
091	grass, shrubs, and a few trees	65	grass	3	5	40
092	shrubs and grass	20	trees, grass, and shrubs	5	8	60
093a	bare	0	grass	1	3	50
093b	grass and a tree	40	grass and a few trees	3	5	70
094	bare	0	mowed grass and a few trees	2.5	5	60
095	shrubs and a few trees	10	trees, grass, and shrubs	3	5	70
096	shrubs and grass	40	trees, grass, and shrubs	3	5	50
097	grass, shrubs, and a few trees	15	trees, grass, and shrubs	5	7	70
098	trees, grass, and shrubs	40	trees, grass, and shrubs	4	6	60
099	grass	15	trees, grass, and shrubs	3	5	50
100	bare	0	trees, grass, and shrubs	2	5	60
101	grass and trees	5	trees and grass	3	5	33
102	grass and a few trees	90	grass	1	3.5	30
103a	trees, grass, and shrubs	80	trees, grass, and shrubs	1	3	33
103b	grass and a few shrubs and trees	25	trees, grass, and shrubs	3	5	50
103c	trees, grass, and shrubs	80	trees, grass, and shrubs	3	5	40
104	grass and a few shrubs	60	trees, grass, and shrubs	7	10	60
105	trees, grass, and shrubs	70	trees, grass, and shrubs	2.5	4.5	50
106a	trees, grass, and shrubs	80	trees, grass, and shrubs	4	7	60
106b	bare	0	grass	5	8	60
107	grass and a few shrubs	30	trees	4	7	50
108	grass and a few trees	20	grass and a few trees	2	5	40
109	grass and a few trees	75	grass	3	5.5	10
110	grass and a few trees	5	grass	3	5.5	60
111	bare	0	trees	6	8	60

112	grass	30	trees, grass, and shrubs	2.5	4.5	40
113a	trees, grass, and shrubs	80	trees, grass, and shrubs	4	6	40
113b	grass and a few trees	5	trees, grass, and shrubs	5	7	70
114	grass and a few trees	50	grass	2	5	40
115	grass	10	grass and a few trees	4	7	40
116	trees, grass, and shrubs	30	trees, grass, and shrubs	7	9	70
117	bare	0	grass	2	5	60
118a	grass and shrubs	30	trees, grass, and shrubs	2.5	6.5	60
118b	grass	25	grass and a few trees	5	8	70
119	grass and a few trees	30	grass and a few trees	4.5	8.5	70
120	trees, grass, and shrubs	40	trees, grass, and shrubs	4	8	60
121	shrubs	5	trees, grass, and shrubs	3	7	70
122	trees, grass, and shrubs	55	trees, grass, and shrubs	6	9	70
123a	trees, grass, and shrubs	25	trees, grass, and shrubs	2.5	5.5	60
123b	trees, grass, and shrubs	70	trees, grass, and shrubs	2	5.5	40
124	trees, grass, and shrubs	75	trees, grass, and shrubs	5	8.5	50
125	grass	5	grass and a few trees	5	9	70
126	grass	40	grass	4	6	30
127	trees, grass, and shrubs	50	trees, grass, and shrubs	1.5	4.5	40
128a	trees, grass, and shrubs	80	grass	5	8	40
128b	grass	5	grass and a few trees	6	9	40
129	bare	0	grass	4	7	50
130	grass	5	grass and a few trees	2	5	30
131	grass and a few trees	65	grass and a few trees	4	6	40
132	trees, grass, and shrubs	80	trees, grass, and shrubs	6	8	40
133	grass	5	grass and trees	4	6	70
134	trees, grass, and shrubs	70	trees, grass, and shrubs	7	11	70
135	trees and shrubs	15	trees and shrubs	4	7	50
136	bare	0	trees, grass, and shrubs	2	5	70
137	trees, grass, and shrubs	60	trees, grass, and shrubs	4	8	70
138a	grass and shrubs	30	trees, grass, and shrubs	5	7.5	70
138b	grass and shrubs	80	grass then trees	2	4	70
138c	bare	0	grass	3	6	70
139	grass	50	trees, grass, and shrubs	2.5	4.5	70
140	trees, grass, and shrubs	65	trees, grass, and shrubs	2.5	6	50
141	trees, grass, and shrubs	60	trees, grass, and shrubs	4	6	50
142	trees	10	trees	3.5	5.5	50
143	grass and a tree	5	trees, grass, and shrubs	3	6	40
144	grass and a few trees	30	trees, grass, and shrubs	3	5	30
145	grass and trees	50	trees, grass, and shrubs	3	6	60
146	trees and grass	30	trees, grass, and shrubs	9	12	30
147	grass	30	trees, grass, and shrubs	3	5	50
148	bare	0	trees, grass, and shrubs	4	7	60
149a	trees	30	grass	3	5	40
149b	bare	0	grass	6	8	70
149c	bare	0	grass	6	8	70
149d	bare	0	grass	6	8	70
149e	grass	5	trees, grass, and shrubs	6	9	40

***flow in the near bank region under bankfull flow conditions (estimated in the field).**

(NBS) is greater than represented by the percent flow in the near bank region. NBS estimates (percent flow in the near bank region under bankfull conditions) were classified into the following ranges: greater than or equal to 65%, 55 - 64%, 45 - 54%, 35 - 44%, and less than 35%. These ranges, taken from a figure in Rosgen (1996a), are slightly different from the ranges generally presented (Rosgen 1996b); however, the percent flow in the near bank region, not the ranges, are the important consideration. The use of the ranges did, however, preclude the use of the adjective NBS ratings (low, moderate, high, very high, and extreme) presented in Rosgen (1996b).

The bank erosion potential ratings and near bank stress estimates were then used to group similar banks. A possibility of 30 groups existed from the combination of 6 bank erosion potential ratings and 5 near bank stress ranges, but only 20 groups resulted because no banks with low or very low bank erodibility potential were characterized. Selection of individual banks within the groups was made based on representation of the group and based on access. At least one bank from each group, a total of 36 sites, were selected for detailed study.

Detailed Characterization of Selected Banks

During August and September 1996, each stream reach containing a selected bank was analyzed for Rosgen Level III stream reach condition evaluation (Rosgen 1996b). The Rosgen system was used for two reasons: 1) it is currently the most widely accepted manner of describing channels for stream classification (Leopold 1994); and 2) it represents an effort to report streambank erosion data in a consistent and reproducible frame of reference for communication with others working with bank erosion in river systems (Rosgen 1994). Rosgen Level III classification (described above in the Literature Review chapter) involves: 1) Rosgen Level II stream reach classification, 2) bank erosion potential and near bank stress ratings, 3) additional information including riparian vegetation and depositional features, and 4) a Pfankuch Stream Reach Inventory and Channel Stability Evaluation (Pfankuch 1975).

The first step in performing the Rosgen Level III stream reach condition evaluation on the 36 selected sites was to classify the reaches to Level II (Rosgen 1996b). First, channel cross sections and longitudinal bank, water surface, and thalweg profiles were surveyed to determine entrenchment ratio, width/depth ratio, sinuosity, and slope. A pebble count was then made to determine the channel material size (Rosgen 1996b). The pebble count was performed by crossing the bankfull channel, blindly touching the channel material 100 times, and recording the sizes of the particles touched. The length of the intermediate axis, defined as neither the longest axis nor the shortest axis, was recorded. The channel material size was then determined as the D_{50} particle size (the particle size such that 50% of the sampled particles are smaller than the D_{50} particle). If the D_{50} particle was not present in the channel, the particle size that was sampled most frequently in the pebble count was used as the dominant channel material. The bank erosion potential and near bank stress estimates, determined in the initial bank characterization trip, were also needed for Level III evaluation.

Level III evaluation also requires field descriptions of riparian vegetation, flow regime, stream size, depositional features, meander patterns, and channel debris (Rosgen 1996b). A detailed description of these parameters appears in Appendix B. Riparian vegetation was described by type and density; for example: deciduous trees - high density, low brush species - low density (Rosgen 1985). Stream size was determined by the channel cross-sectional surveys. Flow regime, depositional features, meander patterns, and channel debris descriptors were determined by matching field conditions to descriptions and example figures in Rosgen (1996b).

The last step in Rosgen Level III evaluation is the Pfankuch Stream Reach Inventory and Channel Stability Evaluation (Pfankuch 1975). The Pfankuch evaluation uses fifteen parameters to estimate channel stability. The parameters used describe: 1) the upper bank - the portion of the bank cross section between the normal high water line and the break in slope of the surrounding land, 2) the lower bank - the portion of the bank cross section between the low flow level and the normal high water line, and 3) the channel bottom - the submerged portion of the channel cross section. These parameters are: 1) on the upper bank: landform slope, mass wasting potential, debris jam potential, and vegetative bank protection; 2) on the lower bank: channel capacity, bank rock content, obstructions, cutting, deposition; and 3) on the channel bottom: rock angularity, brightness, consolidation, percent stable material, scouring/deposition, and clinging aquatic vegetation.

In the field at each site, each one of these 15 parameters was given a rating of excellent, good, fair, or poor based on descriptions and figures provided and a corresponding score. The channel stability score was then determined as the sum of the score of the parameters. The Pfankuch channel stability score was then converted, based on Rosgen Level II stream reach classification, to determine a reach condition of excellent, good, fair, or poor for each site (Rosgen 1996b).

Bank Erosion Measurements in the Field

For each selected bank site, at least one permanent cross section and, if possible, a longitudinal profile along the top of the bank was surveyed to measure short-term erosion and channel form changes. Cross sections, the same ones as used in Level II classification, were surveyed by a procedure similar to the method described in Rosgen (1991). Points, distance and elevation, were measured across the stream at approximately every 10 to 15 ft and at points of significant slope change.

At the cross section of each selected site, two or three bank pins were installed in a vertical row up the bank and in line with the cross-sectional survey to measure short-term erosion. Figure 2 illustrates the location of bank pins installed on site 015. The bank pins were 4 ft long, 0.25 in diameter rebar or rolled steel shaft. In some locations, where driving pins into the bank was difficult, 2 ft pins were used. The pins were hammered horizontally into and perpendicular to the bank until flush with the bank. The location of pins along the bank height was somewhat arbitrary. On short banks and tall, gently sloping banks, pins were generally placed at approximately 1/3 and 2/3 of the bank height. On the tall, steep banks, where the entire bank height could not be reached, one pin was placed approximately two to three feet up from the water level and another at approximately 6 feet from the water level under low-flow conditions.

Two or three pins, installed in a vertical row, were also placed upstream and/or downstream of the cross sections on several of the sites. This purpose of the extra set(s) of pins was to capture the variability of erosion along the bank length.

Erosion was measured along the top of each pin from the end of the pin to the bank. Erosion was measured five times during this 10 month study. Erosion was measured after major flow events, defined in this study as events that exceeded the base flood discharge, 9000 cfs (Blazs et al.1997), at the Tahlequah gage station. References to flow values in this study are to flows at the Tahlequah gage station. Erosion was measured after major flow events in September 1996, November 1996 (2 events), and February 1997. Erosion was measured again after two at or near bankfull events in the spring and summer of 1997. The cross sections and longitudinal bank profiles were resurveyed after 10 months in late July 1997.

A 6 mm wet suit was worn during measurement of bank erosion from the fall of 1996 through the early spring of 1997. This wet suit allowed comfortable, unincumbered river crossings and access, even in cold air temperatures, and provided additional safety with its buoyancy. To others working in similar water-related projects, a wet suit is highly recommended over hip waders because of the dangers involved when waders become submersed.

Bank Erosion Measurements from Aerial Photographs

Along with field measurements of short-term erosion, long-term bank erosion was measured from aerial photographs. Analysis of the aerial photographs was also used to determine the impact of riparian vegetation on bank erosion. USDA-SCS airphotos at a scale of 1:7920 taken in 1958, 1979, and 1991 were analyzed. Complete sets of airphotos for 1991 and 1979 from below the Lake Frances dam to Lake Tenkiller were available and were analyzed. 1958 aerial photos were only available for a portion of the river, but they were analyzed where available.

The procedure used in measuring long-term erosion from aerial photographs was modified from the procedure outlined by Brice (1982). First, banks on the 1991 aerial photos were traced onto mylar sheets. Then, areas where the 1979 banks were in different locations than the 1991 banks were traced on the same mylar sheet. Areas where the 1958 banks were in different locations than the 1979 banks were traced on the same mylar sheet. An effort was made to make tracings from the center of the photographs to minimize error caused by distortion near the edges.

To describe eroding banks and depositional areas, including the 193 characterized sites and other significant erosional/depositional areas, several parameters were measured from the bank tracings. These measurements for each erosional/depositional area for the periods 1958 to 1979 and 1979 to 1991 include:

1) maximum lateral erosion - The maximum lateral erosion, the greatest distance a bank eroded, was measured directly from the bank tracings;

2) area - The land surface area of areas lost to erosion or gained by deposition was determined using the area digitizing utility of SEDCAD$^+$, a computer-aided hydrologic design package (Warner and Schwab 1992);

3) length - The length of each erosional/depositional area was determined with the length/slope SEDCAD$^+$ utility;

4) lateral erosion and/or deposition - The lateral erosion or deposition of each erosional/depositional area, actually an average width, was determined by dividing the area by the length.

Figure 3 illustrates each of these measurements. Erosion that occurred on the opposite side of the river from the site was not included in the maximum lateral erosion measurement; but in determining the land surface areas, lengths, and lateral erosion and/or deposition, erosional and depositional areas on both sides of the river were analyzed.

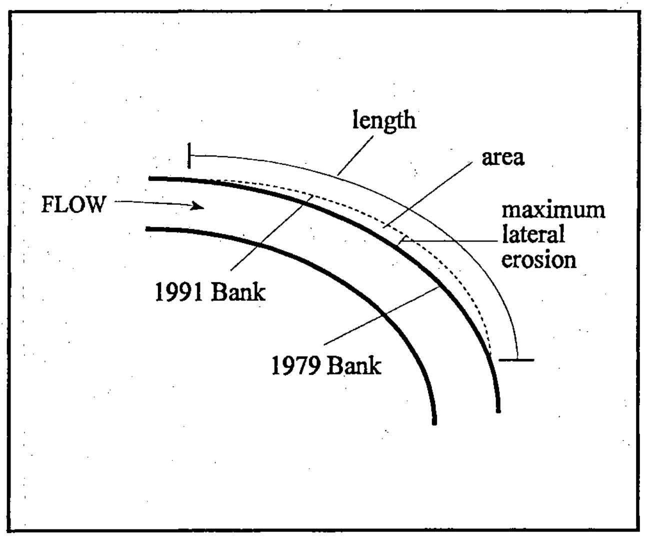

Figure 3: Example Site Illustrating Measurements Taken from Aerial Photographs

The river width at every 0.5 river mile beginning at the Lake Frances Dam was also measured. The river width, determined at the same cross-section for each year, was measured directly from the bank tracings.

Dominant riparian vegetation types were also determined for the Upper Illinois River using aerial photographs. Four vegetation classes, based on the dominant vegetation within 100 ft of the bank, were used. These classes, based on vegetation categories used in Nepple (1996) were: 1) forest - predominantly woody vegetation, 2) grass - improved or native pasture, 3) mix - areas of trees mixed with areas of grasses or a thin row of trees with pasture beyond, and 4) other - includes riprap or other structural protection.

The riparian vegetation for both characterized sites and other significant erosional/ depositional areas was determined directly from aerial photographs. The length of bank with each vegetation type was estimated by tabulating the dominant vegetation type on each side of the river at each 0.25 river mile beginning at the Lake Frances Dam. From this tabulation, the total length of forested, grassed, and mixed riparian areas along the river for the period 1979 to 1991 was estimated by multiplying the percent of the total length with each vegetation type by 126 miles (63 river miles on each sides). The same procedure was used for the period 1958 to 1979, but only 45.8 miles (22.9 miles on each side) were analyzed due to lack of aerial photos from 1958.

Using the data from each erosional/depositional site, the impact of riparian vegetation on maximum lateral erosion rate was evaluated. The differences in maximum lateral erosion between forested, grassed, and mixed sites were tested with a t-test for differences in means of normal distributions (Haan 1977). To use this test, it was assumed that the maximum lateral erosion rates followed a normal distributions within each vegetation class. This assumption is justified when only sites that eroded were analyzed. The test was weakened when all of the sites were analyzed; however, because many of the sites had no lateral erosion resulting in non-normal distributions.

Contribution of Bank Erosion to Sedimentation of Lake Tenkiller

Original interest in a bank erosion study on the Illinois River resulted from concern about sedimentation of Lake Tenkiller. This study quantified bank erosion and then attempted to determine whether streambank erosion is a significant source of sediment to the Illinois River and to estimate the contribution of bank erosion to the sedimentation of Lake Tenkiller.

With data from the initial bank characterization trip and aerial photograph analyses and from data from soil surveys, the volume and mass of soil eroded from 1958 to 1991 was determined. The volume of material eroded was calculated by multiplying the land surface area of each erosional area by the height. The mass of material eroded was then calculated by multiplying the volume eroded by estimates of the soil bulk density for each bank (USDA-SCS 1970, USDA-SCS 1984, Carter - personal communication 1997). Similar calculations, however, could not be performed for depositional areas because heights were not known and in-channel deposits were not analyzed. Suspended load and bed load data were also examined to estimate the transport of the eroded material.

CHAPTER FOUR

RESULTS AND DISCUSSION

In this study on the Upper Illinois River in northeast Oklahoma, bank pins and cross-sectional surveys were used to measure short-term bank erosion from September 1996 to July 1997, and aerial photographs were used to measure long-term erosion from 1958 to 1979. These measurements were then used to evaluate the impact of riparian vegetation on short- and long-term erosion. The bank pin data on short-term bank erosion were used to evaluate the applicability of Rosgen's work in the Western US (relating bank erosion potential and stress in the near bank region to erosion) to the Upper Illinois River. A critical analysis of Rosgen's streambank erosion potential, based on the results of this study, is also presented. The data collected were also used to estimate the contribution of bank erosion along the Illinois River to the sedimentation of Lake Tenkiller. Results for each of these objectives, along with discussions of each step, are presented below.

Initial Bank Characterization

On the July 1996 bank characterization trip, 193 bank segments were characterized. 149 banks were identified, but banks with different physical characteristics along the length of the bank were broken into homogeneous segments. For instance, site 004a averages 12 ft in height and has 90% shrub and grass cover on the bank; site 004b, however, is 9 ft in height with 5% grass cover on the bank. Data collected on the bank characterization trip including length, height, angle, river position, location, material, vegetation type and percent cover, root depth and density, maximum water depth, bankfull depth, and percent flow in the near bank region under bankfull flow conditions for each eroding bank are presented in tables 3a and 3b. The approximate locations of characterized banks appear in Appendix C.

Selection of Banks for Detailed Study

From data gathered on the initial bank characterization trip, each bank was given a bank erosion potential numerical index and a rating from extreme to very low (Rosgen 1996a). Twenty two banks had an extreme bank erosion potential, 48 had very high, 97 had high, 26 had moderate, and none had low or very low bank erosion potential ratings. A bank erosion potential numerical index and rating for each bank appears in table 4. Table 2a shows an example calculation of the bank erosion potential.

A near bank stress estimate, based on percent flow in the near bank region at bankfull discharge (Rosgen 1996b) and on adjustments for extreme hydraulic conditions, such as sharp bends and islands, was also made for each bank. Forty four banks had greater than 65% flow in the near bank region, 45 banks had 55 - 64% flow in the near bank region, 35 banks had 45 - 54%, 43 banks had 35 - 44%, and 26 banks had less than 35% (as noted above, these ranges are slightly different then the ranges generally presented by Rosgen). An estimate of percent flow in the near bank region, for each bank, based on bankfull flow estimates made in the field appears in table 3b.

Table 4: Bank Erosion Potential Indices and Ratings

site	bank erosion potential (index)	(rating)	site	bank erosion potential (index)	(rating)	site	bank erosion potential (index)	(rating)
001	28.17	Moderate	051b	43.89	Very High	102	27.89	Moderate
002	36.51	High	052	39.35	High	103a	36.96	High
003	35.64	High	053	40.55	Very High	103b	45.50	Extreme
004a	33.51	High	054	36.24	High	103c	37.22	High
004b	42.13	Very High	055	39.72	Very High	104	33.60	High
005	32.95	High	056	41.34	Very High	105	37.02	High
006	38.24	High	057	39.46	High	106a	35.41	High
007	30.99	High	058	38.02	High	106b	45.51	Extreme
008	38.26	High	059	32.86	High	107	34.60	High
009	32.90	High	060a	44.91	Very High	108	41.63	Very High
010	24.04	Moderate	060b	36.83	High	109	39.52	Very High
011	39.81	Very High	060c	46.18	Extreme	110	41.45	Very High
012	43.16	Very High	061	34.08	High	111	38.38	High
013	32.71	High	062a	37.69	High	112	38.46	High
014	43.38	Very High	062b	48.68	Extreme	113a	32.84	High
015	51.24	Extreme	063	25.68	Moderate	113b	44.02	Very High
016a	39.05	High	064	35.54	High	114	43.37	Very High
016b	44.25	Very High	065a	44.16	Very High	115	40.15	Very High
016c	36.71	High	065b	51.97	Extreme	116	38.71	High
017	35.36	High	066a	33.76	High	117	40.16	Very High
018	43.94	Very High	066b	24.86	Moderate	118a	27.46	Moderate
019a	35.02	High	067	26.15	Moderate	118b	34.43	High
019b	43.71	Very High	068	42.72	Very High	119	40.47	Very High
020a	30.63	High	069a	26.49	Moderate	120	24.17	Moderate
020b	36.53	High	069b	29.26	Moderate	121	45.70	Extreme
021	36.81	High	070a	37.52	High	122	37.35	High
022	28.99	Moderate	070b	43.76	Very High	123a	38.07	High
023	36.99	High	071	36.72	High	123b	28.45	Moderate
024	35.46	High	072a	36.05	High	124	39.07	High
025	40.61	Very High	072b	50.54	Extreme	125	38.31	High
026a	39.51	Very High	073	33.44	High	126	31.61	High
026b	37.64	High	074a	44.08	Very High	127	30.93	High
026c	37.35	High	074b	29.53	High	128a	23.09	Moderate
027	29.71	High	075	45.40	Extreme	128b	44.74	Very High
028	26.00	Moderate	076	43.49	Very High	129	46.59	Extreme
029	25.48	Moderate	077	44.60	Very High	130	44.78	Very High
030	27.45	Moderate	078	34.35	High	131	37.16	High
031	38.03	High	079	42.09	Very High	132	29.39	Moderate
032	34.02	High	080	35.96	High	133	46.12	Extreme
033	43.41	Very High	081	45.77	Extreme	134	33.00	High
034	33.34	High	082	33.83	High	135	27.51	Moderate
035a	40.46	Very High	083	38.66	High	136	37.31	High
035b	39.55	Very High	084a	32.77	High	137	21.71	Moderate
036a	40.38	Very High	084b	37.27	High	138a	29.93	High
036b	45.13	Extreme	085	49.66	Extreme	138b	24.83	Moderate
037	34.80	High	086	39.85	Very High	138c	46.56	Extreme
038	38.20	High	087	37.26	High	139	38.16	High
039	37.69	High	088a	51.18	Extreme	140	35.44	High
040a	33.99	High	088b	40.56	Very High	141	25.19	Moderate
040b	38.70	High	088c	49.10	Extreme	142	38.73	High
040c	23.95	Moderate	089a	36.36	High	143	50.67	Extreme
041a	34.66	High	089b	33.69	High	144	40.68	Very High
041b	38.29	High	089c	34.06	High	145	32.72	High
042a	48.67	Extreme	090	33.00	High	146	31.20	High
042b	42.32	Very High	091	35.65	High	147	43.29	Very High
043	48.30	Extreme	092	30.80	High	148	37.04	High
044	38.08	High	093a	42.57	Very High	149a	30.36	High
045a	38.86	High	093b	43.87	Very High	149b	39.96	Very High
045b	45.07	Extreme	094	43.65	Very High	149c	37.91	High
046	34.48	High	095	36.11	High	149d	39.96	Very High
047	39.56	Very High	096	35.87	High	149e	31.42	High
048	26.49	Moderate	097	44.16	Very High			
049	24.21	Moderate	098	28.70	Moderate			
050a	22.63	Moderate	099	34.67	High			
050b	31.62	High	100	49.25	Extreme			
051a	43.55	Very High	101	37.43	High			

Similar banks were grouped according to bank erosion potential and near bank stress estimates (figure 4). At least one bank from each group, a total of 36 sites, were selected for detailed study. The sites selected for detailed study were: 010, 015, 040a, 040b, 040c, 041a, 041b, 050a, 050b, 060a, 060b, 061, 060c, 065a, 065b, 069a, 069b, 072a, 072b, 084a, 088a1, 088a2, 088b, 093a, 093b, 094, 096, 105, 106a, 106b, 108, 120, 128a, 128b1, 128b2, and 143. Photographs of each of these sites appear in Appendix A.

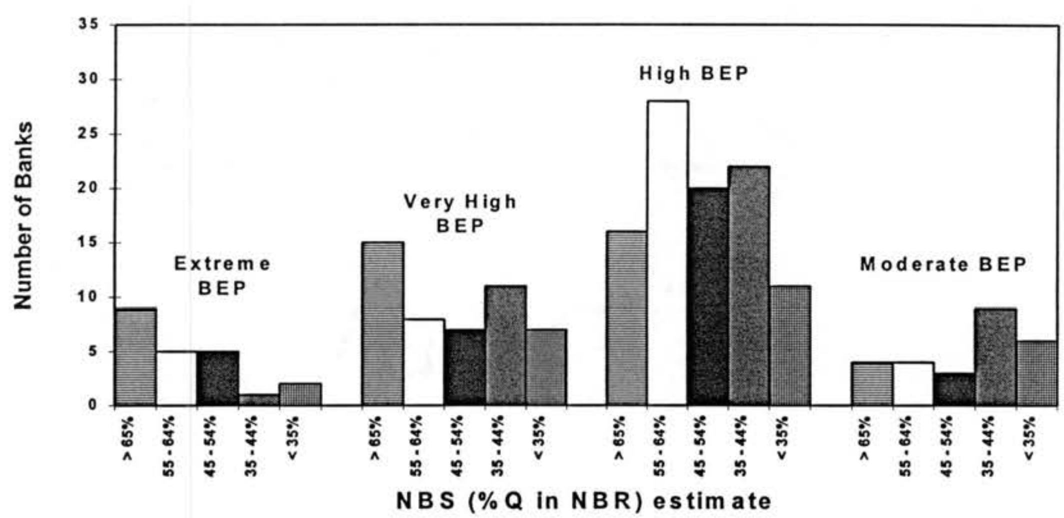

Figure 4: Groupings Based on Bank Erosion Potential and Near Bank Stress Estimates

Detailed Characterization of Selected Banks

During August and September 1996, each of the 36 selected sites was characterized with Rosgen Level III evaluation, which involves: 1) Rosgen Level II stream reach classification, 2) bank erosion potential ratings and near bank stress estimates, 3) additional information including riparian vegetation and depositional features, and 4) a Pfankuch Stream Reach Inventory and Channel Stability Evaluation (Pfankuch 1975).

Results of the Rosgen Level II stream reach classification for each reach containing a selected bank appear in table 5. Twenty three of the sites were classified as C4c- channels, 11 as C4, and 2 as F4. The only difference between C4c- and C4 channels is their slope range. C4c- channels have a slope range of less than 0.001 and C4 channels have a slope range of 0.02 to 0.001.

C4c- and C4 channels are gravel-dominated, slightly entrenched, gentle gradient, riffle/pool channels with high width/depth ratios. These channels, characterized by point bars and other depositional features, are very susceptible to shifts in lateral and vertical stability caused by flow changes and sediment delivery from the watershed. The rates of lateral adjustment are influenced by riparian vegetation. F4 channels are also gravel-dominated, gentle gradient, riffle/pool channels with high width/depth ratios but are entrenched. Channel bars are common, and bank erosion rates may be high due to mass-wasting of the steep banks (Rosgen 1996b).

The remaining steps in Rosgen Level III evaluation attempt to describe the state of the system. Indicators of the stream condition include: 1) bank erosion potential ratings and near bank stress estimates - presented in tables 3a and 3b and discussed above; 2) stream width, riparian vegetation, flow regime, depositional features, meander patterns, and channel debris; and 3) a Pfankuch Stream Reach Inventory and Channel

Table 5: Rosgen Level II Stream Reach Classification

site	entrenchment ratio	width to depth ratio	sinuosity	slope	classification
010	>2.2	17.5	1.01	0.006%	C4c-
015	>2.2	18.5	1.10	0.142%	C4
040a	>2.2	24.2	na	na	C4c-*
040b	>2.2	22.4	na	na	C4c-*
040c	>2.2	44.6	na	na	C4c-*
041a	>2.2	20.8	1.21	0.392%	C4c-
041b	>2.2	23.9	1.21	0.392%	C4c-
050a	>2.2	84.2	1.02	0.013%	C4c-
050b	1.0	115.3	1.02	0.013%	F4
060a	>2.2	23.3	1.04	0.015%	C4c-
060b/061	>2.2	22.2	1.04	0.015%	C4c-
060c	>2.2	59.4	1.04	0.015%	C4c-
065a	1.2	100.1	1.08	0.110%	F4
065b	>2.2	84.1	1.08	0.110%	C4
069a	>2.2	18.9	1.05	0.122%	C4c-
069b	>2.2	39.1	1.05	0.122%	C4c-
072a	>2.2	72.6	1.13	0.038%	C4c-
072b	>2.2	59.8	1.13	0.038%	C4c-
084a	>2.2	80.2	1.09	0.132%	C4
088a1	>2.2	40.1	1.28	0.342%	C4
088a2	>2.2	33.0	1.28	0.342%	C4
088b	>2.2	68.1	1.28	0.342%	C4
093a	>2.2	64.2	1.73	0.504%	C4
093b	>2.2	50.7	1.73	0.504%	C4
094	>2.2	106.2	1.43	0.304%	C4
096	>2.2	35.9	1.11	0.219%	C4
106a/105	>2.2	34.3	1.12	0.097%	C4c-
106b	>2.2	35.5	1.12	0.097%	C4c-
108	>2.2	50.5	1.07	0.567%	C4c-
120	>2.2	32.0	1.20	0.094%	C4c-
128a	>2.2	25.2	1.02	0.013%	C4c-
128b1	>2.2	52.4	1.02	0.013%	C4c-
128b2	>2.2	32.0	1.02	0.013%	C4c-
143	>2.2	74.5	1.07	0.105%	C4

* Reach classification is an estimate because sinuosity and slope were not taken in the field

Stability Evaluation. These parameters for each site are presented in table 6, and a key describing the identifiers appears in Appendix B.

With the data obtained in the cross-sectional survey for each selected bank, another estimate of percent flow in the near bank region under bankfull conditions was made. The cross-sectional area in the near bank region and the total cross-sectional area of each selected site at bankfull discharge was determined with SEDCAD$^+$. The ratio of these areas represents the estimate of the percent flow in the near bank region, based on the assumption presented in Rosgen (1996a) that flow is proportional to area. The previous near bank stress estimates for all of the initially characterized banks were made in the field based on water depth measurements and visual bankfull indicators. Both estimates are presented (table 7) to exemplify that reasonable estimates can be made with either method. Field estimates require water depth measurements and a basic knowledge of bankfull flow and give a better idea of the near bank stress (NBS) in the reach. Estimates from cross-sectional data require field survey data are more accurate for the actual stream cross section. The field estimates of the percent flow in the near bank region, not the estimates made based on cross-sectional areas, were used in all analyses in this study.

Bank Erosion Measurements in the Field

Bank erosion was measured after major flow events (exceeded 9000 cfs at the Tahlequah gage station) in September 1996, twice in November 1996, and in February 1997. Cumulative erosion after the four major flow events averaged 4.5 ft and ranged

Table 6: Rosgen Level III Stream Reach Condition Assessment

site	stream size	stream reach size (ave)	riparian vegetation	flow regime	depositional features	meander patterns	channel debris	Pfankuch Channel Stability (index)	(rating)
010	S8 *	S8	V4b,7c,9b	P2	B1	M1	D2	61	excellent
015	S8	S8	V5c	P2	B7	M3	D1	115	poor
040a	S9	S9	V3a,4a,9c	P2	B3	M3	D4	84	good
040b	S8	S9	V3a,4a,9c	P2	B1	M1	D1	100	fair
040c	S9	S9	V3a,4a,9c	P2	B2	M2	D4	105	fair
041a	S8	S9	V5c,9a	P2	B1	M1	D2	82	good
041b	S9	S9	V4b,6a,9c	P2	B1	M1	D2	88	good
050a	S9	S10	V3b,4a,9c	P2	B1/B3	M1	D2	85	good
050b	S10	S10	V3a,4a,7b,9c	P2	B1	M1	D2	92	good
060a	S9	S9	V5c,9a	P2	B1	M1	D2	95	fair
060b	S9	S9	V3b,4b,9c	P2	B1	M1	D3	87	good
060c	S9	S9	V5c	P2	B1	M1	D2	109	fair
061	S9	S9	V5c,9a	P2	B1	M1	D3	103	fair
065a	S10	S10	V5c	P2	B7	M3	D2	121	fair
065b	S10	S10	V4c (bamboo)	P2	B7	M3	D4	132	poor
069a	S9	S9	V3b,6a,9b	P2	B1	M3	D1	78	good
069b	S9	S9	V3b,6a,9c	P2	B1	M3	D1	78	good
072a	S9	S9	V3b,5b,6a,9c	P2	B1	M3	D3	92	fair
072b	S10	S9	V3a,5c,6a	P2	B2	M3	D1	94	fair
084a	S10	S10	V4c,9b	P2	B7	M2	D3	114	poor
088a1	S9	S9	V3b	P2	B1	M1	D2	87	good
088a2	S9	S9	V4b,9a	P2	B1	M1	D2	106	fair
088b	S9	S9	V5b,6a,9a	P2	B1	M3	D1	86	good
093a	S10	S10	V3b,4b	P2	B2	M2	D2	117	poor
093b	S10	S10	V3a,5c	P2	B1	M2	D2	120	poor
094	S10	S10	V5c	P2	B2	M1	D2	111	poor
096	S9	S9	V3b,6a,9b	P2	B2	M3	D3	112	poor
105	S9	S9	V3a,6a,9c	P2	B4	M3	D3	98	fair
106a	S9	S9	V3a,6a,9c	P2	B4	M3	D3	100	fair
106b	S9	S9	V5c	P2	B1	M1	D1	99	fair
108	S9	S9	V3b,6a,9c	P2	B1	M2/M3	D2	105	fair
120	S10	S10	V3b,6b,9b	P2	B1	M1	D4	106	fair
128a	S9	S9	V6b,9a	P2	B1	M3	D3	88	good
128b1	S9	S9	V5c,9a	P2	B1	M3	D3	103	fair
128b2	S9	S9	V5c	P2	B2	M3	D4	119	poor
143	S10	S10	V3c,9a	P2	B2	M1	D2	103	fair

* a key describing these identifiers appears in Appendix B.

Table 7: Comparison of Estimates of Near Bank Stress

site	flow in NBR estimated in the field (%)	flow in NBR estimated with site cross section data (%)	relative error (%)
010	50	35	-43
015	60	43	-40
040a	40	28	-43
040b	60	48	-25
040c	70	45	-56
041a	40	39	-3
041b	60	44	-36
050a	33	55	40
050b	40	38	-5
060a	33	27	-22
060b	30	24	-25
060c	50	59	15
061	40	40	0
065a	40	49	18
065b	70	46	-52
069a	40	35	-14
069b	40	50	20
072a	70	55	-27
072b	60	42	-43
084a	50	52	4
088a1	30	25	-20
088a2	30	28	-7
088b	30	39	23
093a	50	45	-11
093b	70	44	-59
094	60	45	-33
096	50	48	-4
105	50	34	-47
106a	60	37	-62
106b	60	60	0
108	40	56	29
120	60	67	10
128a	40	30	-33
128b1	40	41	2
128b2	40	36	-11
143	40	48	17

from -0.03 to 26.5 ft. Bank erosion was measured for 33 and 29 sites (out of 36 sites) after the second and fourth major flow events, respectively. After the first and third events, only 11 and 18 sites were measured. Sites 065b, 105, and 108 could not be relocated after the second major flow event, so no data are reported on these sites for any of the flow events. Pins for sites 040c, 050a, 050b, and 061 were not located after the forth major flow event. Erosion results for each of these events appear in tables 8 - 11.

Erosion was also measured once after two bankfull or near bankfull flows that occurred in the spring and summer of 1997. Erosion from these two events measured for selected sites averaged 0.40 ft and ranged from 0.00 to 2.35 ft. Erosion data measured on selected sites once after the two at or near bankfull events is presented in table 12.

During this study the streamflow volume and the frequency of significant flow events exceeded normal conditions. Approximate peak flows and their associated return periods and maximum average daily flows for major flow events appear in tables 13a and 13b. Mean daily flows for the Watts and Tahlequah gage stations from August 1, 1996 to July 31, 1997 appear in figures 5a and 5b.

The average annual flow for the Tahlequah gage station for the period 1936 to 1996 is 935 cfs. From August 1, 1996 to July 31, 1997, the average flow was 1123 cfs. This volume represents a 20% increase from average conditions and has a 3.0 year return period. A plot of average annual flows for the Tahlequah gage station appears in figure 6a. Four flow events with greater or equal to 2.0 yr return period also occurred during the 10 month study period. A plot of historical peak flows for the Tahlequah gage station appears in figure 6b. Percent greater than, plotted on the x-axes of figures 6a and 6b, equals 100 divided by the return period.

Table 8: Erosion Measured with Bank Pins After the First Major Flow Event

site	pin location	pin depth* (ft)	erosion measured with: erosion pins (ft)	other (ft)	cumulative average erosion (ft)	comments
072a	X-sec	2.5	could not find	???	???	probably not lost **
		6	could not find	???	???	
072b	X-sec	6	2.77	na		
		8	2.56	na	2.67	
072	t/p of survey	3.5	0.10	na		
		7.5	0.00	na	0.05	
072	t/p - 072b	3.5	on surface	2		
		7.5	0.31	na	1.16	
094	X-sec	1.2	2.74	na		
		3.6	2.14	na	2.44	
096	X-sec	2.3	lost	4+		
		4.6	lost	4+	4+	
106a	X-sec	4.3	0.00	na		
		6.9	0.23	na	0.12	
106b	X-sec	3	2.38	na		
		6.7	0.38	na	1.38	
120	X-sec	3.3	0.00	na		
		6.4	0.00	na	0.00	
128a	X-sec	4	1.25	na		
		7.6	0.20	na	0.73	
128b1	X-sec	2.5	0.87	na		
		5.5	0.11	na	0.49	
128b2	X-sec	1.7	on surface	6		
		???	maybe buried	0	3	
143	X-sec	0.7	lost	10		estimate based on known distance from tree to bank
		3	lost	10	10	

* pin depth measured from the top of the bank. Recorded to help relocate pins after major flow events.

** pins could not be found but probably were not removed by erosion.

Table 9: Erosion Measured with Bank Pins After the Second Major Flow Event

site	pin location	pin depth (ft)	erosion measured with: bank pins (ft)	other (ft)	cumulative average erosion (ft)	comments
010	X-sec	3	0.02	na		
		6	0.08	na	0.05	erosion is the total from the first and second events
015	X-sec	4	1.21	na		
		10	0.70	na	0.96	erosion is the total from the first and second events
015	70m down stream of X-sec	3	on surface	2+		
		6	0.48	na	1.24+	erosion is the total from the first and second events
040a	X-sec	3	0.02	na		
		6	0.20	na	0.11	erosion is the total from the first and second events
040b	X-sec	3	0.95	na		
		6	1.52	na	1.24	erosion is the total from the first and second events
040c	X-sec	3.5	lost	4+		
		7.5	lost	4+	4+	erosion is the total from the first and second events
041a	X-sec	2	0.08	na		
		5	0.12	na	0.10	erosion is the total from the first and second events
041b	X-sec	???	0.43	na		
		???	0.18	na	0.31	erosion is the total from the first and second events
050a	X-sec	2	lost	2+	2+	erosion is the total from the first and second events
050b	X-sec	2.5	0.13	na		
		4	0.19	na	0.16	erosion is the total from the first and second events
060a	X-sec	7.5	1.98	na		erosion is the total from the first and second events
		11	under water/buried	???	1.98???	cannot calculate average because do not have bottom pin data
060b	X-sec	3.5	0.45	na		
		9.5	under water	???	0.45???	cannot calculate average because do not have bottom pin data
060c	X-sec	3.5	0.21	na		
		6	0.21	na	0.21	erosion is the total from the first and second events
061	X-sec	1.7	0.08	na		
		3	0.39	na	0.24	erosion is the total from the first and second events
065a	X-sec	3	lost	5.15		
		7	1.71	na	3.43	erosion is the total from the first and second events
065b	X-sec	3	could not find	???	???	probably lost
		6.5	could not find	???	???	probably lost
069a	X-sec	2	0.11	na		
		4	0.10	na	0.11	erosion is the total from the first and second events
069b	X-sec	1	2.92	na		
		4	2.64	na	2.78	erosion is the total from the first and second events
072a	X-sec	2.5	0.35	na		
		6	under water	0	0.18	erosion is the total from the first and second events
072b	X-sec	6	1.45	na		
		8	0.13	na	3.46	
072	t/p of survey	3.5	0.17	na		
		7.5	buried	0	0.13	
072	t/p - 072b	3.5	0.22	na		
		7.5	0.08	na	1.31	
084a	X-sec	???	0.10	na		
		???	0.39	na	0.24	erosion is the total from the first and second events
088a1	X-sec	???	0.46	na		
		???	0.21	na	0.33	erosion is the total from the first and second events
088a2	X-sec	???	1.18	na		
		???	0.65	na	0.91	erosion is the total from the first and second events
088b	X-sec	7.6	-0.16	na		buried 0.16ft
		22	0.10	na	-0.03	erosion is the total from the first and second events

093a	X-sec	0.7	lost	4		erosion is the total from the first and second events
		1.8	2.7	na	3.35	did not replace pin
093b	X-sec	1.5	lost	6.5		
		3	lost	6.5		
		5	lost	6.5	6.5	erosion is the total from the first and second events
094	X-sec	1.2	2.39	na		
		3.6	under water/buried	???	3.63???	cannot calculate average because do not have bottom pin data
096	X-sec	2.3	lost	5.2		
		4.6	lost	5.2	9.2	estimate made from measurement to opposite base pin
105	X-sec	???	could not find	???	???	probably lost
		???	could not find	???	???	probably lost
106a	X-sec	4.3	0.08	na		
		6.9	0.00	na	0.16	
106b	X-sec	3	0.09	na		
		6.7	0.16	na	1.50	
108	X-sec	???	could not find	???	???	probably lost
		???	could not find	???	???	probably lost
120	X-sec	3.3	0.09	na		
		6.4	0.10	na	0.09	
128a	X-sec	4	0.18	na		
		7.6	0.00	na	0.82	
128b1	X-sec	2.5	0.07	na		
		5.5	0.12	na	0.59	
128b2	X-sec	1.7	3.22	na		
		???	lost	4	6.61	
143	X-sec	0.7	lost	4		did not replace pins
		3	lost	4	14	

Table 10: Erosion Measured with Bank Pins After the Third Major Storm Event

site	pin location	pin depth (ft)	erosion measured with: bank pins (ft)	other (ft)	cumulative average erosion (ft)	comments
069a	X-sec	2	-0.16	na		buried 2in
		4	0.13	na	0.10	
069b	X-sec	1	1.04	na		slump covered 0.50ft of 1.54ft out
		4	1.46	na	4.03	
072a	X-sec	2.5	buried	0		
		6	0.08	na	0.22	
072b	X-sec	6	lost	4		
		8	lost	4	7.46	
072	t/p of survey	3.5	0.06	na		
		7.5	buried	0	0.16	
088a1	X-sec	???	0.15	na		
		???	0.21	na	0.51	
088a2	X-sec	???	0.07	na		
		???	0.17	na	1.03	
088b	X-sec	7.6	0.00	na		
		22	0.00	na	-0.03	
093a	X-sec	1.8	0.83	na	4.18	
093b	X-sec	4.5	3.00	na		
		6.5	1.00	na	8.5	
094	X-sec	1.2	0.06	na		
		3.6	3.21	na	5.27	
096	X-sec	2.3	1.58	na		
		4.6	2.50	na	11.24	
106a	X-sec	4.3	-0.04	na		buried .04ft
		6.9	0.04	na	0.16	
106b	X-sec	3	0.04	na		
		6.7	0.04	na	1.54	
120	X-sec	3.3	could not find	0		not lost
		6.4	could not find	0	0.09	not lost
128a	X-sec	4	0.10	na		
		7.6	0.02	na	0.88	
128b1	X-sec	2.5	0.04	na		
		5.5	2.12	na	1.67	
128b2	X-sec	1.7	1.29	na	7.90	
143	X-sec	no pins	na	4.5	18.50	estimate based on known distance from tree to bank

Table 11: Erosion Measured with Bank Pins After the Forth Major Storm Event

site	pin location	pin depth (ft)	erosion measured with: bank pins (ft)	other (ft)	cumulative average erosion (ft)	comments
010	X-sec	3	0.60	na		
		6	0.30	na	0.5	erosion is the total from the third and forth events
015	X-sec	4	lost	6+		
		10	lost	6+	6.96+	erosion is the total from the third and forth events
015	70m down	3	lost	???		
	stream of X-sec	6	lost	???	???	
040a	X-sec	3	0.08	na		
		6	0.31	na	0.30	erosion is the total from the third and forth events
040b	X-sec	3	3.18	na		
		6	3.20	na	4.43	erosion is the total from the third and forth events
040c	X-sec	3.5	could not find	???		
		7.5	could not find	???	???	
041a	X-sec	2	0.04	na		
		5	0.08	na	0.16	erosion is the total from the third and forth events
041b	X-sec	???	0.67	na		
		???	1.19	na	1.24	erosion is the total from the third and forth events
060a	X-sec	7.5	0.30	na		
		11	0.04	na	2.15	erosion is the total from the third and forth events
060b	X-sec	3.5	could not find	0		not lost
		9.5	could not find	0	0.45	erosion is the total from the third and forth events
060c	X-sec	3.5	0.33	na		
		6	0.31	na	0.53	erosion is the total from the third and forth events
061	X-sec	1.7	could not find	???		
		3	could not find	???	???	
065a	X-sec	3	2.25	na		erosion is the total from the third and forth events
		7	maybe buried	???	4.55???	cannot calculate average without bottom pin data
069a	X-sec	2	0.21	na		
		4	0.12	na	0.26	
069b	X-sec	1	lost	3.9		
		4	probably buried	0	5.98	tree fell in at site
072a	X-sec	2.5	buried	0		
		6	0.02	na	0.23	
072b	X-sec	6	lost	3.17		
		8	lost	3.17	10.63	
072	t/p of survey	3.5	0.08	na		
		7.5	buried	-0.08	0.16	buried .08ft
072	t/p - 072b	3.5	0.12	na		
		7.5	0.25	na	1.68	erosion is the total from the third and forth events
084a	X-sec	???	0.87	na		
		???	0.00	na	0.68	erosion is the total from the third and forth events
088a1	X-sec	???	0.19	na		
		???	0.08	na	0.64	
088a2	X-sec	???	buried	0		LARGE sloughs from above covered pins
		???	buried	0	1.03	
088b	X-sec	7.6	buried	0		
		22	0.00	na	-0.03	
093a	X-sec	1.8	0.25	na	4.43	
093b	X-sec	4.5	0.29	na		
		6.5	0.00	na	8.64	
094	X-sec	1.2	0.45	na		
		3.6	1.17	na	6.08	

096	X-sec	2.3	lost	4		
		4.6	1.42	na	13.95	
106a	X-sec	4.3	0.02	na		
		6.9	0.08	na	0.21	
106b	X-sec	3	0.56	na		
		6.7	1.04	na	2.34	
120	X-sec	3.3	0.08	0		
		6.4	0.19	0	0.22	
128a	X-sec	4	0.19	na		
		7.6	0.29	na	1.12	
128b1	X-sec	2.5	lost	4		
		5.5	lost	4	5.67	estimated from distance to bank from survey base pin
128b2	X-sec	1.7	lost	12.1	20	estimated from distance to bank from phone pole
143	X-sec	no pins	na	8	26.5	tree which was 26ft from bank is gone

Table 12: Erosion Measured with Bank Pins After at/near Bankfull Events in the Spring and Summer of 1997

site	pin location	pin depth (ft)	erosion measured with: bank pins (ft)	other (ft)	cumulative average erosion (ft)	comments
040a	X-sec	3	0.00	na		
		6	0.00	na	0.30	
040b	X-sec	3	1.56	na		
		6	0.53	na	5.48	
041a	X-sec	2	0.04	na		
		5	0.00	na	0.18	
041b	X-sec	???	0.00	na		
		???	0.17	na	1.33	
060a	X-sec	7.5	0.08	na		
		11	0.00	na	2.19	
060b	X-sec	3.5	could not find	0		
		9.5	could not find	0	0.45	
060c	X-sec	3.5	0.00	na		
		6	0.01	na	0.54	
069a	X-sec	2	0.07	na		
		4	0.20	na	0.40	
094	X-sec	1.2	1.02	na		
		3.6	buried	0	6.59	
096	X-sec	2.3	2.35	na		
		4.6	lost	4	17.13	
120	X-sec	3.3	0.00	na		
		6.4	0.02	na	0.23	
128a	X-sec	4	0.00	na		
		7.6	0.29	na	1.27	
128b1	X-sec	2.5	0.33	na		
		5.5	buried	0	5.84	
128b2	X-sec	1.7	0.00	na	20	

Table 13a: Peak Flow Data for Watts Gage Station

date	estimated peak flow (cfs)	return period (years)	maximum mean daily flow (cfs)
9/27/96	20900	2.1	11900
11/7/96	18000	1.8	9250
11/25/96	16000	1.7	11800
2/21/97	18900	2.0	15100

Table 13b: Peak Flow Data for Tahlequah Gage Station

date	estimated peak flow (cfs)	return period (years)	maximum mean daily flow (cfs)
9/28/96	19200	2.1	12700
11/8/96	17500	2.0	11500
11/26/96	17000	2.0	13200
2/22/97	21100	2.5	18500

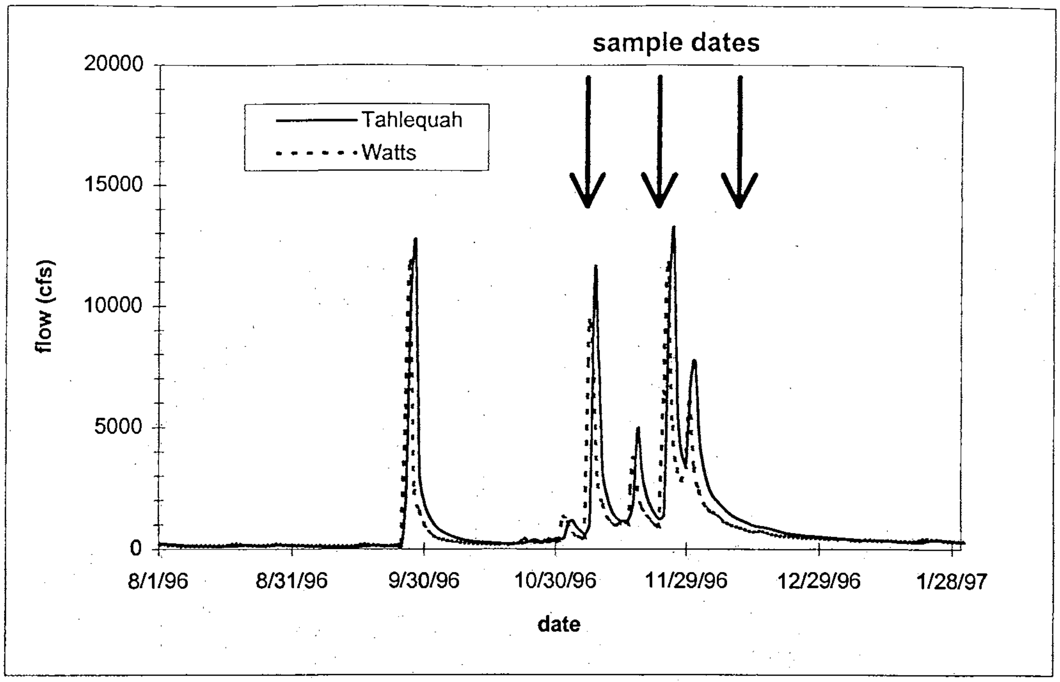

Figure 5a: Mean Daily Flows for the Illinois River Gage Stations at Watts and Tahlequah (provisional data for August 1, 1996 to January 31, 1997)

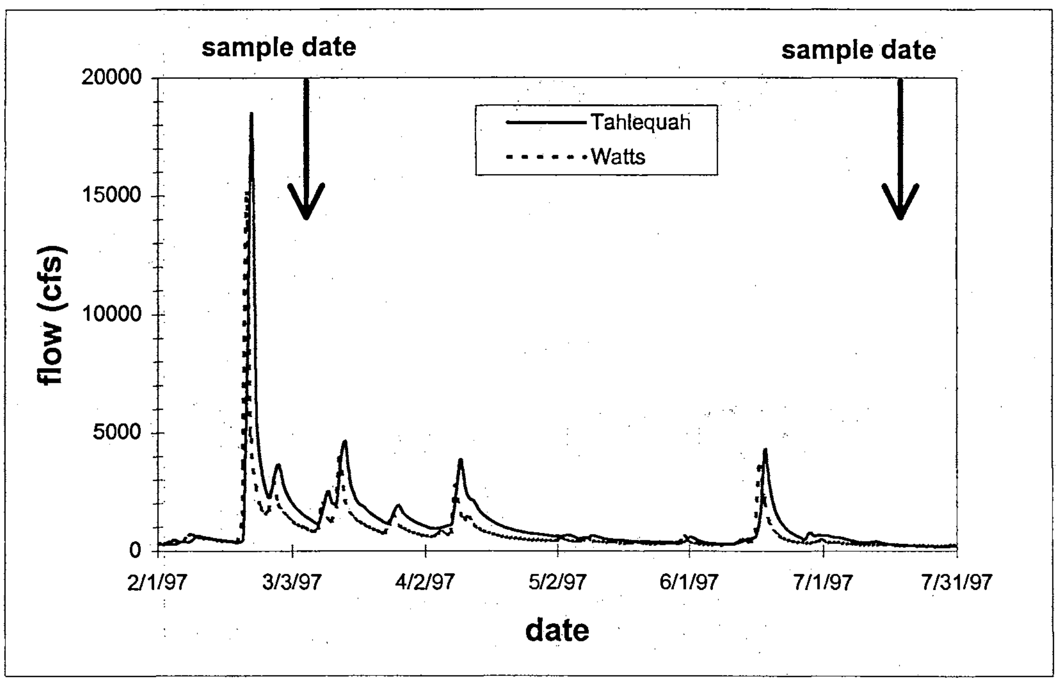

Figure 5b: Mean Daily Flows for the Illinois River Gage Stations at Watts and Tahlequah (provisional data for February 1, 1997 to July 31, 1997)

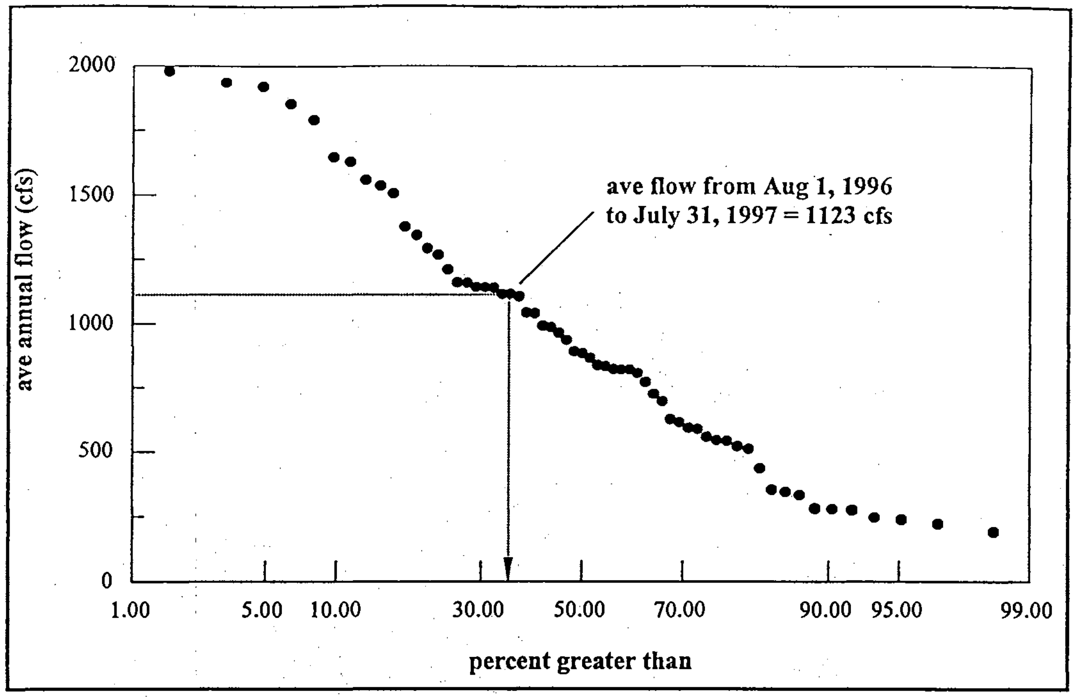

Figure 6a: Average Annual Flows for the Tahlequah Gage Station

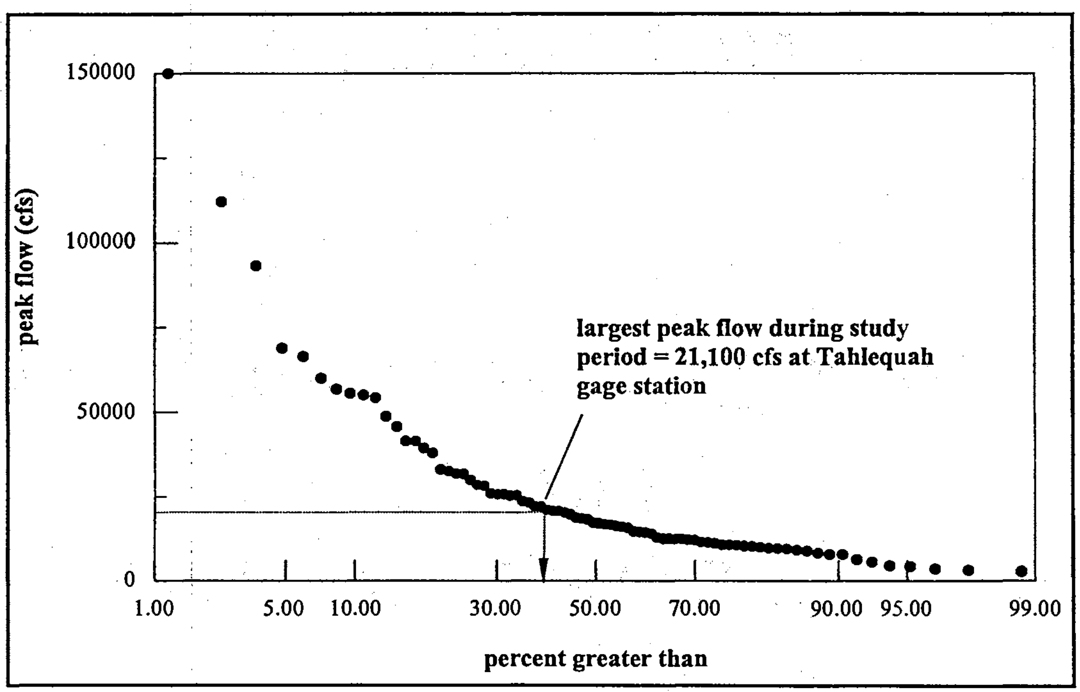

Figure 6b: Peak Flows for the Tahlequah Gage Station

Several difficulties were experienced in the use of bank pins to measure erosion in this study, but overall the pins allowed accurate measurement of bank erosion rates. The pins were often difficult to relocate because unpainted pins were used to minimize the disturbance by canoers. Because the pins were unpainted, a pin finder (metal detector) was necessary to find the pins. When the pins were relocated after the first and second major flow event, flagging was used to mark the cross section of each site. This marking improved the ability to relocate pins. The pins located upstream and/or downstream of the cross sections were especially difficult to find because of their distance from the marked cross sections; therefore, no data are reported for these pins.

Also, in this study several pins were lost due to excessive bank erosion. For each major flow event, several sites experienced greater than 4 ft of erosion which removed the 4 ft pins from the bank. This large magnitude of erosion was not expected and could not be measured with bank pins. When possible in these cases, distance measurements from bank surveys were used to measure erosion.

A possible increase in erosion caused by using bank pins to measure erosion in gravel deposits was noted in Thorne (1981). All of the sites in this study were classified as gravelly; however, the banks generally contained finer materials than the gravelly channels. This characteristic is indicated in Rosgen (1996b). Most of the banks in this study did contain gravel layers or gravel mixed with silt, but only three of the banks were dominated by gravel (050a, 050b, 069b); therefore, the use of bank pins should not have significantly affected measured erosion on a majority of the sites.

Cross-sectional surveys, taken as part of the Rosgen Level II stream reach classification, were also used to measure short-term channel changes such as bank erosion and deposition and aggradation/degradation. Figures showing the cross section changes from August/September 1996 to July 1997 on sites selected for detailed study appear in Appendix D. Many of the base pins, used to establish elevation and directional references, were lost to bank erosion or to scour and redeposition; therefore, many of the cross-sectional surveys are referenced to only one pin and a compass direction. When only one pin was used, it is indicated in the appropriate figure in Appendix D. Several sites including 040a, 040c, 060a, 065b, and 128b2 experienced major aggradation and several others experienced lesser aggradation (060b/061, 088a2, 120). Other sites such as 041b, 060c, 094, and 128a experienced degradation, but this degradation was generally of lesser magnitude than aggradation on aggrading sites. The channel thalweg of sites 084a and 093 experienced lateral shifts of 140 ft and 220 ft, respectively.

Observations on Current Illinois River Behavior

Over the period from September 1996 to July 1997, short-term bank erosion was measured five times on the Upper Illinois River. The magnitude of bank erosion was determined from these bank pin measurements. However, the extent of rapid change including extensive channel widening and channel course adjustment was not fully realized and quantified until the last measurement trip in July 1997.

The extent of bank erosion was illustrated by the cumulative erosion totals after the four major flow events (extreme examples include: 10.63, 8.64, 13.95, 20.0, and 26.5 ft). These figures exceeded expected erosion rates, especially since no large magnitude flows (greater than 5 yr return period) occurred during the study period.

Rapid channel change was also observed in the last measurement trip in July 1997. Cross-sectional surveys performed during this measurement trip indicated that extensive channel widening and channel shift had occurred over the 10 month study period. Many sites experienced greater than 10 ft width increases over the study period, including sites 065b (20 ft - estimated from 1997 cross section survey), 096 (14 ft), site 128b2 (20ft), and site 143 (30 to 70ft). These changes are shown in Appendix D. The width increase of site 143, which experienced major erosion on both sides of the channel causing loss of both survey base pins, was estimated with survey equipment at the approximate location of the cross section.

Another indication of rapid channel change occurred on sites 093 and 084a. At some time during the 10 month study period, the channel thalweg at sites 093 and 084a changed courses by moving laterally approximately 220 ft and 140 ft, respectively (Appendix D). Local residents have indicated that channel course change and channel abandonment occurs periodically on several of the Illinois River reaches.

These data seem to show that the Illinois River is in a period of rapid change. Whether the river is in a cyclic pattern that will reverse due to natural tendencies or stabilization efforts or is in a pattern of change that will result in a new or possibly original river pattern is not known.

Bank Erosion Measurements from Aerial Photographs

Measurements of long-term bank erosion were made from 1:7920 scale USDA aerial photographs from 1958, 1979, and 1991 using a method modified from Brice

(1982). This analysis yielded information on the 193 initially characterized sites as well as 28 other significant erosional/depositional areas (generally areas with greater than 0.5 ac of land surface area lost by erosion or gained by deposition). Appendix E is an example of a site changing over the periods 1958 to 1979 and 1979 to 1991.

In the analysis of erosion from aerial photographs, 168 areas had significant erosion and/or deposition in either the period from 1958 to 1979 or from 1979 to 1991. In the determination of the parameters: maximum lateral erosion, lateral erosion and/or deposition, area, and length, sites that could not be distinguished were grouped. These groupings are indicated in the appropriate tables (tables 14 and 15). Also, data from sites 108, 117, 118a, 118b, 119, and 143 were not used because the banks could not be adequately located on the aerial photographs. It should also be kept in mind that a complete set of photographs for the Upper Illinois River for 1958 was not available. Therefore, all data reported for 1958 or for the period 1958 to 1979 are not complete sets for the entire river study area.

Because of the scale of the aerial photographs used, differences in bank position of less than 0.01 in (0.25 mm), measured on the photos, were not clearly distinguishable. On the aerial photographs, this distance equals 6.5 ft in actual distance; therefore, areas having less than 6.5 ft of lateral erosion and/or deposition over the periods 1958 to 1979 or 1979 to 1991 are reported to have no erosion or deposition.

The maximum lateral erosion and the lateral erosion and/or deposition during each time period, 1958 to 1979 and 1979 to 1991, appear in table 14. The maximum lateral erosion, described above as the maximum distance a bank eroded, averaged 74 ft for 1979 to 1991 and 67 ft from 1958 to 1979 for all of the areas. The lateral erosion

Table 14: Maximum Lateral Erosion and Lateral Erosion and Deposition of Erosional/Depositional Areas

site	maximum lateral erosion		lateral erosion				lateral deposition			
	1979 - 1991	1958 - 1979	1979 - 1991		1958 - 1979		1979 - 1991		1958 - 1979	
	(ft)	(ft)	(ft)	(ft/yr)	(ft)	(ft/yr)	(ft)	(ft/yr)	(ft)	(ft/yr)
001	52	0	31	2.7	0	0.0	0	0.0	0	0.0
002	19	65	12	1.1	39	1.8	0	0.0	0	0.0
003	0	0	0	0.0	0	0.0	0	0.0	0	0.0
004a,b	84	39	54	4.8	21	1.0	0	0.0	34	1.6
005	0	0	0	0.0	0	0.0	0	0.0	0	0.0
006, 007	84	0	57	5.0	0	0.0	0	0.0	0	0.0
008	0	0	0	0.0	0	0.0	0	0.0	0	0.0
009	104	136	51	4.5	53	2.5	0	0.0	48	2.2
010	0	0	0	0.0	0	0.0	0	0.0	0	0.0
011	32	0	24	2.1	0	0.0	0	0.0	0	0.0
012	52	117	33	2.9	66	3.1	0	0.0	73	3.4
013	39	65	25	2.2	37	1.7	0	0.0	46	2.1
014	91	0	73	6.5	0	0.0	0	0.0	69	3.2
015	39	26	36	3.1	21	1.0	0	0.0	136	6.4
016a,b,c	104	52	66	5.8	34	1.6	0	0.0	0	0.0
017	13	52	7	0.6	42	2.0	0	0.0	0	0.0
018	0	234	0	0.0	155	7.3	0	0.0	138	6.5
019a,b	58	71	52	4.6	43	2.0	0	0.0	101	4.7
020a,b	52	65	50	4.4	31	1.5	0	0.0	0	0.0
021	97	71	39	3.4	53	2.5	0	0.0	36	1.7
022	32	na	25	2.2	na	na	0	0.0	na	na
023	45	na	23	2.1	na	na	0	0.0	na	na
024	0	na	0	0.0	na	na	0	0.0	na	na
025	0	na	0	0.0	na	na	0	0.0	na	na
026a,b,c	182	162	57	5.0	94	4.4	0	0.0	99	4.7
027	52	136	50	4.4	60	2.8	0	0.0	0	0.0
028	0	65	0	0.0	0	0.0	0	0.0	57	2.7
029	26	78	22	1.9	48	2.2	0	0.0	99	4.6
030	52	52	35	3.1	0	0.0	0	0.0	0	0.0
031	104	123	62	5.5	42	1.9	0	0.0	0	0.0
032	78	39	70	6.2	28	1.3	0	0.0	56	2.6
033	117	46	45	4.0	41	1.9	0	0.0	38	1.8
034	163	33	81	7.2	28	1.3	0	0.0	0	0.0
035a,b	214	130	77	6.8	57	2.7	0	0.0	113	5.3
036a,b	286	227	115	10.2	144	6.8	68	6.0	133	6.2
037	0	45	0	0.0	36	1.7	0	0.0	0	0.0
038	26	39	24	2.1	18	0.8	0	0.0	0	0.0
039	84	0	24	2.2	0	0.0	0	0.0	0	0.0
040a,b,c	45	65	19	1.7	48	2.3	0	0.0	38	1.8
041a,b	26	na	14	1.2	na	na	0	0.0	224	10.5
042a,b	33	na	27	2.4	na	na	63	5.5	72	3.4
043	58	0	30	2.6	0	0.0	0	0.0	0	0.0
044	91	78	76	6.7	49	2.3	0	0.0	54	2.6
045a,b	39	130	20	1.8	60	2.8	0	0.0	42	2.0
046	65	0	64	5.6	0	0.0	0	0.0	117	5.5
047	78	85	50	4.4	79	3.7	0	0.0	90	4.2
048	59	48	53	4.7	37	1.7	0	0.0	14	0.6
049	44	65	43	3.8	22	1.0	0	0.0	62	2.9
050a,b	0	39	0	0.0	19	0.9	0	0.0	0	0.0
051a,b	117	325	75	6.6	159	7.5	50	4.4	206	9.7
052	52	45	42	3.7	31	1.5	0	0.0	0	0.0
053	65	234	40	3.6	81	3.8	0	0.0	48	2.2
054	130	65	53	4.7	50	2.3	0	0.0	0	0.0
055	78	0	32	2.8	0	0.0	0	0.0	0	0.0
056	130	78	59	5.2	46	2.1	0	0.0	66	3.1
057	26	91	24	2.2	73	3.4	18	1.6	60	2.8
058	20	39	16	1.4	38	1.8	0	0.0	0	0.0
059	0	78	0	0.0	41	1.9	0	0.0	0	0.0
060a,b,c	33	39	28	2.5	30	1.4	0	0.0	0	0.0
061	91	0	58	5.1	0	0.0	0	0.0	135	6.3
062a,b	33	52	27	2.4	29	1.4	0	0.0	296	13.9
063	78	0	44	3.9	0	0.0	0	0.0	0	0.0
064	0	na	0	0.0	na	na	0	0.0	na	na
065a,b	26	na	16	1.4	na	na	0	0.0	na	na
066a,b	65	na	31	2.8	na	na	0	0.0	na	na
067, 068	26	na	18	1.6	na	na	0	0.0	na	na
069a,b	26	na	23	2.1	na	na	0	0.0	na	na
070a,b	0	na	0	0.0	na	na	0	0.0	na	na
071	78	na	56	4.9	na	na	0	0.0	na	na
072a	26	na	14	1.2	na	na	0	0.0	na	na

072b	117	na	67	6.0	na	na	0	0.0	na	na
073	104	na	65	5.8	na	na	0	0.0	na	na
074a,b	188	na	51	4.5	na	na	0	0.0	na	na
075	702	na	243	21.4	na	na	38	3.4	na	na
076	286	na	116	10.3	na	na	0	0.0	na	na
077	0	na	0	0.0	na	na	0	0.0	na	na
078	0	na	0	0.0	na	na	0	0.0	na	na
079	117	na	75	6.7	na	na	0	0.0	na	na
080	149	na	88	7.8	na	na	0	0.0	na	na
081	0	na	0	0.0	na	na	0	0.0	na	na
082	0	na	0	0.0	na	na	0	0.0	na	na
083	0	na	0	0.0	na	na	0	0.0	na	na
084a,b	286	na	89	7.9	na	na	0	0.0	na	na
085	78	na	43	3.8	na	na	0	0.0	na	na
086	182	na	140	12.4	na	na	40	3.5	na	na
087	52	na	38	3.4	na	na	0	0.0	na	na
088a,b,c	65	na	39	3.4	na	na	0	0.0	na	na
089a,b,c	234	na	115	10.1	na	na	41	3.6	na	na
090	78	na	49	4.3	na	na	23	2.0	na	na
091	0	na	0	0.0	na	na	0	0.0	na	na
092	104	na	70	6.1	na	na	67	5.9	na	na
093a,b	234	na	118	10.5	na	na	89	7.9	na	na
094	104	na	52	4.6	na	na	0	0.0	na	na
095	0	na	0	0.0	na	na	0	0.0	na	na
096	344	na	173	15.3	na	na	0	0.0	na	na
097	0	na	0	0.0	na	na	0	0.0	na	na
098	71	na	45	4.0	na	na	0	0.0	na	na
099	46	na	24	2.1	na	na	26	2.3	na	na
100	0	na	0	0.0	na	na	0	0.0	na	na
101	247	na	87	7.7	na	na	0	0.0	na	na
102	39	na	31	2.7	na	na	0	0.0	na	na
103a,b,c	65	na	43	3.8	na	na	0	0.0	na	na
104	143	na	86	7.6	na	na	0	0.0	na	na
105	65	na	61	5.4	na	na	0	0.0	na	na
106a,b	45	na	28	2.5	na	na	0	0.0	na	na
107	26	na	18	1.5	na	na	0	0.0	na	na
109, 110, 111	130	na	50	4.4	na	na	0	0.0	na	na
112	65	na	35	3.1	na	na	0	0.0	na	na
113a,b	227	na	142	12.5	na	na	0	0.0	na	na
114	78	na	42	3.7	na	na	0	0.0	na	na
115	299	na	153	13.5	na	na	81	7.1	na	na
116	0	na	0	0.0	na	na	0	0.0	na	na
120	0	na	0	0.0	na	na	0	0.0	na	na
121	195	na	95	8.4	na	na	0	0.0	na	na
122	45	na	38	3.4	na	na	0	0.0	na	na
123a,b	195	na	115	10.1	na	na	0	0.0	na	na
124	0	na	0	0.0	na	na	0	0.0	na	na
125	84	na	53	4.7	na	na	81	7.1	na	na
126	0	na	0	0.0	na	na	0	0.0	na	na
127	52	na	47	4.1	na	na	0	0.0	na	na
128a,b, 129	52	na	27	2.4	na	na	0	0.0	na	na
130	0	na	0	0.0	na	na	0	0.0	na	na
131	46	na	42	3.7	na	na	0	0.0	na	na
132	0	na	0	0.0	na	na	0	0.0	na	na
133	143	na	83	7.3	na	na	0	0.0	na	na
134	78	na	50	4.5	na	na	0	0.0	na	na
135	33	na	32	2.8	na	na	0	0.0	na	na
136	110	na	53	4.7	na	na	0	0.0	na	na
137	208	na	93	8.2	na	na	0	0.0	na	na
138a,b,c	130	na	75	6.7	na	na	37	3.3	na	na
139	0	na	0	0.0	na	na	0	0.0	na	na
140	39	na	27	2.4	na	na	0	0.0	na	na
141	0	na	0	0.0	na	na	0	0.0	na	na
142	65	na	48	4.3	na	na	0	0.0	na	na
144	91	na	61	5.4	na	na	0	0.0	na	na
145	52	na	0	0.0	na	na	0	0.0	na	na
146	0	na	0	0.0	na	na	0	0.0	na	na
147	39	na	38	3.3	na	na	0	0.0	na	na
148	0	na	0	0.0	na	na	0	0.0	na	na
149a,b,c,d,e	97	na	41	3.6	na	na	37	3.2	na	na
others										
1	65	0	43	3.8	0	0.0	0	0.0	0	0.0
2	97	91	60	5.3	58	2.7	0	0.0	0	0.0

3	0	65	0	0.0	31	1.4	0	0.0	67	3.1
4	91	65	56	5.0	27	1.2	0	0.0	50	2.3
5	26	52	21	1.9	45	2.1	0	0.0	0	0.0
6	19	136	13	1.1	27	1.3	0	0.0	91	4.3
7	65	0	48	4.2	0	0.0	0	0.0	85	4.0
8	130	na	77	6.8	na	na	0	0.0	na	na
9	45	na	34	3.0	na	na	0	0.0	na	na
10	52	na	37	3.3	na	na	0	0.0	na	na
11	78	na	47	4.2	na	na	0	0.0	na	na
12	65	na	39	3.5	na	na	0	0.0	na	na
13	45	na	35	3.1	na	na	0	0.0	na	na
14	65	na	28	2.5	na	na	0	0.0	na	na
15	39	na	34	3.0	na	na	0	0.0	na	na
16	130	na	77	6.8	na	na	0	0.0	na	na
17	0	na	0	0.0	na	na	0	0.0	na	na
18	104	na	46	4.0	na	na	0	0.0	na	na
19	65	na	30	2.7	na	na	0	0.0	na	na
20	52	na	37	3.3	na	na	0	0.0	na	na
21	52	na	30	2.7	na	na	0	0.0	na	na
22	65	na	58	5.1	na	na	0	0.0	na	na
23	58	na	29	2.6	na	na	0	0.0	na	na
24	0	156	0	0.0	81	3.8	0	0.0	33	1.6
25	0	45	0	0.0	34	1.6	0	0.0	0	0.0
26	78	na	54	4.8	na	na	0	0.0	na	na
27	59	na	53	4.6	na	na	0	0.0	na	na
28	65	na	32	2.8	na	na	0	0.0	na	na

and/or deposition was determined by dividing the land surface area of the erosional/ depositional area by the length. For the period 1979 to 1991 for all of the sites, the lateral erosion averaged 41 ft or 3.6 ft/yr, and the lateral deposition averaged 5 ft or 0.4 ft/yr. For the period 1958 to 1979 for all of the sites, the lateral erosion averaged 37 ft or 1.7 ft/yr, and the lateral deposition averaged 47 ft or 2.2 ft/yr.

The land surface areas and length of each erosional/depositional area, measured using SEDCAD$^+$, appear in table 15. During the period 1979 to 1991, the land surface area of eroding areas averaged 1.2 ac and depositional areas averaged 0.1 ac. During the period 1958 to 1979, the land surface area of eroding areas averaged 1.0 ac and depositional areas averaged 1.2 ac. For the period 1979 to 1991, the length of eroding areas averaged 1131 ft and depositional areas averaged 665 ft. For the period 1958 to 1979, the length of eroding areas averaged 1014 ft and depositional areas averaged 999 ft. Between 1979 and 1991, a total of 195 ac of land surface area was eroded and 13 ac was deposited. Between 1958 and 1979, a total of 64 ac of land was eroded and 78 ac was deposited.

Uncertainties are involved in each step of measuring distances and areas from tracing of features on aerial photographs (ie: measuring distances, converting units based on map scale, and digitizing areas). For example, the uncertainty associated with measuring the maximum lateral erosion for site 001 for the period 1979 to 1991 is presented in table 16a.

The cumulative uncertainty associated with the measurement of each of these parameters appears in table 16b. Cumulative probable uncertainties are presented, as opposed to maximum uncertainties, because it is very unlikely that each of the quantities

Table 15: Land Surface Areas and Lengths of Erosional/Depositional Areas

site	1979-1991 erosion area (ac)	1979-1991 erosion length (ft)	1979-1991 deposition area (ac)	1979-1991 deposition length (ft)	1958-1979 erosion area (ac)	1958-1979 erosion length (ft)	1958-1979 deposition area (ac)	1958-1979 deposition length (ft)
001	0.38	533	0.00	0	0.00	0	0.00	0
002	0.10	351	0.00	0	0.50	552	0.00	0
003	0.00	0	0.00	0	0.00	0	0.00	0
004a,b	1.84	1483	0.00	0	0.36	739	0.62	796
005	0.00	0	0.00	0	0.00	0	0.00	0
006, 007	0.70	536	0.00	0	0.00	0	0.00	0
008	0.00	0	0.00	0	0.00	0	0.00	0
009	1.14	971	0.00	0	1.94	1585	1.20	1098
010	0.00	0	0.00	0	0.00	0	0.00	0
011	0.64	1150	0.00	0	0.00	0	0.00	0
012	0.18	237	0.00	0	1.26	830	2.94	1754
013	0.28	480	0.00	0	1.50	1772	1.28	1225
014	1.64	973	0.00	0	0.00	0	1.00	630
015	0.92	1124	0.00	0	0.28	582	3.66	1171
016a,b,c	1.60	1059	0.00	0	0.80	1025	0.00	0
017	0.04	243	0.00	0	0.40	414	0.00	0
018	0.00	0	0.00	0	5.78	1622	2.28	721
019a,b	0.96	798	0.00	0	1.24	1255	2.48	1070
020a,b	0.98	862	0.00	0	1.14	1594	0.00	0
021	0.44	491	0.00	0	2.56	2092	0.60	733
022	0.58	995	0.00	0	na	na	na	na
023	1.00	1859	0.00	0	na	na	na	na
024	0.00	0	0.00	0	na	na	na	na
025	0.00	0	0.00	0	na	na	na	na
026a,b,c	2.80	2158	0.00	0	3.22	1496	4.48	1962
027	0.30	263	0.00	0	1.78	1282	0.00	0
028	0.00	0	0.00	0	0.00	0	0.42	321
029	0.48	961	0.00	0	1.66	1508	1.42	624
030	0.32	401	0.00	0	0.00	0	0.00	0
031	0.66	461	0.00	0	1.44	1509	0.00	0
032	1.50	927	0.00	0	0.14	221	0.58	454
033	1.10	1060	0.00	0	1.18	1263	0.56	650
034	2.10	1123	0.00	0	0.28	434	0.00	0
035a,b	3.02	1704	0.00	0	1.62	1233	1.36	525
036a,b	5.86	2213	0.96	619	3.36	1015	4.60	1512
037	0.00	0	0.00	0	0.70	836	0.00	0
038	0.54	976	0.00	0	0.64	1556	0.00	0
039	0.46	820	0.00	0	0.00	0	0.00	0
040a,b,c	0.34	784	0.00	0	1.16	1042	0.56	637
041a,b	0.20	620	0.00	0	na	na	7.22	1402
042a,b	0.42	683	1.58	1101	na	na	0.94	569
043	0.44	642	0.00	0	0.00	0	0.00	0
044	1.68	961	0.00	0	0.58	515	0.68	544
045a,b	0.92	1980	0.00	0	1.52	1107	0.82	841
046	0.96	654	0.00	0	0.00	0	1.38	514
047	2.00	1747	0.00	0	1.92	1053	1.56	751
048	1.34	1099	0.00	0	0.54	632	0.06	189
049	2.20	2232	0.00	0	0.32	640	2.03	1421
050a,b	0.00	0	0.00	0	0.52	1216	0.00	0
051a,b	1.90	1099	0.76	661	8.04	2201	8.86	1873
052	0.76	781	0.00	0	0.48	676	0.00	0
053	0.58	628	0.00	0	4.16	2233	0.60	547
054	1.50	1231	0.00	0	0.58	510	0.00	0
055	0.34	463	0.00	0	0.00	0	0.00	0
056	2.38	1749	0.00	0	0.46	438	2.32	1520
057	0.82	1462	0.14	345	1.02	610	2.46	1797
058	0.20	533	0.00	0	0.72	821	0.00	0
059	0.00	0	0.00	0	0.74	784	0.00	0
060a,b,c	0.64	990	0.00	0	1.12	1616	0.00	0
061	1.24	926	0.00	0	0.00	0	4.00	1291
062a,b	0.66	1069	0.00	0	0.36	541	5.82	856
063	0.54	535	0.00	0	0.00	0	0.00	0
064	0.00	0	0.00	0	na	na	na	na
065a,b	0.22	585	0.00	0	na	na	na	na
066a,b	0.30	419	0.00	0	na	na	na	na

067, 068	0.80	1923	0.00	0	na	na	na	na
069a,b	0.40	747	0.00	0	na	na	na	na
070a,b	0.00	0	0.00	0	na	na	na	na
071	1.38	1080	0.00	0	na	na	na	na
072a	0.26	830	0.00	0	na	na	na	na
072b	1.42	917	0.00	0	na	na	na	na
073	2.94	1958	0.00	0	na	na	na	na
074a,b	3.12	2639	0.00	0	na	na	na	na
075	10.70	1919	0.60	681	na	na	na	na
076	4.20	1571	0.00	0	na	na	na	na
077	0.00	0	0.00	0	na	na	na	na
078	0.00	0	0.00	0	na	na	na	na
079	1.60	925	0.00	0	na	na	na	na
080	3.68	1825	0.00	0	na	na	na	na
081	0.00	0	0.00	0	na	na	na	na
082	0.00	0	0.00	0	na	na	na	na
083	0.00	0	0.00	0	na	na	na	na
084a,b	2.50	1223	0.00	0	na	na	na	na
085	1.26	1276	0.00	0	na	na	na	na
086	4.78	1486	0.90	992	na	na	na	na
087	1.46	1658	0.00	0	na	na	na	na
088a,b,c	1.28	1440	0.00	0	na	na	na	na
089a,b,c	4.46	1692	0.46	488	na	na	na	na
090	1.36	1205	0.36	681	na	na	na	na
091	0.00	0	0.00	0	na	na	na	na
092	0.94	588	0.76	494	na	na	na	na
093a,b	4.42	1626	0.92	448	na	na	na	na
094	0.82	688	0.00	0	na	na	na	na
095	0.00	0	0.00	0	na	na	na	na
096	3.98	1003	0.00	0	na	na	na	na
097	0.00	0	0.00	0	na	na	na	na
098	1.40	1350	0.00	0	na	na	na	na
099	0.34	621	0.22	364	na	na	na	na
100	0.00	0	0.00	0	na	na	na	na
101	4.54	2279	0.00	0	na	na	na	na
102	0.32	454	0.00	0	na	na	na	na
103a,b,c	0.80	814	0.00	0	na	na	na	na
104	2.82	1433	0.00	0	na	na	na	na
105	1.36	977	0.00	0	na	na	na	na
106a,b	0.44	687	0.00	0	na	na	na	na
107	0.18	447	0.00	0	na	na	na	na
109, 110, 111	3.40	2979	0.00	0	na	na	na	na
112	1.20	1511	0.00	0	na	na	na	na
113a,b	7.22	2221	0.00	0	na	na	na	na
114	0.58	599	0.00	0	na	na	na	na
115	5.16	1471	2.00	1080	na	na	na	na
116	0.00	0	0.00	0	na	na	na	na
120	0.00	0	0.00	0	na	na	na	na
121	2.02	930	0.00	0	na	na	na	na
122	0.72	816	0.00	0	na	na	na	na
123a,b	2.74	1041	0.00	0	na	na	na	na
124	0.00	0	0.00	0	na	na	na	na
125	1.32	1087	2.14	1152	na	na	na	na
126	0.00	0	0.00	0	na	na	na	na
127	1.06	989	0.00	0	na	na	na	na
128a,b, 129	2.12	3409	0.00	0	na	na	na	na
130	0.00	0	0.00	0	na	na	na	na
131	1.46	1530	0.00	0	na	na	na	na
132	0.00	0	0.00	0	na	na	na	na
133	1.02	536	0.00	0	na	na	na	na
134	1.46	1260	0.00	0	na	na	na	na
135	0.28	384	0.00	0	na	na	na	na
136	0.76	622	0.00	0	na	na	na	na
137	2.56	1203	0.00	0	na	na	na	na
138a,b,c	3.48	2008	0.40	468	na	na	na	na
139	0.00	0	0.00	0	na	na	na	na
140	0.74	1199	0.00	0	na	na	na	na
141	0.00	0	0.00	0	na	na	na	na
142	0.54	488	0.00	0	na	na	na	na

144	1.26	898	0.00	0	na	na	na	na
145	0.00	0	0.00	0	na	na	na	na
146	0.00	0	0.00	0	na	na	na	na
147	0.84	970	0.00	0	na	na	na	na
148	0.00	0	0.00	0	na	na	na	na
149a,b,c,d,e	2.30	2473	0.34	403	na	na	na	na
others								
1	1.60	1631	0.00	0	0.00	0	0.00	0
2	1.08	782	0.00	0	1.36	1021	0.00	0
3	0.00	0	0.00	0	0.58	825	2.38	1549
4	1.80	1392	0.00	0	0.18	295	1.30	1135
5	0.86	1760	0.00	0	0.62	603	0.00	0
6	0.14	480	0.00	0	0.26	424	3.76	1794
7	1.04	946	0.00	0	0.0	0	1.94	991
8	1.78	1001	0.00	0	na	na	na	na
9	1.12	1427	0.00	0	na	na	na	na
10	0.66	779	0.00	0	na	na	na	na
11	0.80	739	0.00	0	na	na	na	na
12	0.38	422	0.00	0	na	na	na	na
13	1.42	1781	0.00	0	na	na	na	na
14	0.54	840	0.00	0	na	na	na	na
15	0.76	970	0.00	0	na	na	na	na
16	1.80	1022	0.00	0	na	na	na	na
17	0.00	0	0.00	0	na	na	na	na
18	0.98	937	0.00	0	na	na	na	na
19	0.92	1328	0.00	0	na	na	na	na
20	0.58	679	0.00	0	na	na	na	na
21	0.50	719	0.00	0	na	na	na	na
22	2.44	1829	0.00	0	na	na	na	na
23	0.68	1006	0.00	0	na	na	na	na
24	0.00	0	0.00	0	2.34	1262	0.38	496
25	0.00	0	0.00	0	0.90	1170	0.00	0
26	0.82	660	0.00	0	na	na	na	na
27	1.06	878	0.00	0	na	na	na	na
28	2.32	3175	0.00	0	na	na	na	na

Table 16a: Example Illustrating Uncertainty Calculations

site 001	value	uncertainty
maximum lateral erosion 1979 to 1991	2 mm	+/- 0.25 mm
conversion factor based on map scale	1 mm = 26 ft	+/- 1.3 ft

maximum lateral erosion (ft) = (2 mm) (26 ft/mm)

maximum lateral erosion (ft) = **52 ft**

cumulative probable uncertainty = [(relative error 1)^2 + (relative error 2)^2] ^ 0.5 from Barry (1978)

cumulative probable uncertainty = [(.25 mm / 2 mm)^2 + (1.3 ft/mm / 26 ft/mm)^2] ^ 0.5

cumulative probable uncertainty = **13.5%**

Table 16b: Cumulative Uncertainty of Parameters Calculated from Aerial Photograph Analyses

parameter	period	probable uncertainty (%)	comments
maximum lateral erosion	1979-1991	12.9	- average
	1958-1979	11.9	
lateral erosion	1979-1991	14.3	- average
	1958-1979	14.5	
lateral deposition	1979-1991	15.8	- average
	1958-1979	13.5	
length of eroded areas	1979-1991	5.1	- average weighted based on lengths of eroded areas
	1958-1979	5.1	(average = 5.1% for both periods)
length of depositional areas	1979-1991	5.1	- average weighted based on lengths of depositional areas
	1958-1979	5.1	(average = 5.1% for both periods)
areas of eroded areas	1979-1991	7.7	- average weighted based on land surface areas of eroded areas
	1958-1979	7.8	(average = 9.6% for 1979-1991, average = 9.7% for 1958-1979)
areas of depositional areas	1979-1991	9.1	- average weighted based on land surface areas of depositional areas
	1958-1979	7.1	(average = 10.8% for 1979-1991, average = 8.8% for 1958-1979)

used in calculation of the parameters are uncertain by the maximum amount and each in the same direction (Barry 1978).

Odgaard (1987) also used the method of Brice (1982) to measure bank erosion on two Iowa rivers. Odgaard found that 0.56 ac of land per mile of river length was lost annually to erosion on the Des Moines River. The Des Moines River reaches studied have an average annual discharge of approximately 5000 cfs, and most of the banks had light or no vegetative cover. On the East Nishnabotna River, Odgaard found that 0.28 to 0.60 ac of land per mile of river length was lost annually to erosion. The East Nishnabotna River reaches, most of which have little or no vegetative cover on the bends, have an average annual discharge of approximately 290 cfs. On the Upper Illinois River, which has an average annual discharge of 935 cfs, approximately 0.27 ac per mile were lost to erosion annually between 1979 and 1991.

The river width at each 0.5 river mile, measured directly from bank tracings, appears in table 17. The average river width for 1991 and 1979 was 206 ft and 175 ft, respectively. To compare river widths for various sections of the river, the river was divided into three, 21-mile sections. In the first 21 miles, the average river width increased from 147 ft in 1958 to 158 ft in 1979 and to 185 ft in 1991. For miles 21 to 42, the average river width increased from 169 ft in 1979 to 195 ft in 1991. For the lower third, the average width increased from 199 ft in 1979 to 239 ft in 1991. These data indicate that river width increases in the downstream direction, which occurs in rivers as flow volumes increase, and more importantly that the Illinois River became an average of 18% wider in the period 1979 to 1991.

Table 17: River Widths

approximate distance below Lake Francis Dam (miles)	1991 river width (ft)	1979 river width (ft)	1958 river width (ft)	% change in river width from 1979 to 1991
0.5	201	169	169	19
1	208	130	156	60
1.5	156	156	156	0
2	117	117	117	0
2.5	156	156	143	0
3	130	130	130	0
3.5	169	136	136	24
4	130	104	130	25
4.5	429	429	169	0
5	143	117	117	22
5.5	234	143	110	64
6	156	156	65	0
6.5	286	286	221	0
7	149	104	130	44
7.5	156	130	na	20
8	130	130	na	0
8.5	520	520	na	0
9	156	156	156	0
9.5	110	78	78	42
10	117	117	117	0
10.5	104	104	104	0
11	208	208	208	0
11.5	429	130	286	230
12	156	136	110	14
12.5	143	130	130	10
13	117	104	na	13
13.5	273	247	247	11
14	130	130	130	0
14.5	130	130	130	0
15	130	52	182	150
15.5	208	130	130	60
16	130	97	71	33
16.5	182	182	182	0
17	130	130	104	0
17.5	260	156	117	67
18	156	123	175	26
18.5	130	130	130	0
19	169	169	234	0
19.5	169	169	169	0
20	156	130	130	20
20.5	156	156	156	0
21	273	234	156	17
21.5	234	208	260	13
22	117	117	117	0
22.5	117	104	104	13
23	130	130	130	0
23.5	169	156	na	8
24	143	123	na	16
24.5	338	338	na	0
25	195	169	na	15
25.5	546	546	na	0
26	260	182	na	43
26.5	468	468	na	0
27	208	156	na	33
27.5	201	130	na	55
28	104	65	na	60
28.5	65	65	na	0
29	195	221	na	-12
29.5	104	104	na	0
30	195	130	na	50
30.5	156	156	na	0
31	234	156	na	50
31.5	117	117	na	0
32	123	123	na	0
32.5	117	78	na	50

33	143	143	na	0
33.5	130	130	na	0
34	598	364	na	64
34.5	201	156	na	29
35	182	182	na	0
35.5	117	130	na	-10
36	143	104	na	38
36.5	104	104	na	0
37	130	91	na	43
37.5	338	338	na	0
38	143	143	na	0
38.5	234	130	na	80
39	234	234	na	0
39.5	234	182	na	29
40	182	104	na	75
40.5	110	123	na	-11
41	130	117	na	11
41.5	104	104	na	0
42	182	182	na	0
42.5	312	312	na	0
43	162	123	na	32
43.5	156	156	na	0
44	156	156	na	0
44.5	234	130	na	80
45	260	208	na	25
45.5	104	104	na	0
46	195	117	na	67
46.5	169	169	na	0
47	234	208	na	13
47.5	351	182	na	93
48	221	247	na	-11
48.5	546	390	na	40
49	286	182	na	57
49.5	286	247	na	16
50	416	208	na	100
50.5	117	91	na	29
51	149	149	na	0
51.5	390	156	na	150
52	416	416	na	0
52.5	104	104	na	0
53	247	247	na	0
53.5	247	247	na	0
54	195	130	na	50
54.5	130	130	na	0
55	117	117	na	0
55.5	117	65	na	80
56	156	104	na	50
56.5	149	149	na	0
57	117	117	na	0
57.5	149	149	na	0
58	130	130	na	0
58.5	143	143	na	0
59	182	143	na	27
59.5	208	182	na	14
60	286	247	na	16
60.5	156	117	na	33
61	292	273	na	7
61.5	182	182	na	0
62	935	831	na	13
62.5	312	273	na	14
63	312	312	na	0

The cause of the extensive erosion and increased width shown in this research is not known. A change in peak flows and average annual flows is probably not the cause because neither of these factors changed significantly from 1936 to 1994 (Appendix F). Possible contributors to the extensive erosion and increased width problems may be riparian vegetation alteration or increased sediment load from tributaries.

Several factors, including scale, flow levels, and time of year of the aerial photographs, made analysis difficult. The scale on the 1979 photos was slightly different than on the 1991 and 1958 photos. The difference in scale between 1991 and 1979 was determined to range from +/- 3%, but between 1991 and 1958, it was less than 0.1%. The difference in flow levels, which occurred because photographs were taken over a one to five-week period, created difficulty in distinguishing banks. On steep banks, changes in flow did not affect the ability to distinguish banks; but on gently sloping banks and bars, small changes in water level made it difficult to distinguish banks. Another difference in photographs, the time of year the photo was taken, also created difficulty in distinguishing banks. The 1991 photos were taken in March and April, and the 1958 photos were taken in July and August; both are periods with "leaf-on" vegetation. The 1958 photos were very clear, and the 1991 photos were generally clear; but "leaf-on" vegetation often obscured banks in both years. The 1979 photos were often unclear, but the lack of leaf cover made banks generally distinguishable.

Impact of Riparian Vegetation on Bank Erosion

Impact on Short-term Erosion

From the short-term erosion data, the impact of riparian vegetation was evaluated. Cumulative erosion data for 29 sites after the four major flow events was compared with riparian vegetation (figure 7). The differences in bank erosion between forested, grassed, and mixed sites selected for study were tested with a t-test for differences in means of normal distributions (Haan 1977). The results of these tests appear in table 18. Mean erosion from grassed sites and mixed sites appears to exceed mean erosion from forested sites. However, the large variability of erosion within vegetation type caused none of the differences to be statistically significant ($\alpha = 0.05$).

Cumulative bank erosion from forested sites ranged from 0.21 to 13.95 ft, from mixed sites from -0.03 to 26.5 ft, and from grassed sites 0.53 to 20 ft. The large variation in erosion was expected, especially on mixed vegetation sites due to the wide range of vegetative conditions found on these sites. These data show that even on forested sites substantial erosion can occur (13.95 ft on site 096) and that on some grassed sites little erosion may occur (0.64 ft on site 088a1 and 0.53 ft on site 060c).

Impact on Long-term Erosion

Aerial photographs and riparian vegetation data were also used to determine the long-term impact of riparian vegetation (table 19) on erosion and deposition. Several

Table 18: Short-term Erosion Versus Riparian Vegetation

	vegetation type		
	forest	mix	grass
mean (ft)	2.55	5.08	6.24
standard deviation	4.26	8.55	6.07
n	11	9	9
calculated t values		df	
t (forest-mix) =	0.86	18	
t (forest-grass) =	1.60	16	
t (mix-grass) =	0.33	18	

* indicates significant difference at p = 0.05

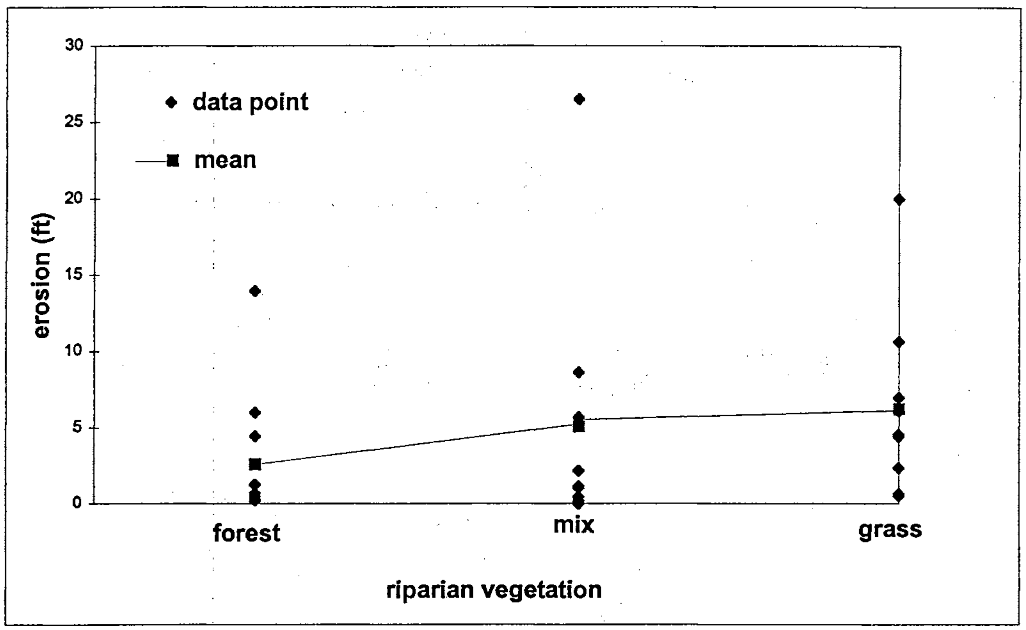

Figure 7: Short-term Erosion Versus Riparian Vegetation
(line drawn through means to show trend)

Table 19: Dominant Riparian Vegetation Within 100 ft of Streambank

	riparian vegetation		
site	1958	1979	1991
001	mix	mix	mix
002	forest	forest	forest
003	forest	forest	forest
004a	forest	mix	mix
004b	forest	forest	mix
005	mix	mix	mix
006	mix	mix	mix
007	forest	forest	forest
008	forest	forest	mix
009	forest	forest	forest
010	forest	forest	forest
011	forest	forest	forest
012	forest	forest	forest
013	forest	forest	forest
014	mix	mix	mix
015	mix	grass	grass
016a	mix	mix	mix
016b	mix	grass	grass
016c	mix	forest	forest
017	forest	mix	mix
018	forest	forest	forest
019a	forest	forest	forest
019b	forest	forest	forest
020a	forest	forest	forest
020b	forest	forest	forest
021	mix	mix	mix
022	na	mix	mix
023	na	forest	forest
024	na	forest	forest
025	na	forest	mix
026a	na	mix	grass
026b	na	grass	grass
026c	na	grass	grass
027	mix	forest	forest
028	mix	mix	mix
029	forest	forest	forest
030	forest	forest	forest
031	forest	mix	mix
032	forest	forest	forest
033	forest	forest	forest
034	forest	forest	forest
035a	mix	forest	forest
035b	mix	forest	forest
036a	forest	forest	forest
036b	forest	forest	forest
037	forest	forest	forest
038	forest	forest	forest
039	forest	forest	forest
040a	forest	forest	forest
040b	forest	forest	forest
040c	forest	forest	forest
041a	mix	mix	mix
041b	forest	forest	forest
042a	mix	mix	mix
042b	mix	mix	mix
043	forest	mix	mix
044	forest	forest	mix

045a	forest	forest	forest
045b	forest	mix	mix
046	forest	mix	mix
047	forest	forest	forest
048	forest	forest	forest
049	mix	mix	mix
050a	forest	forest	forest
050b	forest	forest	forest
051a	mix	grass	grass
051b	mix	mix	mix
052	forest	forest	forest
053	forest	forest	forest
054	mix	mix	mix
055	mix	mix	mix
056	mix	mix	mix
057	mix	forest	forest
058	mix	forest	forest
059	forest	forest	forest
060a	mix	mix	mix
060b	mix	grass	grass
060c	grass	grass	grass
061	mix	forest	forest
062a	grass	mix	mix
062b	grass	grass	grass
063	mix	forest	forest
064	na	forest	forest
065a	na	forest	forest
065b	na	forest	forest
066a	na	mix	forest
066b	na	mix	forest
067	na	mix	mix
068	na	mix	mix
069a	na	forest	forest
069b	na	forest	forest
070a	na	mix	mix
070b	na	mix	mix
071	na	mix	mix
072a	na	forest	forest
072b	na	mix	grass
073	na	forest	forest
074a	na	mix	mix
074b	na	forest	forest
075	na	mix	mix
076	na	grass	grass
077	na	mix	mix
078	na	forest	forest
079	na	mix	mix
080	na	forest	forest
081	na	mix	mix
082	na	forest	forest
083	na	mix	mix
084a	na	forest	forest
084b	na	forest	forest
085	na	forest	forest
086	na	forest	forest
087	na	mix	mix
088a	na	mix	mix
088b	na	mix	mix
088c	na	mix	mix
089a	na	forest	forest

089b	na	forest	forest
089c	na	forest	forest
090	na	forest	forest
091	na	grass	grass
092	na	forest	mix
093a	na	mix	mix
093b	na	mix	mix
094	na	mix	grass
095	na	forest	forest
096	na	forest	forest
097	na	forest	forest
098	na	mix	mix
099	na	forest	forest
100	na	forest	forest
101	na	forest	forest
102	na	mix	mix
103a	na	forest	forest
103b	na	forest	forest
103c	na	forest	forest
104	na	mix	forest
105	na	forest	forest
106a	na	forest	forest
106b	na	mix	grass
107	na	mix	mix
108	na	grass	mix
109	na	grass	grass
110	na	mix	mix
111	na	forest	forest
112	na	forest	forest
113a	na	mix	mix
113b	na	mix	mix
114	na	mix	other
115	na	mix	mix
116	na	forest	forest
117	na	grass	grass
118a	na	mix	forest
118b	na	mix	mix
119	na	mix	mix
120	na	forest	forest
121	na	forest	forest
122	na	mix	mix
123a	na	forest	forest
123b	na	forest	forest
124	na	mix	other
125	na	grass	grass
126	na	grass	grass
127	na	forest	forest
128a	na	mix	mix
128b	na	mix	grass
129	na	mix	grass
130	na	mix	mix
131	na	mix	mix
132	na	forest	forest
133	na	mix	mix
134	na	forest	forest
135	na	mix	mix
136	na	forest	mix
137	na	forest	forest
138a	na	mix	mix
138b	na	grass	grass

138c	na	grass	grass
139	na	forest	forest
140	na	forest	forest
141	na	forest	forest
142	na	forest	forest
143	na	mix	mix
144	na	forest	forest
145	na	forest	forest
146	na	forest	forest
147	na	forest	forest
148	na	forest	forest
149a	na	mix	mix
149b	na	grass	grass
149c	na	grass	grass
149d	na	grass	grass
149e	na	forest	mix
others			
1	mix	mix	mix
2	mix	forest	mix
3	mix	forest	mix
4	forest	forest	mix
5	mix	mix	forest
6	forest	forest	forest
7	forest	forest	forest
8	na	mix	grass
9	na	forest	forest
10	na	mix	mix
11	na	mix	mix
12	na	mix	mix
13	na	mix	mix
14	na	mix	mix
15	na	forest	forest
16	na	mix	mix
17	na	mix	mix
18	na	forest	mix
19	na	forest	mix
20	na	forest	forest
21	na	mix	mix
22	na	forest	forest
23	na	mix	mix
24	forest	forest	forest
25	forest	forest	forest
26	na	mix	mix
27	na	forest	forest
28	na	forest	forest

relationships were tested including: 1) maximum lateral erosion rate for forested, grassed, and mixed sites; 2) maximum lateral erosion rate for forested, grassed, and mixed sites given that the site eroded during the period 1958 to 1991; and 3) percent of forested, grassed, and mixed bank length that eroded or received deposition.

The differences in the maximum lateral erosion between forested, grassed, and mixed sites were tested with a t-test for differences in means of normal distributions (Haan 1977). The results of these tests appear in tables 20a and 20b. For the period 1979 to 1991, mean erosion from grassed and mixed sites appears to exceed mean erosion from forested sites; however, none of the differences were statistically significant ($\alpha = 0.05$). From 1958 to 1979, several significant differences in maximum lateral erosion between forested, grassed, and mixed sites were found (table 20a and 20b).

As with short-term erosion measured with bank pins, data from this analysis indicate that major erosion can occur on forested sites as well as on grassed and mixed vegetation sites. Major erosion and channel shifts were evident from aerial photographs on sites with each vegetation type.

The riparian vegetation data, along with lengths of erosional and depositional areas, were used to determine the percent of forested, grassed, and mixed riparian area length that eroded or received deposition in each time period (table 21). In both time periods, grassed areas had the greatest percent of length with erosion and deposition, and forested areas had the least. It should be noted that deposition generally occurred on the opposite side of the river or downstream of erosional areas, so landowners should not count on deposition replacing land lost to erosion.

Table 20a: Maximum Lateral Erosion for Each Vegetation Class for All Sites

time period: 1979-1991

	vegetation type		
	forest	mix	grass
mean (ft)	66	79	92
standard deviation	75	95	77
n	83	71	14

calculated t values

t (forest-mix) =	0.95
t (mix-grass) =	0.48
t (forest-grass) =	1.20

time period: 1958-1979

	vegetation type		
	forest	mix	grass
mean (ft)	74	44	188
standard deviation	65	44	193
n	34	28	2

calculated t values

t (forest-mix) =	2.10 *
t (mix-grass) =	3.54 *
t (forest-grass) =	2.21 *

* indicates significant difference at p = 0.05

Table 20b: Maximum Lateral Erosion for Each Vegetation Class for Eroding Sites

time period: 1979-1991

	vegetation type		
	forest	mix	grass
mean (ft)	90	95	107
standard deviation	75	97	73
n	61	59	12

calculated t values

t (forest-mix) =	0.32
t (mix-grass) =	0.41
t (forest-grass) =	0.73

time period: 1958-1979

	vegetation type		
	forest	mix	grass
mean (ft)	90	73	188
standard deviation	60	32	193
n	28	17	2

calculated t values

t (forest-mix) =	1.09
t (mix-grass) =	2.82 *
t (forest-grass) =	1.97 **

* indicates significant difference at p = 0.05
** indicates significant difference at p = 0.10

Table 21: Lengths of Riparian Areas in Each Vegetation Class

time period: 1979-1991

vegetation type	eroding length (miles)	depositional length (miles)	total length (miles)	% of length with erosion	% of length with deposition
forest	12.3	0.7	78.0	16	1
mix	12.2	0.8	41.0	30	2
grass	3.5	0.4	5.3	66	7
other	na	na	1.8	na	na
totals:	28.1	1.9	126.0	23	2

time period: 1958-1979

vegetation type	eroding length (miles)	depositional length (miles)	total length (miles)	% of length with erosion	% of length with deposition
forest	5.6	3.0	29.6	19	10
mix	3.0	2.3	14.0	22	17
grass	0.5	0.5	1.5	35	35
other	na	na	0.8	na	na
totals:	9	6	45.8	20	13

Over the two periods, grassed areas were 3.5 times more likely to experience detectable erosion (greater than 6.5 ft) than forested areas and almost twice as likely as mixed vegetation areas. These results are probably this research's strongest support of the ability of riparian vegetation to contribute to minimizing or preventing bank erosion.

Results from this study are in agreement with a similar study by Beeson and Doyle (1996) who found that non-vegetated banks were five times more likely to experience detectable erosion than vegetated banks and almost twice as likely to experience detectable erosion as semi-vegetated banks. Beeson and Doyle (1996) also found that major erosion (>147 ft) was 30 times more prevalent on non-vegetated banks than on vegetated banks for a 1990 flood (25 - 200 yr return period at various gage stations). In this study, however, major erosion was evident from aerial photographs on sites with each vegetation type during the period 1958 to 1991 even though only four flows greater than 50,000 cfs (8 yr return period) and one flow greater than 66,000 cfs (16 yr return period) occurred. From information in this study, it seems that all banks on the Illinois River, even well-vegetated, forested banks, are susceptible to major erosion in large flow events. Bottomland areas with recent deposition seem especially susceptible to major erosion. This is probably due to the unconsolidated alluvial material and to lack of well-established, deep-rooted vegetation.

Analysis of Rosgen's Streambank Erosion Potential

Bank erosion potential ratings and near bank stress estimates, developed by Rosgen (1996b) as a component of Level III Assessment of Stream Condition, were determined for each stream reach containing a selected bank. In order to evaluate the bank erosion potential (BEP) ratings and near bank stress (NBS) estimates, Rosgen Level IV field data verification was performed. Specifically, channel adjustment was measured in the field with bank pins. Using these Level III assessments and Level IV field data, the ability of Rosgen's bank erosion potential ratings and near bank stress estimates to predict bank erosion was explored. The difficulties involved and suggestions for improvement in their use are also discussed.

Ability of BEP Ratings and NBS Estimates to Predict Bank Erosion

The objectives of Level III assessment that are related to streambank erosion potential include: 1) to provide guidelines for documenting and evaluating additional field parameters that influence stream state and 2) to develop and/or refine channel stability prediction methods (Rosgen 1996b). Level IV monitoring activities are then required to evaluate the extent and magnitude of channel adjustment that are possibly indicated in Level III assessment. The ability of two components of Rosgen Level III assessment, BEP ratings and NBS estimates, to predict erosion was evaluated in this study.

Rosgen developed the BEP and NBS ratings based on data from two 1989 studies, a Colorado fluvial sites study and a Yellowstone National Park study (Gordon 1995, Rosgen 1996b). The bank erosion results from this study in Oklahoma are quite different from Rosgen's results, especially the range of erosion experienced and the ability of the BEP ratings and NBS estimates to predict erosion. In this study, cumulative streambank erosion ranged from -0.03 ft to 26.5 ft (table 11) after the four major flow events in 10 months. In Rosgen's studies, erosion rates ranged from 0.02 to 3.0 ft/yr in the Colorado fluvial sites study and from 0.015 to 2.5 ft/yr in the Yellowstone study (Rosgen 1996b).

Differences in erosion rates can be attributed to differences in stream types and flow magnitude. In this study of bank erosion on the Illinois River, 34 of the 36 reaches classified were C4 or C4- channels. In Rosgen's Colorado fluvial sites study, less than 0.5% of the sites were C4 channels. In the Colorado fluvial sites study, 33% of the stream length evaluated was classified as A2 and A3 (steep, cascading, step-pool streams), 40% was classified as B1, B2, B3, B4, and B6 (moderately steep, riffle-dominated streams), and 19% was classified as C3 and C6 (low gradient, meandering, riffle-pool streams) (Gordon 1995). The classification of the Yellowstone study reaches was not given.

Differences in erosion rates between those measured by Rosgen and those measured in this study can also be partially attributed to differences in flow magnitude. In this 10 month study, four flows greatly exceeding bankfull and two at or near bankfull occurred. In Rosgen's studies, bank erosion rates were recorded for 1989, a year in which discharges were well below normal (60 to 70 percent of normal in the fluvial sites study) (Rosgen 1996b).

The ability of Rosgen's BEP ratings and NBS estimates and of the Pfankuch Channel Stability Evaluation to predict short-term erosion rates in this study was evaluated and compared to results of Rosgen's studies. Cumulative erosion data measured with erosion pins after the fourth major flow event were used in this analysis. In this study the combined BEP ratings and NBS estimates did not perform as well in predicting bank erosion. Individually, the Pfankuch Channel Stability and BEP ratings performed relatively well (compared to the combined ratings - discussed on page 99) in relating ratings to bank erosion, but the NBS estimates did not perform well.

For the Pfankuch Channel Stability Evaluation, the linear regression between the Pfankuch score and cumulative erosion was significant at $\alpha = 0.05$ but had an r^2 value of 0.17 (table 22, figure 8). When the Pfankuch scores were grouped into rating categories adjusted based on stream type, the mean erosion increased as the stability rating decreased from excellent to poor (table 23, figure 9), and the difference between means of poor and good sites and between poor and excellent sites was significant ($\alpha = 0.05$).

For the BEP ratings, the linear regression between the BEP numerical index and cumulative erosion was significant at $\alpha = 0.05$ but had an r^2 value of 0.16 (table 24, figure 10). When the BEP numerical indices were grouped into rating categories, the mean and median erosion increased as the rating increased from moderate to extreme (table 25, figure 11), but no significant difference in means was detected at $\alpha = 0.05$.

For the NBS estimates, linear regression between the NBS stress estimate and cumulative erosion was not significant at $\alpha = 0.05$ (table 26, figure 12). When the NBS estimates were grouped into rating categories, the mean and the median showed no clear pattern as the estimates increased from $< 35\%$ to $> 65\%$ (table 27, figure 13), and no significant difference in means was detected at $\alpha = 0.05$.

In Rosgen's two studies, the combined BEP and NBS ratings performed well in relating the ratings to bank erosion (figure 14a). In Rosgen's studies within BEP rating

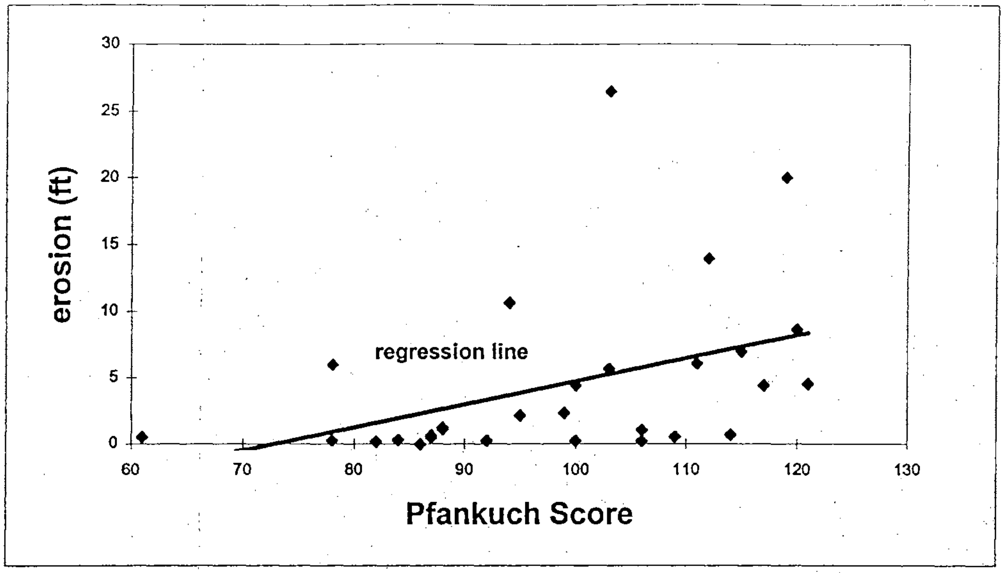

Figure 8: Bank Erosion Versus Pfankuch Channel Stability Score
(data in this figure appear in tables 6 and 11)

Table 22: Analysis of Variance for Bank Erosion Versus Pfankuch Channel Stability Score

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.41
R Square	0.17
Adjusted R Square	0.14
Standard Error	5.90
Observations	29

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	190.89	190.89	5.48	0.03
Residual	27	940.90	34.85		
Total	28	1131.78			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-12.66	7.41	-1.71	0.10	-27.86	2.53
Slope	0.17	0.07	2.34	0.03	0.02	0.33

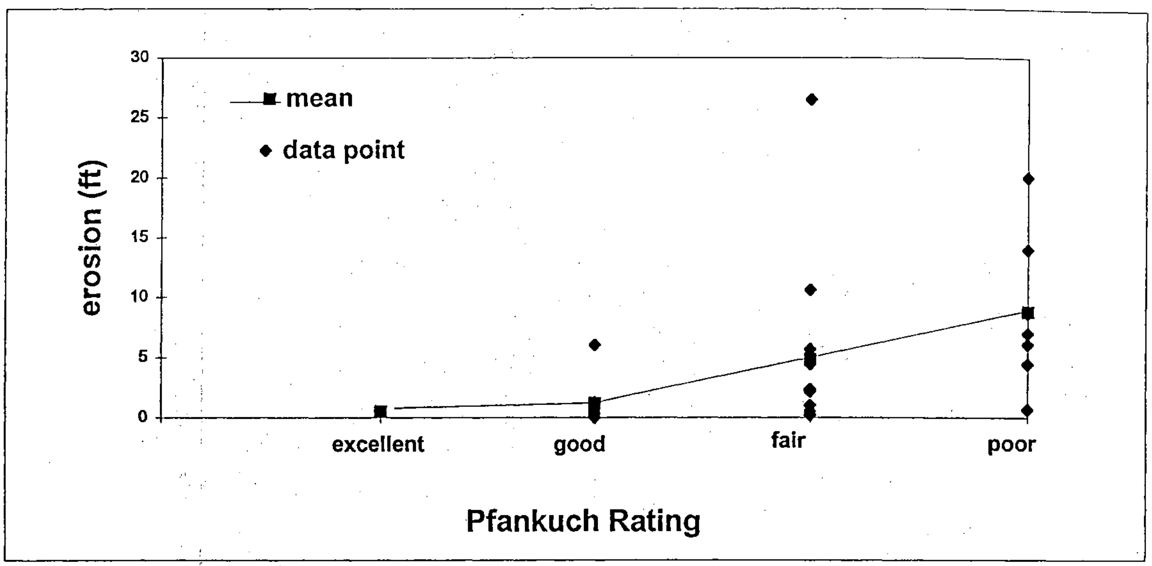

Figure 9: Bank Erosion Versus Pfankuch Channel Stability Rating
(line drawn through means to show trend)

Table 23: Bank Erosion and Pfankuch Channel Stability Ratings

rating	erosion (ft) average	median	variance
poor	8.68	6.96	43.1
fair	4.87	2.24	55.8
good	1.13	0.45	3.5
excellent	0.50	0.50	0.0

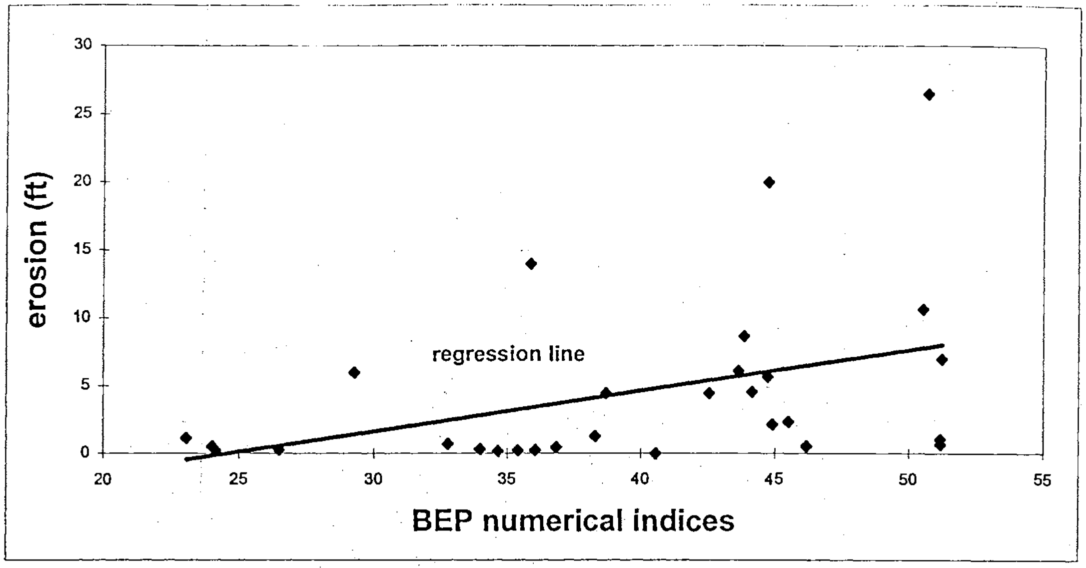

Figure 10: Bank Erosion Versus Bank Erosion Potential Numerical Indices
(data in this figure appear in tables 4 and 11)

Table 24: Analysis of Variance for Bank Erosion Versus Bank Erosion Potential Numerical Indices

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.40
R Square	0.16
Adjusted R Square	0.13
Standard Error	5.92
Observations	29

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	185.06	185.06	5.28	0.03
Residual	27	946.91	35.07		
Total	28	1131.96			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-7.36	5.27	-1.40	0.17	-18.18	3.45
Slope	0.30	0.13	2.30	0.03	0.03	0.57

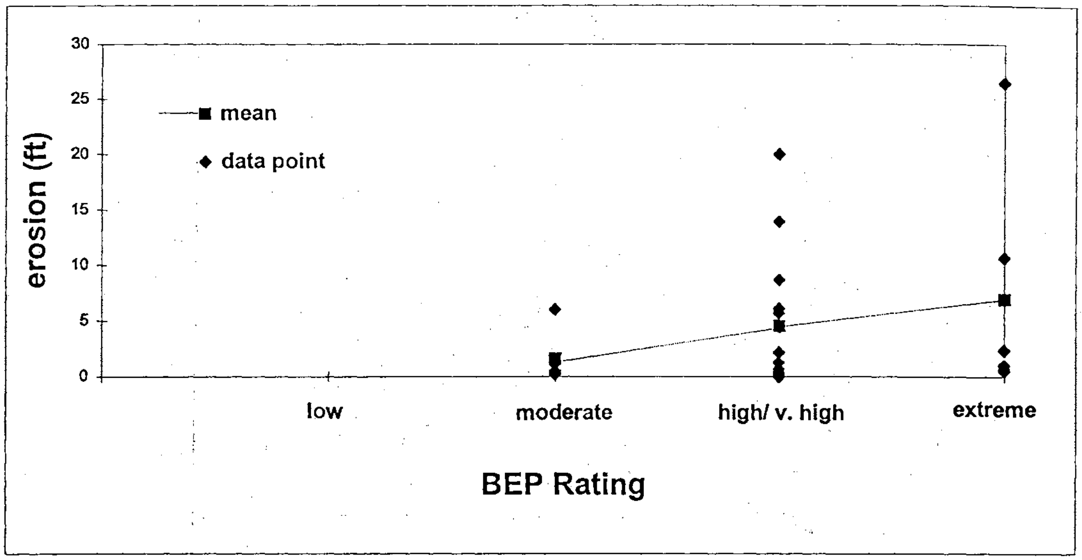

Figure 11: Bank Erosion Versus Bank Erosion Potential Ratings
(line drawn through means to show trend)

Table 25: Bank Erosion and Bank Erosion Potential Ratings

rating	erosion (ft) average	median	variance
extreme	6.95	2.34	88.8
high/v. high	4.30	2.15	30.7
moderate	1.62	0.50	6.1
low	na	na	na

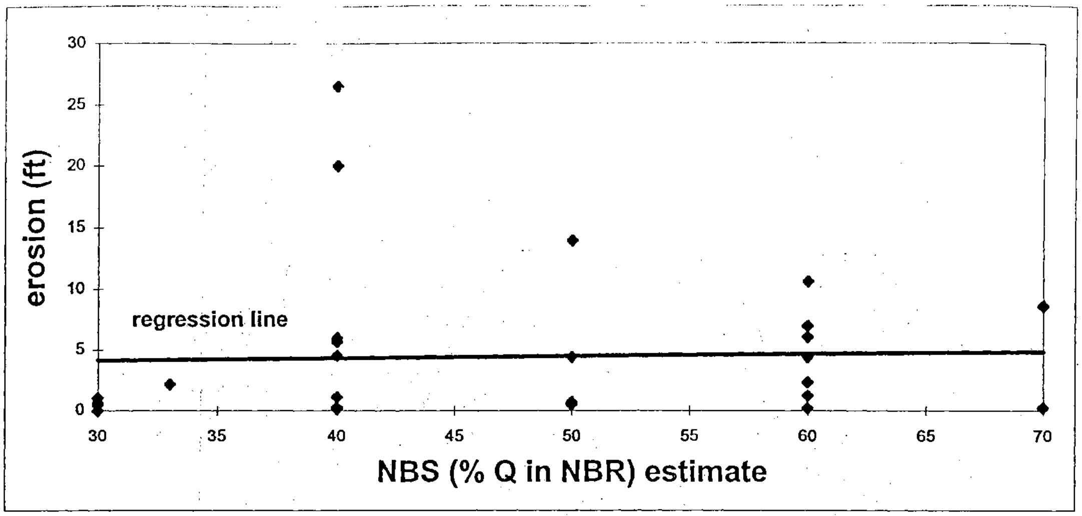

Figure 12: Bank Erosion Versus Near Bank Stress Estimates
(data in this figure appear in tables 3b and 11)

Table 26: Analysis of Variance for Bank Erosion Versus Near Bank Stress Estimates

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.03
R Square	0.00
Adjusted R Square	-0.04
Standard Error	6.47
Observations	29

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.32	1.32	0.03	0.86
Residual	27	1130.92	41.89		
Total	28	1132.24			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.64	4.89	0.74	0.46	-6.40	13.68
Slope	0.02	0.10	0.18	0.86	-0.19	0.22

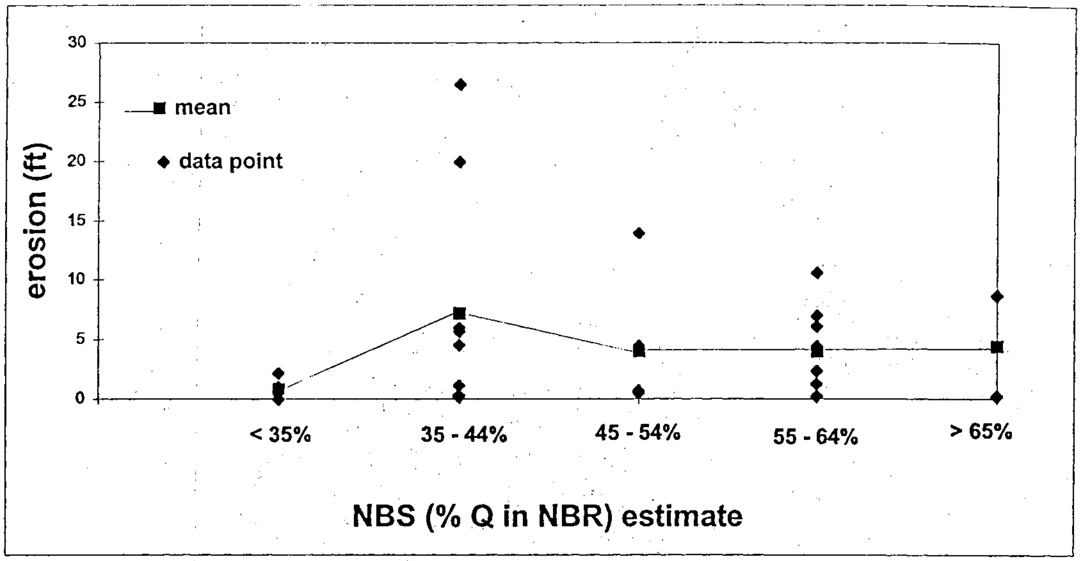

Figure 13: Bank Erosion Versus Grouped Near Bank Stress Estimates
(line drawn through means to show trend)

Table 27: Bank Erosion and Near Bank Stress Estimates

estimate	erosion (ft) average	median	variance
> 65%	4.44	4.44	35.4
55 - 64%	4.01	3.39	13.8
45 - 54%	4.02	0.68	33.6
35 - 44%	7.17	4.55	41.2
< 35%	0.85	0.64	0.7

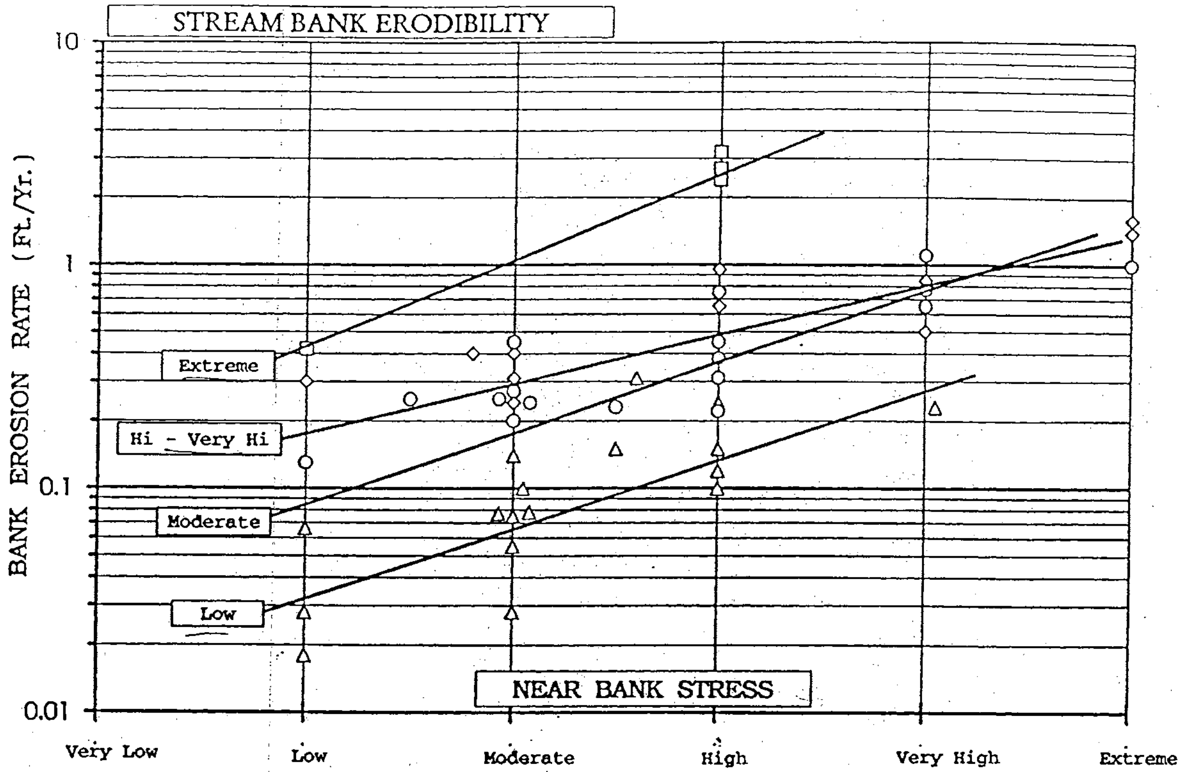

Figure 14a: Relationship Between Bank Erosion Potential and Near Bank Stress Ratings Versus Measured Erosion (from Rosgen 1996b)

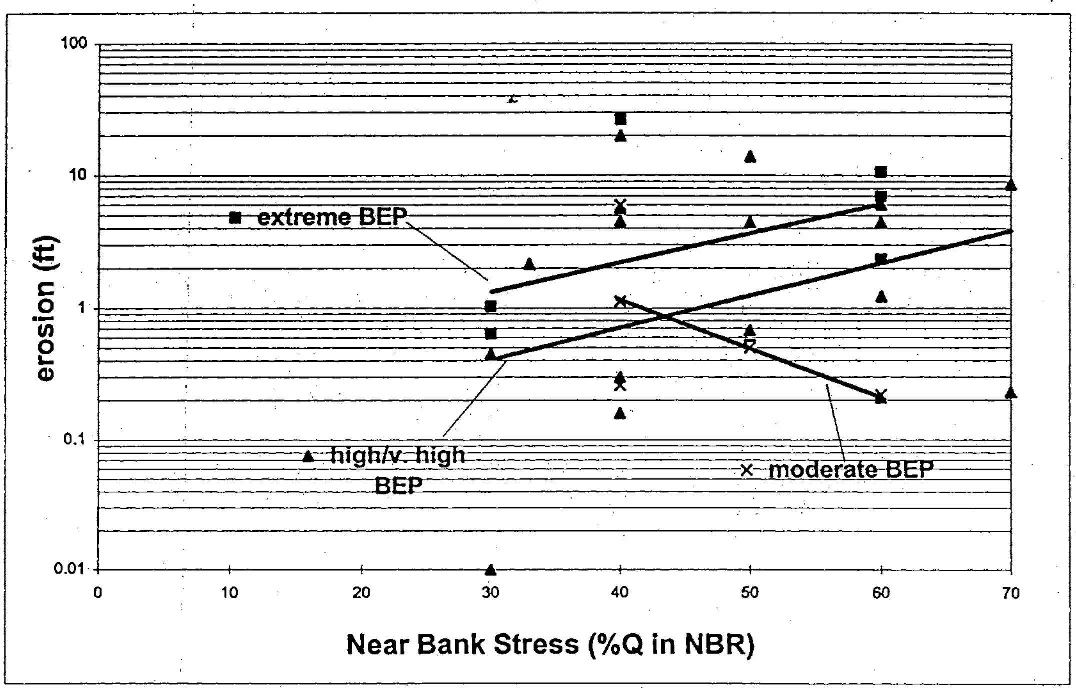

Figure 14b: Relationship Between Bank Erosion Potential and Near Bank Stress Estimates Versus Measured Erosion

categories, the relationship between NBS and erosion rate shows little variance. In the Colorado fluvial sites study, in an analysis of variance with the BEP and NBS ratings as independent variables and the log of erosion as the dependent variable, the r^2 value was 0.93 (Rosgen 1996b). In the Yellowstone National Park study, the coefficient of determination was 0.87 (Rosgen 1996b). Also in Rosgen's studies, the bank erosion rate increased, over the range of NBS ratings, as BEP increased; and the bank erosion rate increased as NBS increased within a BEP category.

In the presentation of data from these studies in Rosgen (1996b), high and very high BEP sites are grouped into one high/very high group. Data from this study are grouped into the same categories and graphed in the same manner to aid in comparison (figure 14b).

In this study the combined BEP ratings and NBS estimates did not perform well in predicting bank erosion as in Rosgen's studies (1996b). The variation in erosion data was greater, the bank erosion rate did not consistently increase as BEP increased, and the bank erosion did not increase as NBS increased within BEP categories. Within the extreme BEP category, when comparing NBS to the log of erosion, r^2 was 0.15; within the very high/high BEP category, r^2 was 0.09; and within the moderate BEP category, r^2 was 0.32. These values exemplify the high variability of data in this study compared to the Rosgen studies. In this study, the general relationships between bank erosion rate, NBS, and BEP were not found to be consistent as was the case in the Rosgen studies. The inconsistencies in the relationships can be seen in figure 14b. The regression lines are plotted to help visualize the relationship between erosion and NBS, within BEP categories, but the regression relationships are not significant at $\alpha = 0.05$.

Only the relationship between BEP ratings, Pfankuch ratings, and NBS estimates and short-term erosion (not the long-term aerial photograph data) were evaluated in this study because major channel changes occurred in such a short period (10 months). Using the ratings/estimates for longer periods of time on the Upper Illinois River would not be practical. It would be impractical because the large magnitude of channel and bank changes that can occur as a result of major flow events significantly alters the BEP and Pfankuch ratings and the NBS estimates from year to year. In areas where erosion rates are low (inches per year), the rating systems may be used for long-term prediction of erosion.

Critical Analysis

In general, Rosgen's BEP ratings and NBS estimates were easy to understand and use in the field; however, several difficulties were also encountered. These difficulties include: 1) determination of bank height and root density, 2) conversion of parameter values to numerical indices, 3) adjustments based on gravel content and on stratification, and 4) use of the various NBS indices. Comments on these methods are based on explanations in Rosgen (1996a, 1996b). Limitations that are discussed may be a result of misunderstanding of the material presented rather than errors in the material. However, in either case, additional information and/or corrections are needed to aid in the effective use of Rosgen's procedures in the field.

Four of the six parameters needed to determine BEP (bankfull height, root depth, bank angle, and surface protection) are well-presented and, for a person with a basic knowledge of fluvial processes, are relatively easy to estimate in the field. Bank height and root density, however, are difficult. Bank height, needed in calculation of the bank height/bankfull height and the root depth/bank height ratios, seems to be a simple parameter; however, a definition of bank height to insure consistent field determination is needed. Is bank height the height measured from the water surface at low flow to the top of the bank? Is it the height from the water surface to the bank top plus the water depth? For this study, the bank height was determined by the height measured from the water surface at low flow to the top of the bank plus the water depth at the channel thalweg (Hickin and Nanson 1984), i.e. the vertical distance from the bottom of the channel thalweg to the top of the bank (shown in figure 2).

The determination of root density was also difficult. The determination of root density was challenging as roots were difficult to see, because density varied dramatically along the bank, and because little guidance was provided. In this study, root density was estimated as the percent of the bank, within the rooting depth, covered by exposed roots in an effort to represent the density of the root mat within the bank. Root density was the parameter estimated with the least confidence.

Once the parameter values discussed above are determined, the next step in determination of BEP rating is the conversion of parameter values to numerical indices. In Rosgen (1996b) the endpoints of the parameter value and numerical index ranges are presented; however, it is not clear which parameter value endpoint corresponds to each index endpoint. For example, for root density in the very low BEP rating category, the parameter value range presented is 80 - 100% and the index range is 1.0 - 1.9, but 100% corresponds to 1.0 (table 2b). The corresponding values need to be clearly stated to avoid confusion. The relationships used to interpolate between the index endpoints are also not clearly stated. In Rosgen (1996a) the relationships are presented graphically; however, the equation for each of these relationships would be helpful. In this study with 193 sites on which to determine BEP ratings, linear interpolation between endpoints was used to relate parameter values to corresponding numerical indices. Another confusing aspect of the BEP ratings is the range of indices presented. The indices presented graphically in Rosgen (1996a) range from 0 to 10, but in tabular form (table 2b) from Rosgen (1996b) range from 1 to 10.

Once the BEP indices are totaled, adjustments are made based on channel material and stratification. The adjustments are generally easily understood, but the bank material adjustment for gravel banks and the stratification adjustment are not clear. The bank material adjustment for gravel banks is to adjust values up by 5 to 10 points depending on the composition of sand, but no guidance is provided to explain this further. The adjustment based on stratification is to adjust values up by 5 to 10 points depending on the position of unstable layers in relation to bankfull stage. A figure showing various stratification and bankfull stage levels does accompany the BEP rating table, but nowhere is the adjustment quantified. Gordon (1995) provides additional guidance from material presented by Rosgen stating that a bank with many clay lenses or many layers of different materials would have a high potential for erosion. In this study, gravel banks were given a 5 point adjustment upward, banks with a mixture of silt and gravel were adjusted 10 points upward, and stratified banks were adjusted 10 points upward.

To determine the NBS in Rosgen Level III assessment, three options are presented (Rosgen 1996b). It is assumed that these methods are presented in the order of decreasing accuracy but increasing ease. The first option requires determination of a cross-sectional velocity profile to determine velocity gradients. Rosgen defines the velocity gradient as the difference between the velocity at the core of the velocity isovel and the velocity in the near bank region divided by the horizontal distance between the core of the velocity isovel and the near bank region. It is assumed that the velocity gradient profile is to be determined under bankfull discharge conditions to remain consistent with his previous emphasis on the importance of bankfull discharge; however, this is not clearly stated.

The second option requires determination of the cross-sectional area of the near bank region and total cross-sectional area (again assumed at bankfull discharge). The NBS estimate is determined by:

[1] $$NBS\ estimate = \frac{A_{nbr}}{A}$$

where: A_{nbr} = cross-sectional area of the near bank region and A = total cross-sectional area, both at bankfull discharge. This determination relies on the assumption that flow is proportional to cross-sectional area, which is not true in natural channels, but Rosgen uses this procedure to estimate the percent flow in the near bank region. This procedure was chosen for use in this research because it is relatively straight-forward and could be applied quickly in the field. Also in this research, an additional 10% was added to the

NBS estimates in extreme hydrologic conditions, such as sharp bends and islands, in an effort to better represent the NBS conditions.

The third method of NBS determination is presented as a ratio of the near bank stress to the mean shear stress:

[2] $$NBS\ estimate = \frac{\tau_{nbr}}{\tau_{ave}} = \frac{d_{nbr} S \rho}{d_{ave} S \rho}$$

where: τ_{nbr} = shear stress in the near bank region, τ_{ave} = average shear stress, d_{nbr} = water depth in the near bank region, d_{ave} = average water depth (both at bankfull discharge), S = slope, and ρ = water density. Equation [2] above is a form of the classical equation for average shear stress in a channel with uniform flow:

[3] $$\tau = \gamma R S$$

where: τ = shear stress, γ = specific weight of water, R = channel hydraulic radius, and S = water surface slope (equals the channel slope under uniform flow) (Gordon et al. 1992). If the channel is wide, the hydraulic radius can be replaced with average water depth. When applied, the slope (assumed to be the water surface slope because water surface slope is determined in Rosgen Level II classification) and the water density are cancelled, thus only water depth measurements are needed. Therefore, the NBS estimate based on this method reduces to:

[4] $$NBS\ estimate = \frac{d_{nbr}}{d_{ave}}$$

The method of converting the numerical indices to NBS ratings from each of the three NBS estimation procedures is presented in table 28 (Rosgen 1996b). The values of the numerical indices on the first method, using the velocity gradient, and on the third method, using shear stress estimates, seem incorrect. If the first method is applied to the velocity profiles presented in Rosgen (1996b) as examples, velocity gradients of 0.4 fps/ft and 0.5 fps/ft result. The magnitude of these gradients is reasonable, but they do not fit into the categories in table 28. As listed in table 28, the velocity gradient magnitudes seem extreme.

Table 28: Conversion of Near Bank Stress Numerical Indices to Adjective Ratings (from Rosgen 1996b)

NBS rating	I. velocity gradient (fps/ft)	II. A_{nbr} / A	III. τ_{nbr}/τ_{ave}
low	1.0 - 1.2	0.32 or less	0.32 or less
moderate	1.21 - 1.6	0.33 - 0.41	0.3 - 0.5
high	1.61 - 2.0	0.42 - 0.45	0.6 - 1.0
very high	2.1 - 2.3	0.46 - 0.50	1.1 - 1.3
extreme	2.4 or more	0.51 or more	1.4 or more

The numerical indices for the third method, using shear stress estimates, also seem incorrect. To compare the second and third methods, the following steps were used:

[5] $$\frac{A_{nbr}}{A} = \frac{d_{nbr} * w_{nbr}}{d_{ave} * w}$$

where: w_{nbr} = width of the near bank region and w = total bankfull width.

The near bank region is defined as the 1/3 of the total bankfull width nearest the bank of interest; therefore:

[6] $$\frac{A_{nbr}}{A} = \frac{d_{nbr} * w/3}{d_{ave} * w}$$

and

[7] $$3 * \frac{A_{nbr}}{A} = \frac{d_{nbr}}{d_{ave}}$$

As is illustrated, the numerical indices in method three should be three times that of method two.

As well as correcting the difficulties discussed above, several factors not expressed in the bank erosion potential ratings could be incorporated to improve its ability to predict bank erosion. These factors include compaction of bank materials, flow magnitudes, and riparian vegetation. Compaction of bank particles and adjustments based on flow magnitudes are influences on bank erosion that were recognized in the field when sites behaved much differently than expected based upon bank erosion potential (BEP) ratings and near bank stress (NBS) estimates. The influence of riparian vegetation also seemed evident from analysis of erosion with aerial photographs and in the field.

The impact of highly compacted bank material is not accounted for by the BEP rating. Sites 088a1 and 088a2 experienced much less erosion than expected from their extreme BEP ratings and from the presence of a rock ledge that increased pressure on the banks. Sites 088a1 and 088a2, however, were hard, highly-compacted sites. The extreme hardness was noticed when driving bank pins into the bank. It may explain the low erosion rate because of the difficulty of flowing water to remove bank particles. Thorne (1982) attributes this resistance to fluvial entrainment to the ability of hard banks to remain dry, thereby reducing the weakening caused by wet conditions. An adjustment in BEP based on compaction of bank materials should improve the relationship between BEP and erosion. Banks that were formed in recently deposited, unconsolidated alluvial material also seemed to have higher susceptibility to erosion than banks formed in more well-developed soil profiles. This makes sense intuitively but was not statistically quantified in this study.

Another factor not accounted for is the difference of flow magnitudes between sites of similar BEP ratings. It can be intuitively expected that a given site experiencing a large flow will erode more than a similar site experiencing lower flows. Site 143 is located approximately 0.2 miles below Baron Fork, a major tributary. In major flow events, Baron Fork routinely contributes a 50 - 65% flow increase to the Illinois River. The increased stress at site 143, whether caused by increased flow magnitude or by location below a major tributary, should be accounted for in the NBS estimates. A description of the process to scale erosion rates based on differences in flow magnitude should improve the relationship between BEP, NBS, and erosion.

The influence of riparian vegetation on reducing bank erosion has been shown in many studies, including this one. Riparian vegetation, including vegetation on the bank and on the adjacent land area, is especially important in long-term erosion reduction. Rosgen, however, does not account for riparian vegetation in his BEP ratings; only vegetation protection on the bank is included. In the long-term, as vegetation on the bank is lost to erosion, adjacent riparian vegetation can provide effective stabilization. If native riparian vegetation is removed adjacent to the bank, when the vegetation on the bank is lost to erosion, no vegetation remains to provide stabilization.

Contribution of Bank Erosion to Sedimentation of Lake Tenkiller

This study has shown that sediment from eroding streambanks is a significant source of sediment to the Illinois River. This study also attempted to estimate the contribution of bank erosion to the sedimentation of Lake Tenkiller; however, this goal was not adequately accomplished. The volume and mass of eroded material was estimated, but the volume and mass of deposited material and transport of eroded material was not successfully estimated.

The volume and mass of eroded material was determined for the periods 1958 to 1979 and 1979 to 1991 (table 29). For the period 1979 to 1991, an estimated 62 million cubic ft (3.5 million tons) of bank material was eroded. For the period 1958 to 1979, an estimated 21 million cubic ft (1.2 million tons) of bank material was eroded on the portion of the river examined.

Similar calculations, however, were not made for deposition. The amount of sediment deposited in new and established depositional areas could not be determined because heights of these areas could not be determined. The amount of sediment deposited in in-channel bars was also not quantified because small changes in water level between aerial photographs significantly changed surface areas of the gently sloping deposits eliminating calculation of deposited material. The transport of eroded material

Table 29: Volume and Mass of Material Eroded from Streambanks

site	soil bulk density (g/cm^3)	1979-1991 erosion area (ac)	1979-1991 erosion volume (ft^3)	1979-1991 erosion mass (ton)	1958-1979 erosion area (ac)	1958-1979 erosion volume (ft^3)	1958-1979 erosion mass (ton)
001	1.5	0.38	165528	7750	0.00	0	0
002	1.9	0.10	56628	3358	0.50	283140	16792
003	1.9	0.00	0	0	0.00	0	0
004a,b	1.9	1.84	961805	57041	0.36	188179	11160
005	1.9	0.00	0	0	0.00	0	0
006, 007	1.9	0.70	365904	21701	0.00	0	0
008	1.9	0.00	0	0	0.00	0	0
009	1.9	1.14	248292	14725	1.94	422532	25059
010	1.6	0.00	0	0	0.00	0	0
011	1.9	0.64	223027	13227	0.00	0	0
012	1.9	0.18	47045	2790	1.26	329314	19530
013	1.9	0.28	48787	2893	1.50	261360	15500
014	1.9	1.64	714384	42368	0.00	0	0
015	1.9	0.92	561053	33274	0.28	170755	10127
016a,b,c	1.9	1.60	906048	53735	0.80	453024	26867
017	1.9	0.04	17424	1033	0.40	174240	10334
018	1.9	0.00	0	0	5.78	3021322	179184
019a,b	1.9	0.96	167270	9920	1.24	216058	12814
020a,b	1.9	0.98	128066	7595	1.14	148975	8835
021	1.9	0.44	134165	7957	2.56	780595	46294
022	1.9	0.58	101059	5993	na	na	na
023	1.9	1.00	174240	10334	na	na	na
024	1.9	0.00	0	0	na	na	na
025	1.9	0.00	0	0	na	na	na
026a,b,c	1.6	2.80	1463616	73096	3.22	1683158	84061
027	1.9	0.30	65340	3875	1.78	387684	22992
028	1.6	0.00	0	0	0.00	0	0
029	1.9	0.48	62726	3720	1.66	216929	12865
030	1.9	0.32	55757	3307	0.00	0	0
031	1.9	0.66	287496	17050	1.44	627264	37201
032	1.9	1.50	261360	15500	0.14	24394	1447
033	1.9	1.10	335412	19892	1.18	359806	21339
034	1.9	2.10	365904	21701	0.28	48787	2893
035a,b	1.9	3.02	1315512	78019	1.62	705672	41851
036a,b	1.9	5.86	1531570	90832	3.36	878170	52081
037	1.9	0.00	0	0	0.70	274428	16275
038	1.9	0.54	70567	4185	0.64	83635	4960
039	1.7	0.46	120226	6380	0.00	0	0
040a,b,c	1.9	0.34	118483	7027	1.16	404237	23974
041a,b	1.7	0.20	43560	2311	na	na	na
042a,b	1.7	0.42	182952	9708	na	na	na
043	1.7	0.44	134165	7119	0.00	0	0
044	1.9	1.68	292723	17360	0.58	101059	5993
045a,b	1.7	0.92	320602	17012	1.52	529690	28107
046	1.9	0.96	167270	9920	0.00	0	0
047	1.9	2.00	348480	20667	1.92	334541	19840
048	1.9	1.34	175111	10385	0.54	70567	4185
049	1.5	2.20	670824	31409	0.32	97574	4569
050a,b	1.9	0.00	0	0	0.52	90605	5373
051a,b	1.9	1.90	579348	34359	8.04	2451557	145393
052	1.9	0.76	165528	9817	0.48	104544	6200
053	1.9	0.58	202118	11987	4.16	1449677	85975
054	1.9	1.50	653400	38751	0.58	252648	14984
055	1.9	0.34	44431	2635	0.00	0	0
056	1.9	2.38	518364	30742	0.46	100188	5942
057	1.9	0.82	285754	16947	1.02	355450	21081
058	1.9	0.20	69696	4133	0.72	250906	14880
059	1.9	0.00	0	0	0.74	193406	11470
060a,b,c	1.9	0.64	334541	19840	1.12	585446	34721
061	1.9	1.24	324086	19220	0.00	0	0
062a,b	1.9	0.66	201247	11935	0.36	109771	6510
063	1.9	0.54	188179	11160	0.00	0	0
064	1.9	0.00	0	0	na	na	na
065a,b	1.9	0.22	86249	5115	na	na	na
066a,b	1.7	0.30	91476	4854	na	na	na

067, 068	1.7	0.80	209088	11095	na	na	na
069a,b	1.7	0.40	121968	6472	na	na	na
070a,b	1.9	0.00	0	0	na	na	na
071	1.9	1.38	240451	14260	na	na	na
072a	1.9	0.26	101930	6045	na	na	na
072b	1.5	1.42	618552	28961	na	na	na
073	1.9	2.94	768398	45571	na	na	na
074a,b	1.9	3.12	2854051	169264	na	na	na
075	1.9	10.70	4194828	248781	na	na	na
076	1.9	4.20	1280664	75952	na	na	na
077	1.9	0.00	0	0	na	na	na
078	1.7	0.00	0	0	na	na	na
079	1.9	1.60	627264	37201	na	na	na
080	1.9	3.68	1282406	76055	na	na	na
081	1.9	0.00	0	0	na	na	na
082	1.9	0.00	0	0	na	na	na
083	1.7	0.00	0	0	na	na	na
084a,b	1.7	2.50	544500	28893	na	na	na
085	1.9	1.26	768398	45571	na	na	na
086	1.9	4.78	1249301	74092	na	na	na
087	1.9	1.46	317988	18859	na	na	na
088a,b,c	1.5	1.28	724838	33938	na	na	na
089a,b,c	1.9	4.46	1359943	80654	na	na	na
090	1.9	1.36	533174	31621	na	na	na
091	1.9	0.00	0	0	na	na	na
092	1.7	0.94	245678	13037	na	na	na
093a,b	1.9	4.42	385070	22837	na	na	na
094	1.9	0.82	107158	6355	na	na	na
095	1.5	0.00	0	0	na	na	na
096	1.5	3.98	1386950	64938	na	na	na
097	1.7	0.00	0	0	na	na	na
098	1.7	1.40	670824	35596	na	na	na
099	1.9	0.34	59242	3513	na	na	na
100	1.9	0.00	0	0	na	na	na
101	1.9	4.54	593287	35186	na	na	na
102	1.5	0.32	97574	4569	na	na	na
103a,b,c	1.9	0.80	313632	18600	na	na	na
104	1.9	2.82	737035	43711	na	na	na
105	1.9	1.36	414691	24594	na	na	na
106a,b	1.7	0.44	134165	7119	na	na	na
107	1.7	0.18	39204	2080	na	na	na
109, 110, 111	1.9	3.40	1332936	79052	na	na	na
112	1.9	1.20	365904	21701	na	na	na
113a,b	1.9	7.22	2201522	130565	na	na	na
114	1.9	0.58	454766	26971	na	na	na
115	1.9	5.16	1573387	93312	na	na	na
116	1.9	0.00	0	0	na	na	na
120	1.7	0.00	0	0	na	na	na
121	1.9	2.02	703930	41748	na	na	na
122	1.9	0.72	219542	13020	na	na	na
123a,b	1.9	2.74	358063	21236	na	na	na
124	1.9	0.00	0	0	na	na	na
125	1.5	1.32	1034986	48459	na	na	na
126	1.5	0.00	0	0	na	na	na
127	1.9	1.06	230868	13692	na	na	na
128a,b, 129	1.5	2.12	554083	25943	na	na	na
130	1.9	0.00	0	0	na	na	na
131	1.9	1.46	317988	18859	na	na	na
132	1.7	0.00	0	0	na	na	na
133	1.9	1.02	266587	15810	na	na	na
134	1.9	1.46	317988	18859	na	na	na
135	1.5	0.28	36590	1713	na	na	na
136	1.5	0.76	165528	7750	na	na	na
137	1.5	2.56	446054	20885	na	na	na
138a,b,c	1.5	3.48	1061122	49683	na	na	na
139	1.5	0.00	0	0	na	na	na
140	1.9	0.74	193406	11470	na	na	na
141	1.5	0.00	0	0	na	na	na
142	1.9	0.54	94090	5580	na	na	na

144	1.5	1.26	384199	17989	na	na	na
145	1.9	0.00	0	0	na	na	na
146	1.5	0.00	0	0	na	na	na
147	1.9	0.84	256133	15190	na	na	na
148	1.5	0.00	0	0	na	na	na
149a,b,c,d,e	1.5	2.30	601128	28145	na	na	na
others							
1	1.9	1.60	508781	30174	0.00	0	0
2	1.9	1.08	343427	20367	1.36	432464	25648
3	1.9	0.00	0	0	0.58	184433	10938
4	1.9	1.80	572378	33946	0.18	57238	3395
5	1.9	0.86	273470	16219	0.62	197153	11692
6	1.9	0.14	44518	2640	0.26	82677	4903
7	1.9	1.04	330708	19613	0.0	0	0
8	1.9	1.78	566019	33569	na	na	na
9	1.9	1.12	356147	21122	na	na	na
10	1.9	0.66	209872	12447	na	na	na
11	1.9	0.80	254390	15087	na	na	na
12	1.9	0.38	120835	7166	na	na	na
13	1.9	1.42	451543	26779	na	na	na
14	1.9	0.54	171714	10184	na	na	na
15	1.5	0.76	241671	11315	na	na	na
16	1.9	1.80	572378	33946	na	na	na
17	1.9	0.00	0	0	na	na	na
18	1.9	0.98	311628	18482	na	na	na
19	1.9	0.92	292549	17350	na	na	na
20	1.9	0.58	184433	10938	na	na	na
21	1.9	0.50	158994	9429	na	na	na
22	1.9	2.44	775891	46015	na	na	na
23	1.9	0.68	216232	12824	na	na	na
24	1.9	0.00	0	0	2.34	744092	44130
25	1.9	0.00	0	0	0.90	286189	16973
26	1.9	0.82	260750	15464	na	na	na
27	1.9	1.06	337067	19990	na	na	na
28	1.9	2.32	737732	43752	na	na	na

was also not estimated because no bedload data were available for the river. Therefore, an estimation of the contribution of bank erosion to sedimentation of Lake Tenkiller was not adequately determined.

An interesting result did occur when examining depositional areas in the aerial photograph analysis. More new depositional areas (table 15) with a larger total land surface area formed between 1958 and 1979 than from 1979 to 1991, even though only a portion of the river was examined for the period 1958 to 1979. This seems to indicate that between 1979 and 1991 more eroded material was deposited in depositional areas established between 1958 and 1979, in in-channel bars, and/or was transported downstream.

In many areas cropland and construction site erosion inputs large amounts of sediment to streams. The inputs may then be transported downstream and contribute to reservoir sedimentation. However, in the Illinois River Basin, inputs of sediment from soil erosion are relatively small because much of the land in the Oklahoma portion of the basin is grassland or forest (92%); both of which tend to have low soil erosion rates under proper management. Based on this information and the estimated input of material from bank erosion (3.5 million tons eroded between 1979 and 1991), bank erosion is a significant, if not the major, source of sediment input to the Illinois River. On a per acre basis for erosional areas between the Watts and Tahlequah gage stations, 3.5 million tons equals 0.94 tons/acre per year. This is not a large annual erosion rate, such as would be expected from unmanaged cropland or construction sites, but it does represent a significant sediment source. This is especially true since much of the eroded material from upland sources would be trapped in the watershed before entering the river.

CHAPTER FIVE

CONCLUSIONS

With accelerated streambank erosion contributing increased sediment loads to streams in many areas and thus increasing many detrimental impacts, data on streambank erosion for the Illinois River needed to be gathered and presented. Quantification of erosion rates was a vital initial step in assessing streambank erosion's negative agricultural, environmental, recreational, and economic impacts within the basin.

The specific objectives of this research on the Upper Illinois River: 1) to use bank pins and cross-sectional surveys to measure short-term bank erosion for selected bank sites with a range of conditions, 2) to measure long-term erosion from 1958 to 1991 with aerial photographs, 3) to evaluate the impact of riparian vegetation on short- and long-term erosion, 4) to compare the short-term results of this study to Rosgen's work, and 5) to estimate the contribution of bank erosion along the Illinois River to the sedimentation of Lake Tenkiller, were generally accomplished.

1) Cumulative short-term erosion, measured with bank pins on selected banks, averaged 4.5 ft and ranged from -0.03 to 26.5 ft after the four major flow events over the 10 month period of this study (table 11). Two at or near bankfull events in the spring and summer of 1997 eroded an average of 0.40 additional ft. This 10 month period experienced four flows with 2.0 to 2.5 yr return periods and two additional bankfull or near bankfull flows; however, no large magnitude flows (larger than 5 year return period)

occurred. The average annual flow for the study period exceeded the average annual flow by 20%.

2) In the analyses of erosion made from aerial photographs, 168 areas had significant erosion and/or deposition from 1958 to 1979 and/or from 1979 to 1991. For these areas in the period 1979 to 1991, maximum lateral erosion averaged 79 ft and ranged from 0 to 702 ft, and lateral erosion averaged 3.6 ft/yr. In the period 1958 to 1979, maximum lateral erosion averaged 67 ft and ranged from 0 to 325 ft, and lateral erosion averaged 1.7 ft/yr. During the periods 1979 to 1991 and 1958 to 1979, the Illinois River eroded a total of 195 ac and 64 ac of land surface area, respectively. Because of missing aerial photographs from 1958, data reported for 1958 or for the period 1958 to 1979 are not complete sets for the entire river study area.

3) In this study, long-term aerial photograph analyses showed that natural riparian forest vegetation is important in reducing and preventing bank erosion on the Illinois River. During the period 1958 to 1991, grassed banks were 3.5 times more likely to experience detectable erosion (greater than 6.5 ft) than forested banks and almost twice as likely as mixed vegetation banks.

Analysis of short-term erosion from August/September 1996 to July 1997, however, resulted in no significant difference ($\alpha = 0.05$) between vegetation types. In this study once a site was eroding, short-term erosion rate was not influenced by vegetation type.

Major short- and long-term erosion did occur on banks with each vegetation type, so natural riparian forest vegetation does not always prevent major erosion but can lessen the likelihood of its occurrence.

4) In general, the Rosgen Level III bank erosion potential evaluation was easy to understand and apply in the field. However, as it currently stands, the Rosgen evaluation performed relatively poorly in predicting bank erosion (possibly due to the current state of rapid change on the Illinois River). With the improvements listed above, the bank erosion potential evaluation might better accomplish its goals to provide a mechanism to extrapolate site-specific data to reaches of similar character and to provide a consistent and reproducible frame of reference of communication. The analyses performed should also contribute to refining channel stability prediction methods, another goal of Rosgen's classification system. When used independently, the bank erosion potential ratings and the Pfankuch Channel Stability ratings did perform relatively well in relating ratings to short-term bank erosion on the Illinois River, but the near bank stress estimates did not. Evaluating the ability of the ratings/estimates to predict long-term erosion was not appropriate for the Illinois River because of the large magnitude of change that occurred.

5) Estimation of the contribution of bank erosion to sedimentation of Lake Tenkiller was not adequately accomplished. The volume (62 million cubic ft) and mass (3.5 million tons) of eroded material was successfully estimated for the period 1979 to 1991. However, because of difficulty in quantifying depositional areas and because of

lack of data on bedload transport, the volume and mass of deposited material and the transport of eroded material was not successfully estimated.

Additional Comments and Related Conclusions

Two important considerations related to this research need additional attention. These considerations are: 1) the importance of riparian vegetation in maintaining natural stable channels and 2) the impact of channel behavior in the Illinois River Basin.

Early studies listed in Thorne (1982) report that erosion rates are reduced by several orders of magnitude on vegetated banks (Weaver 1937, Edminister et al. 1949). Even though the ability of riparian vegetation to reduce bank erosion has been known for some time, landowners in many watersheds continue to remove riparian vegetation to increase farmable acres, to build campsites or other recreational areas, and to build homes and businesses. As a result, many streams suffer accelerated erosion rates. Site specific studies, such as this one that show reduced erosion in areas with native riparian vegetation, may convince landowners to protect native riparian vegetation in an effort to control bank erosion.

Based on results of this research, the Upper Illinois seems to be changing from a meandering river to a wide, shallow, maybe braided river. Data show that extensive bank erosion is occurring, that the river has widened from an average of 175 ft in 1979 to 206 ft in 1991, that the width to depth ratio in many reaches is approaching or exceeding 40 (the Rosgen criteria for a braided channel), that the sinuosity in many reaches is approaching or less than 1.2 (the Rosgen criteria for a braided channel), and that many channel reaches may be aggrading. This behavior, similar to that described in Beeson and Doyle (1996), Rosgen (1996b), and Church (1992), can follow a cycle of high sediment input (from bank erosion or upland sources), increased in-channel deposition, and increased bank erosion.

If the Illinois River is indeed in this cycle, the increased width to depth ratio will result in shallower flows and may significantly impact the recreational value of the river. Further research on the behavior of the river is needed to adequately address this concern.

Recommendations for Further Research

Several areas of possible future research on the Upper Illinois River have become evident during the completion of this project. These areas include:

1) long-term cross section surveys - additional cross section profiles with established elevation references resurveyed over several years would provide valuable information on the river behavior, such as channel widening (bank erosion and deposition) and aggradation/degradation. Established cross-sections could also be used;

2) additional aerial photograph analyses - if a complete set of 1958 aerial photographs could be found, two complete periods would add allow valuable comparisons. In addition, recent aerial photos (ie. 1996) would allow comparison between three periods: 1958 to 1979, 1979 to 1991, and 1991 to 1996;

3) determination of the location of major erosional areas - aerial photograph analysis showed many areas with greater than 200 ft of lateral erosion in the 33 year

period from 1958 to 1991, but reasons for major erosion occurring in certain areas was not clear;

4) determination of bed load transported by the river under various discharges - to date no bedload studies of the Illinois River have been conducted, but because of its gravelly nature, bedload may be (and probably is) the major component of sediment transported. Thus bedload transport data are vital information in the determination of sedimentation of Lake Tenkiller;

5) the use of scour chains to measure scour/redeposition - scour chains are important tools in determination of maximum scour and fill of channel beds during high flow events. They provide valuable information on the transport of bed material; and

6) contribution of tributary sediment loads to the river - based on observations over the past year, it is expected that the Illinois River tributaries contribute significant amounts of sediment loads to the river; therefore, bedload and suspended load determinations on the major tributaries would provide valuable information.

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APPENDIX A

PHOTOGRAPHS OF SITES SELECTED FOR DETAILED STUDY

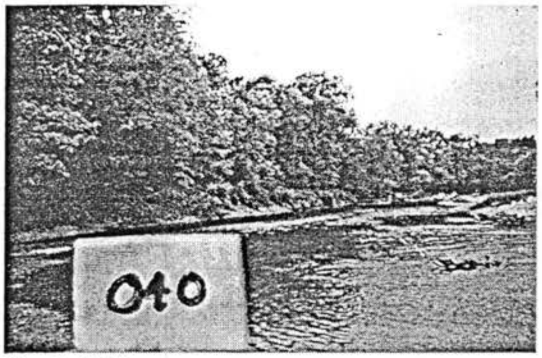
Bank 010

Site 010 - upstream view from cross section

Site 010 - downstream view from cross section

Site 015 - upstream view from cross section

Site 015 - downstream view from cross section



Bank 040

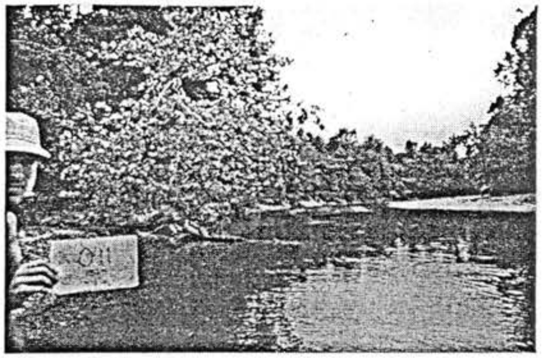
Site 040a - downstream view from cross section

Site 040b - upstream view from cross section

Site 040b - downstream view from cross section

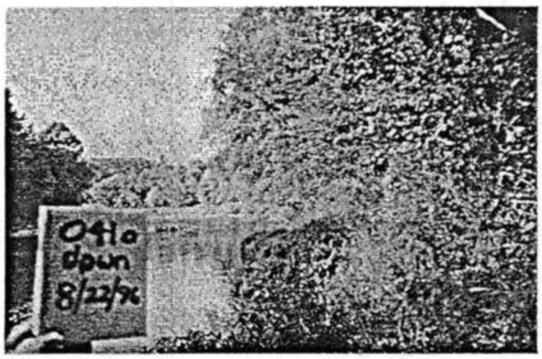
Site 040b - upstream view from cross section

Site 040c - downstream view from cross section

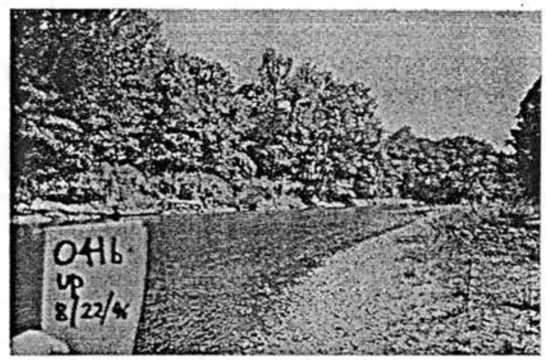


Bank 041

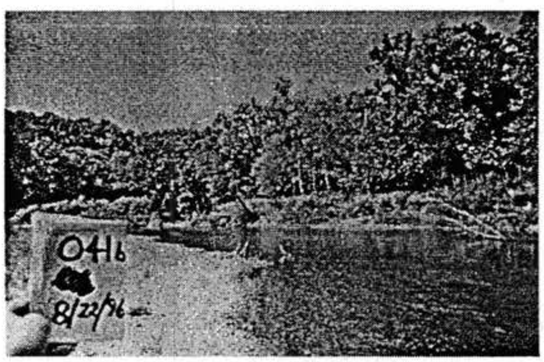
Site 041a - upstream view from cross section



Site 041a - downstream view from cross section



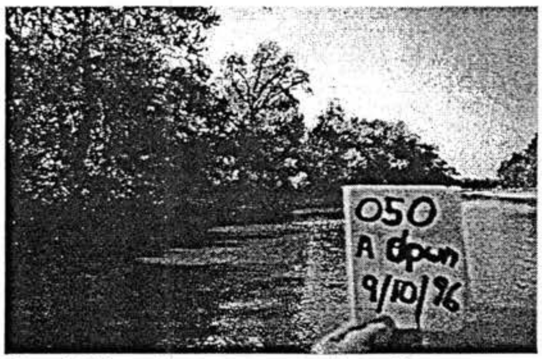
Site 041b - upstream view from cross section



Site 041b - downstream view from cross section

Bank 050

Site 050a - upstream view from cross section



Site 050a - downstream view from cross section

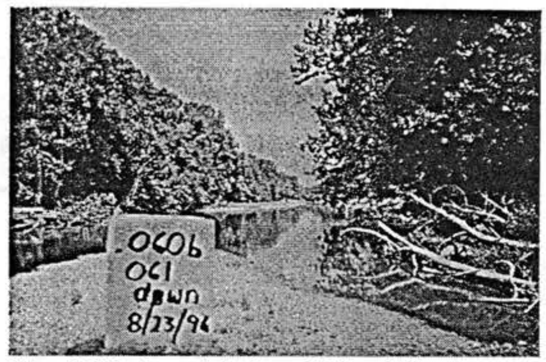
Site 050b - upstream view from cross section

Site 050b - downstream view from cross section

Site 060a - upstream view from cross section

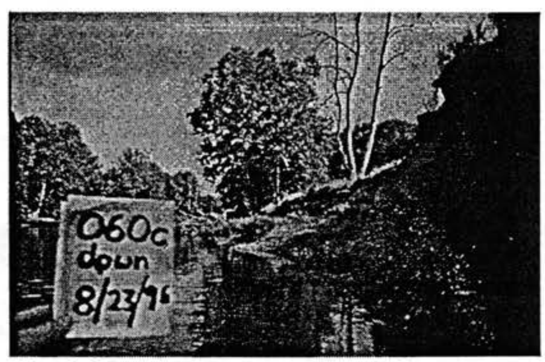
Site 060a - downstream view from cross section

Site 060b (on left) and Site 061 - upstream view from cross section

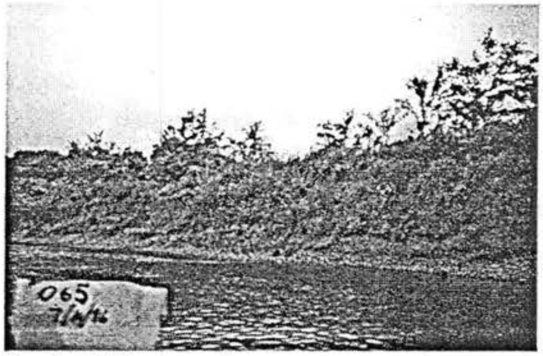


Site 060b (on right) and Site 061 - downstream view from cross section

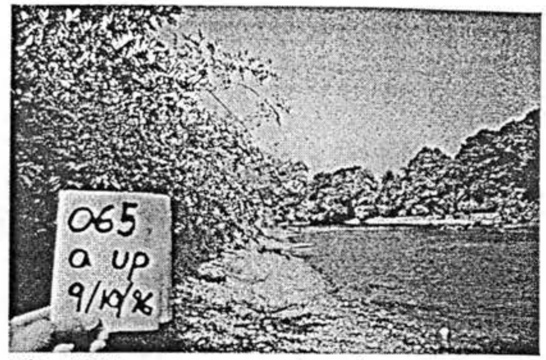
Site 060c



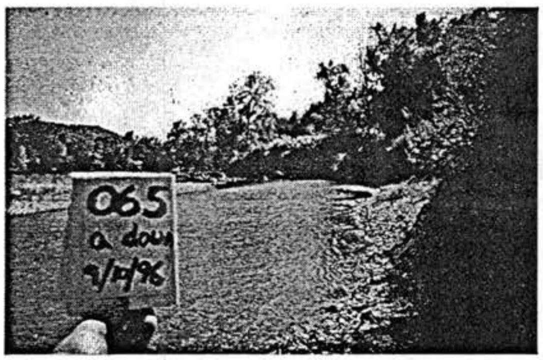
Site 060c - downstream view from cross section



Bank 065



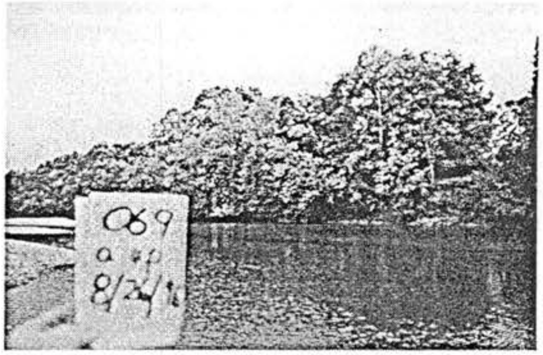
Site 065a - upstream view from cross section



Site 065a - downstream view from cross section

Site 065b - upstream view from cross section

Site 065b - downstream view from cross section

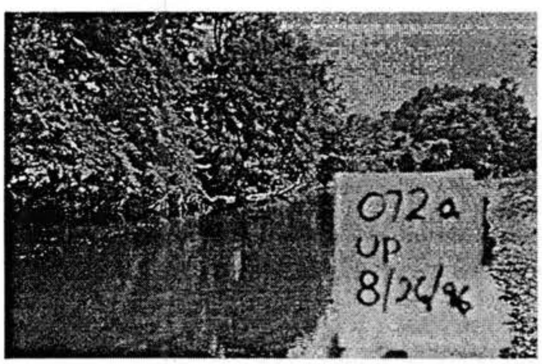


Site 069a - upstream view from cross section

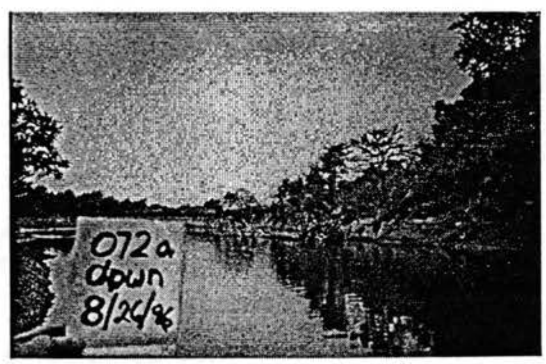
Site 069a - downstream view from cross section

Site 069b - upstream view from cross section

Site 069b - downstream view from cross section



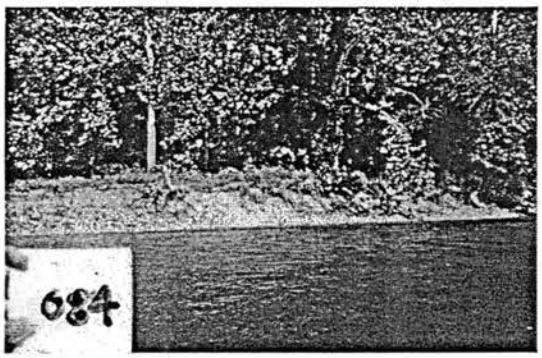
Site 072a - upstream view from cross section



Site 072a - downstream view from cross section

Site 072a - upstream view from cross section

Site 072a - downstream view from cross section



Bank 084

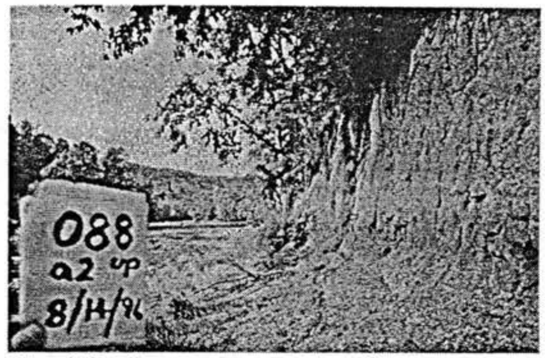
Site 084a - upstream view from cross section


Site 084a - downstream view from cross section

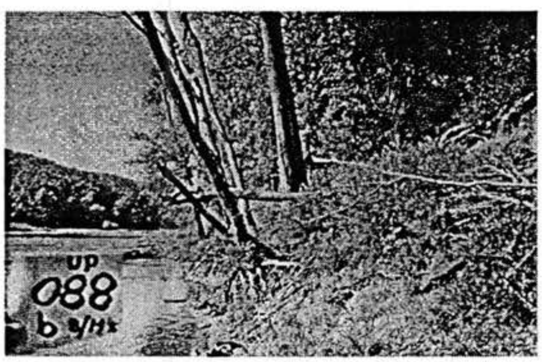
Bank 088

Site 088a1 - upstream view from cross section

Site 088a1 - downstream view from cross section

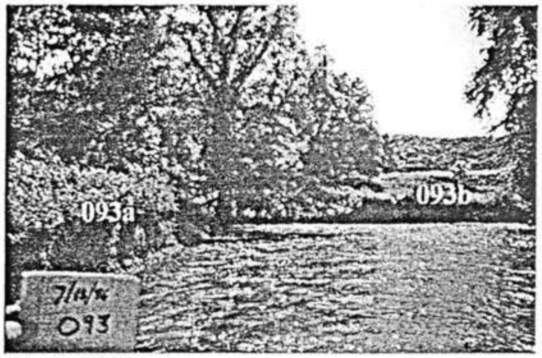


Site 088a2 - upstream view from cross section



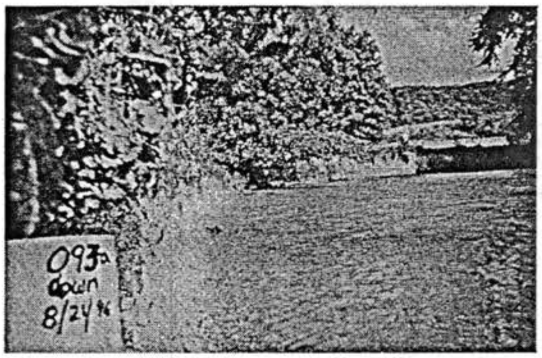
Site 088b - upstream view from cross section

Site 088b - downstream view from cross section



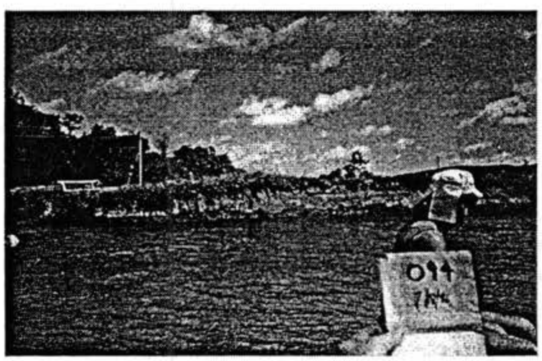
Bank 093

Site 093a - upstream view from cross section



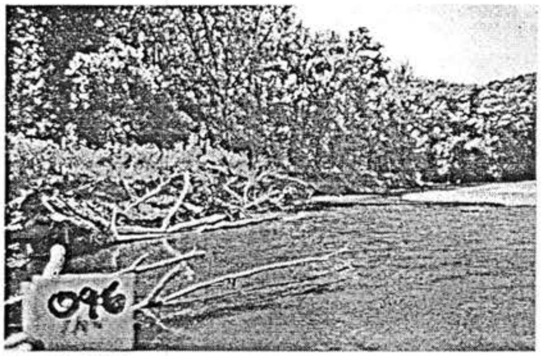
Site 093a - downstream view from cross section

Site 093b - downstream view from cross section



Site 094

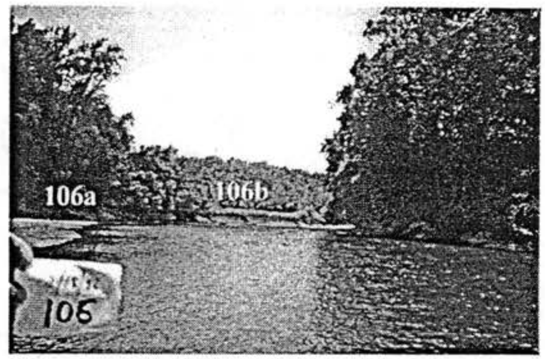
Site 094 - downstream view from cross section



Bank 096

Site 096 - upstream view from cross section

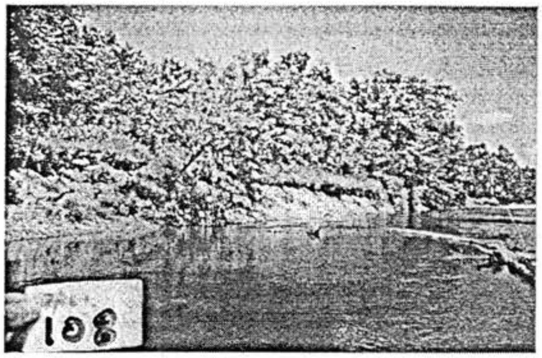
Site 096 - downstream view from cross section



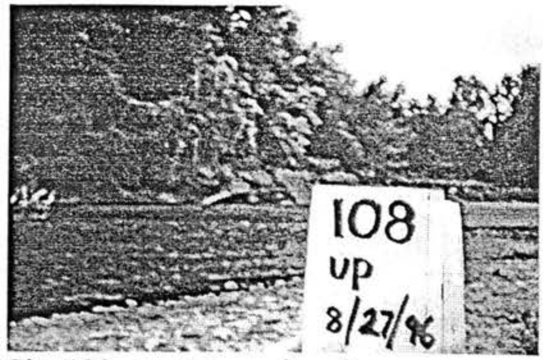
Bank 106

Site 106a - downstream view from cross section

Site 106b - upstream view from cross section



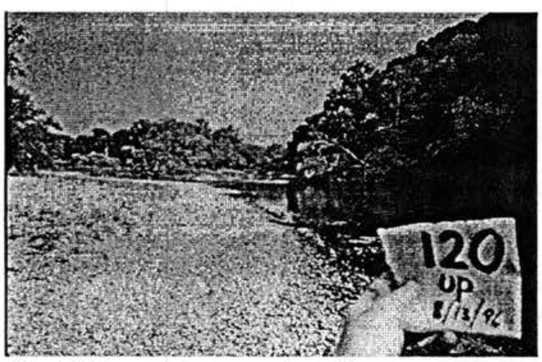
Bank 108



Site 108 - upstream view from cross section

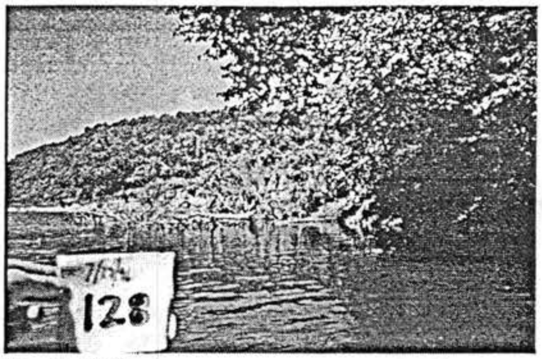
Site 108 - downstream view from cross section

Bank 120

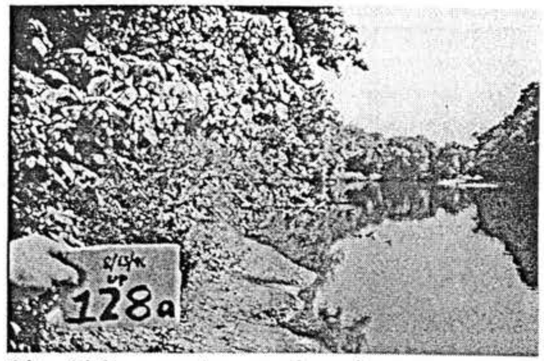


Site 120 - upstream view from cross section

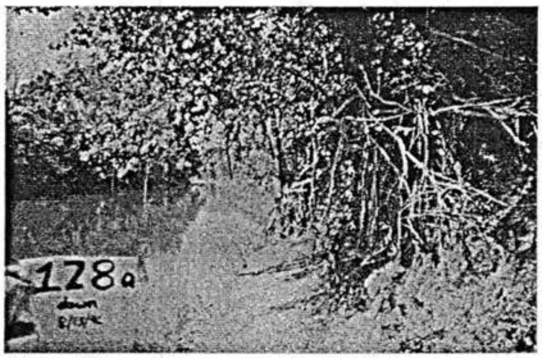
Site 120 - downstream view from cross section



Bank 128



Site 128a - upstream view from cross section



Site 128a - downstream view from cross section

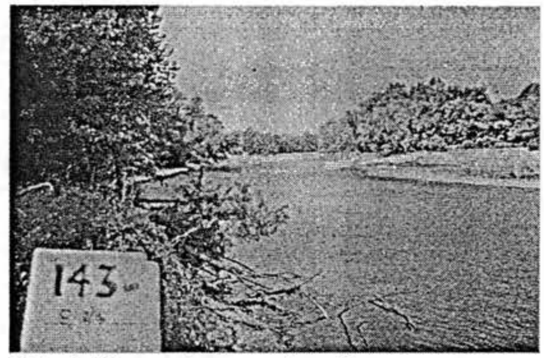
Site 128b1 - upstream view from cross section

Site 128b1 - downstream view from cross section

Site 128b2 - upstream view from cross section

Site 128b2 - downstream view from cross section

Bank 143



Site 143 - upstream view from cross section

Site 143 - downstream view from cross section

APPENDIX B

DESCRIPTION OF ROSGEN LEVEL III FIELD PARAMETERS

(from Rosgen 1996b, 1985)

RIPARIAN VEGETATION

Existing Vegetation

V1 - Rock
V2 - Bare soil, little or no vegetative cover
V3 - Annuals, forbs
V4 - Grass - perennial bunch grasses
V5 - Grass - sod-formers
V6 - Low brush species
V7 - High brush species
V8 - Coniferous trees
V9 - Deciduous trees
V10 - Wetlands

Density

a - low
b - moderate
c - high

STREAM SIZE

S1 - Bankfull width less than 1ft
S2 - Bankfull width 1 - 5ft
S3 - Bankfull width 5 - 15ft
S4 - Bankfull width 15 - 30ft
S5 - Bankfull width 30 - 50ft
S6 - Bankfull width 50 - 75ft
S7 - Bankfull width 75 - 100ft
S8 - Bankfull width 100 - 150ft
S9 - Bankfull width 150 - 250ft
S10 - Bankfull width 250 - 350ft
S11 - Bankfull width 350 - 500ft
S12 - Bankfull width 500 - 1000ft
S13 - Bankfull width greater than 1000ft

FLOW REGIME

General Category

E. Ephemeral stream channels - flows only in response to precipitation. Often used in conjunction with intermittent.

S. Subterranean stream channel - flows parallel to and near the surface for various seasons or a sub-surface flow which follows the stream bed.

I. Intermittent stream channel - one which flows only seasonally, or sporadically. Surface sources involve springs, snow melt, artificial controls, etc. Often this term is associated with flows that reappear along various locations of a reach, then run subterranean.

P. Perennial stream channels - surface water persists year long.

Specific Category

1. Seasonal variation in streamflow dominated primarily by snowmelt runoff.

2. Seasonal variation in streamflow dominated primarily by stormflow runoff.

3. Uniform stage and associated streamflow due to spring fed condition, backwater etc.

4. Stream flow regulated by glacial melt.

5. Ice flows, ice torrents from ice dam breaches.

6. Alternating flow/backwater due to tidal influence.

7. Regulated stream flow due to diversions, dam release, dewatering, etc.

8. Altered due to development, such as urban streams, cut-over watersheds, vegetation conversions (forested to grassed) that changes flow response to precipitation events.

DEPOSITIONAL FEATURES

B1 - Point Bars
B2 - Point Bars with few midchannel bars
B3 - Many midchannel bars
B4 - Side bars
B5 - Diagonal Bars
B6 - Main channel branching with many midchannel bars and islands
B7 - Mixed side bars and midchannel bars exceeding twice width
B8 - Delta bars

MEANDER PATTERNS

M1 - Regular meander
M2 - Tortuous meander
M3 - Irregular meanders
M4 - Truncated meanders
M5 - Unconfined meander scrolls
M6 - Confined meander scrolls
M7 - Distorted Meander loops
M8 - Irregular with oxbows and oxbow cutoffs

STREAM CHANNEL DEBRIS/BLOCKAGES

DESCRIPTION/EXTENT: Materials, which upon placement into the active channel or floodprone area may cause an adjustment in channel dimensions or conditions, due to influences on the existing flow regime.

D1 - NONE - Minor amounts of small, floatable material.

D2 - INFREQUENT - Debris consists of small, easily moved, floatable material; i.e. leaves, needles, small limbs, twigs, etc.

D3 - MODERATE - Increasing frequency of small to medium sized material, such as large limbs, branches and small logs that when accumulated effect 10% or less of the active channel cross-sectional area.

D4 - NUMEROUS - Significant build-up of medium to large sized materials, i.e. large limbs, branches, small logs or portions of trees that may occupy 10 to 30% of the active channel cross-section area.

D5 - EXTENSIVE - Debris "dams" of predominantly larger materials, i.e. branches, logs, trees, etc., occupying *30 to* 50% of the active channel cross-section; often extending across the width of the active channel.

D6 - DOMINATING - Large, somewhat continuous debris madams," extensive in nature and occupying over 50% of the active channel cross-section. Such accumulations may divert water into the floodprone areas and form fish migration barriers, even when flows are at less than bankfull.

D7 - FEW BEAVER DAMS - An infrequent number of dams spaced such that normal streamflow and expected channel conditions exist in the reaches between dams.

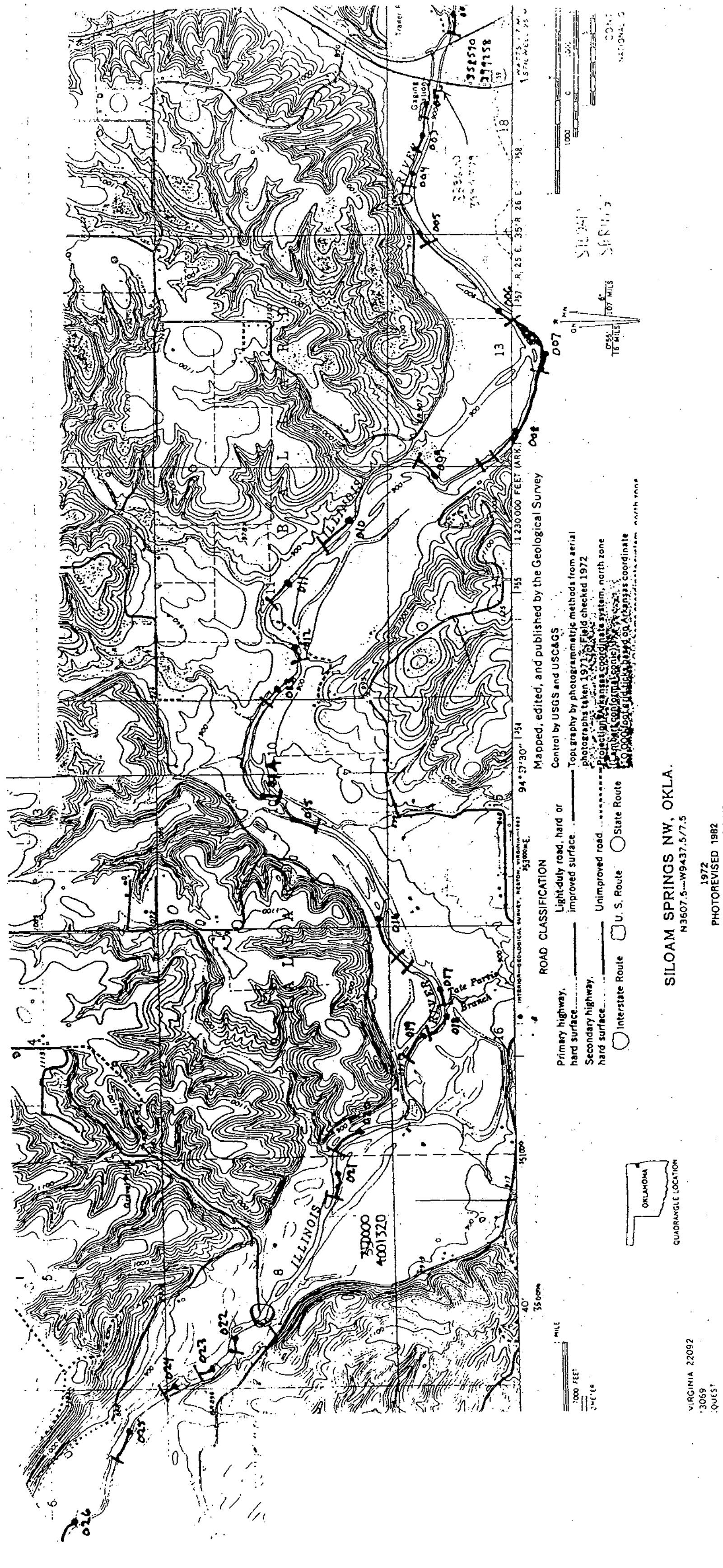
D8 - FREQUENT BEAVER DAMS - Frequency of dams is such that backwater conditions exist for channel reaches between structures; where streamflow velocities are reduced and channel dimensions or conditions are influenced.

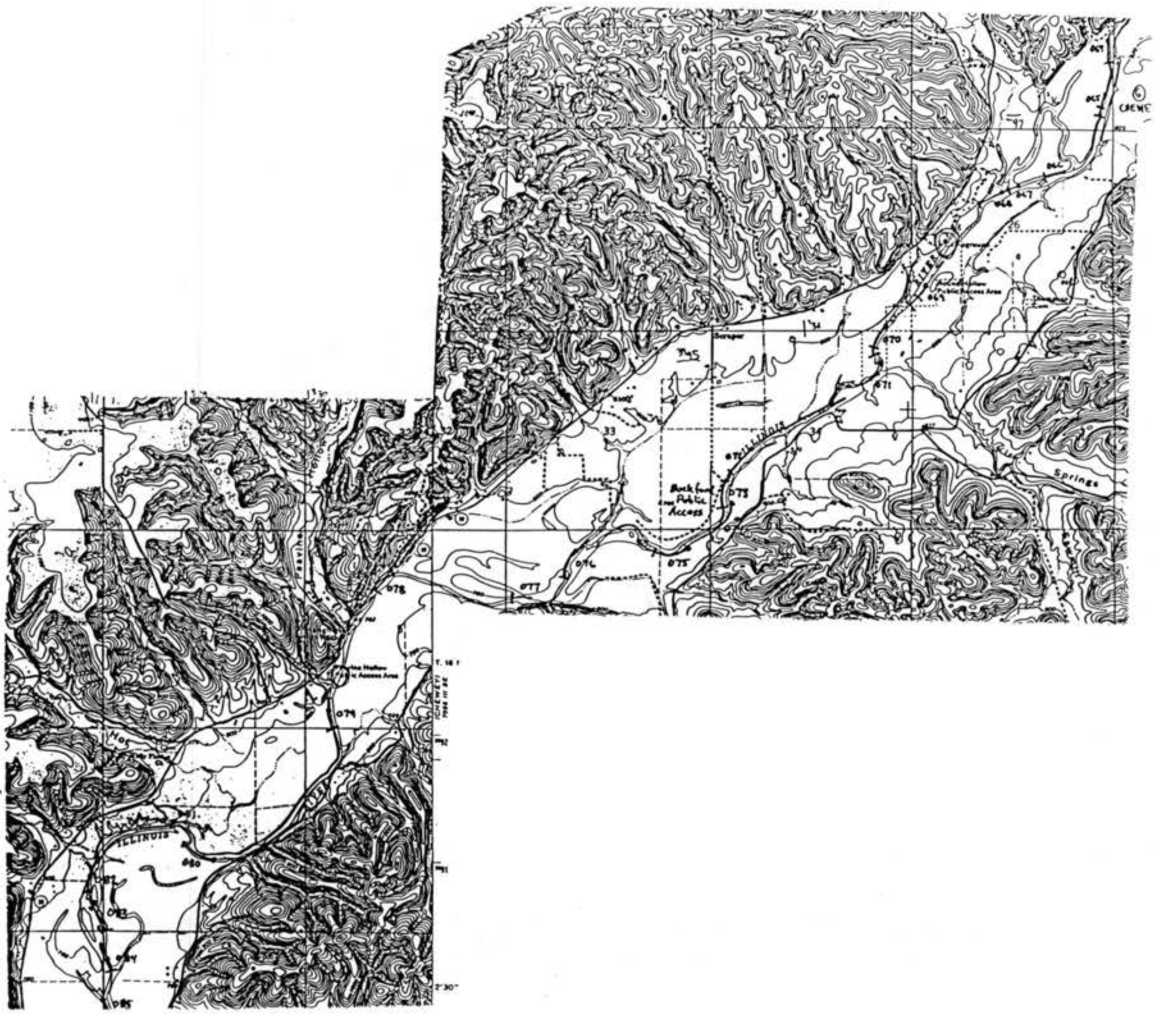
D9 - ABANDONED BEAVER DAMS - Numerous abandoned dams, many of which have filled with sediment and/or breached, initiating a series of channel adjustments such as bank erosion, lateral migration, evulsion, aggradation and degradation.

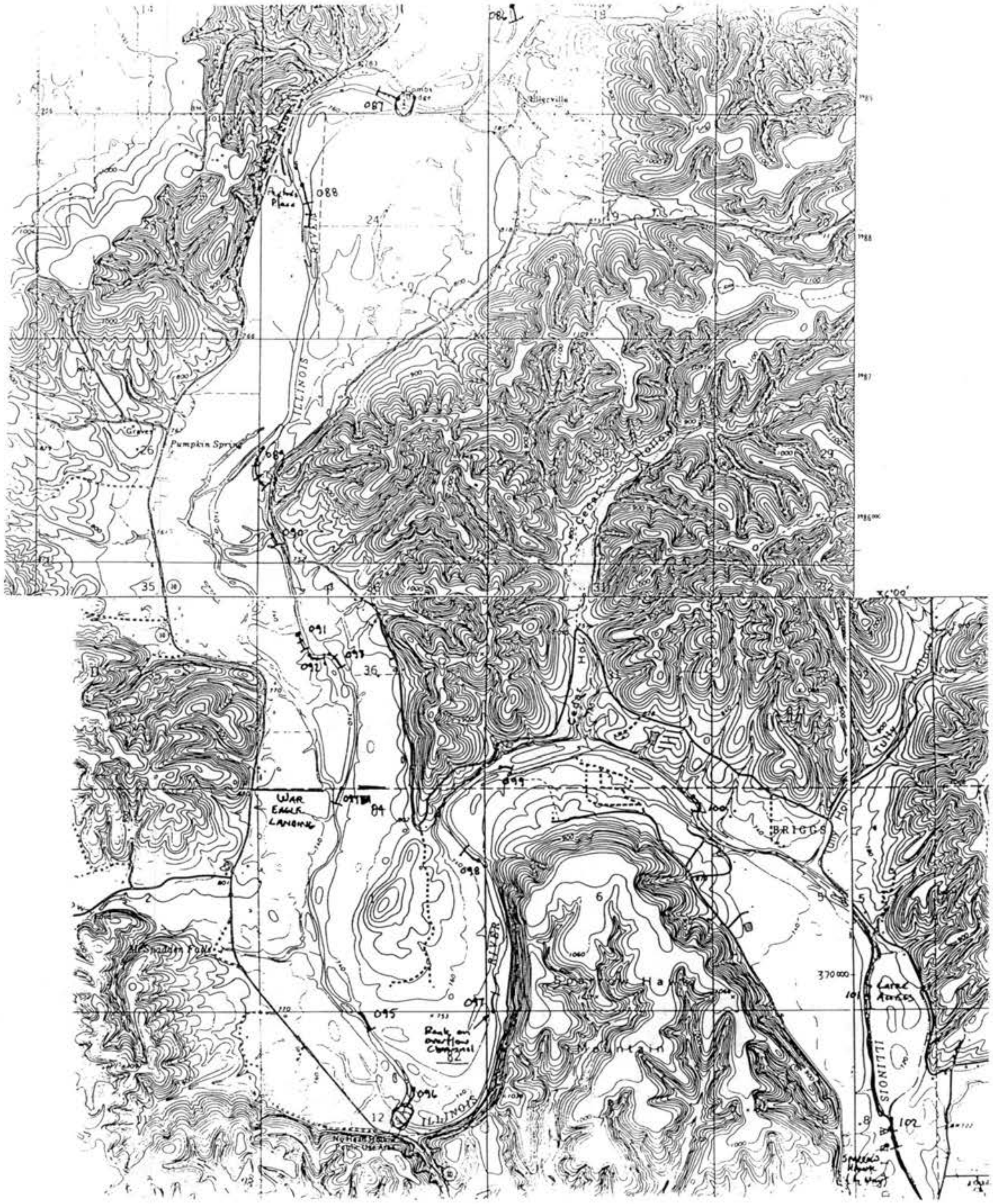
D10 - HUMAN INFLUENCES - Structures, facilities, or materials related to land uses or development located within the floodprone area, such as diversions or low-head dams, controlled by-pass channels, velocity control structures, and various transportation encroachments that have an influence on the existing flow regime, such that significant channel adjustments occur.

APPENDIX C

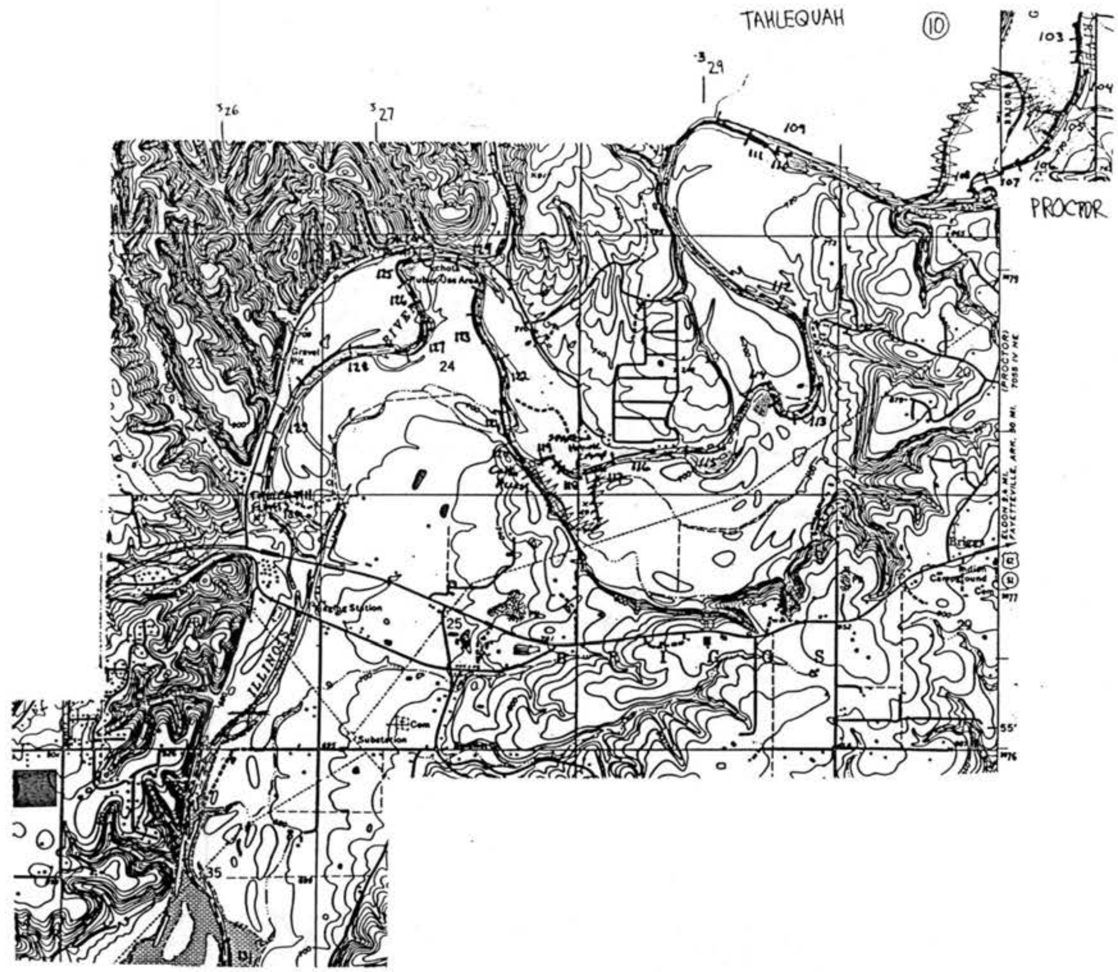
APPROXIMATE LOCATIONS OF CHARACTERIZED BANKS

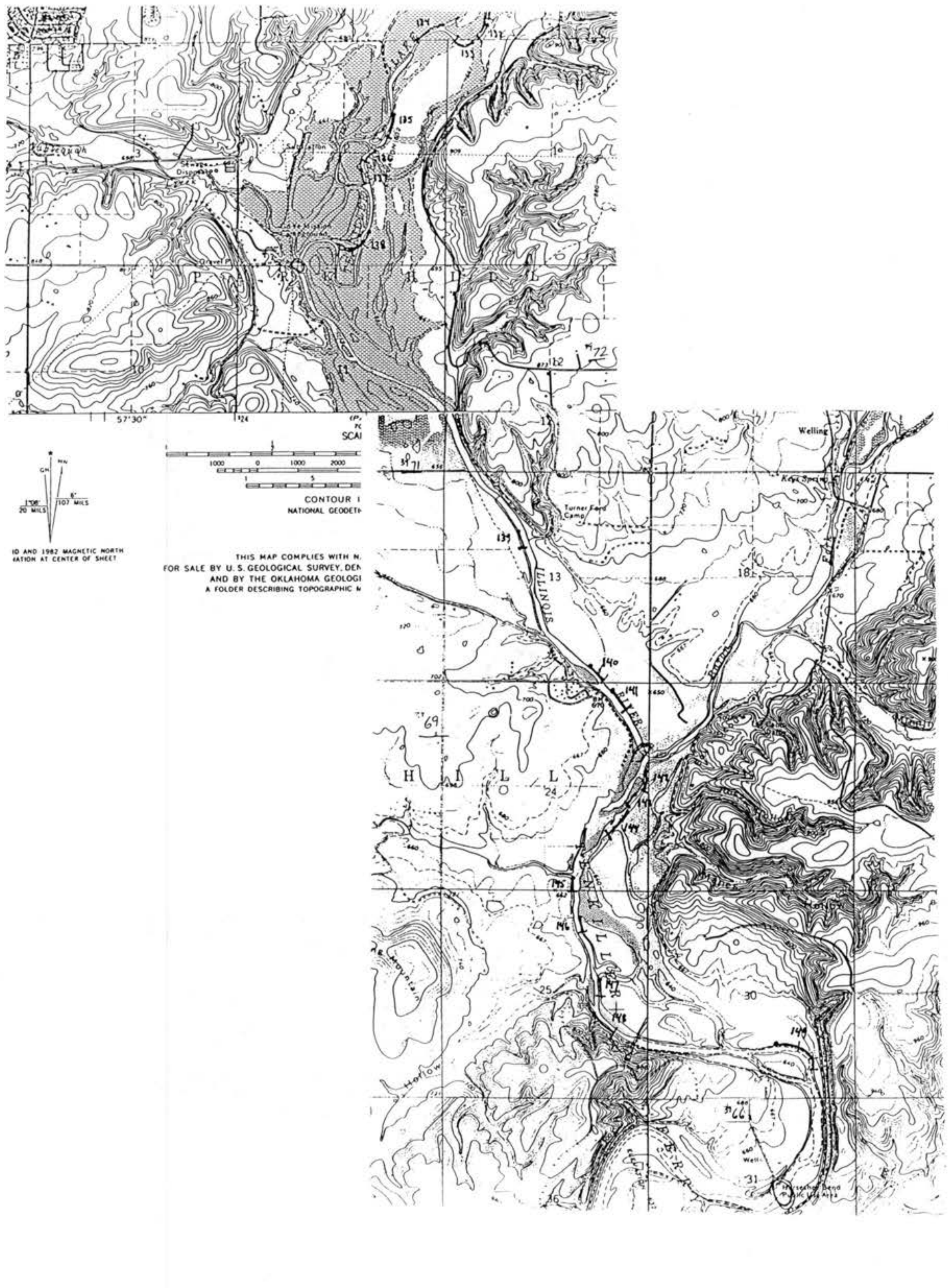

ROAD CLASSIFICATION
Primary highway, hard surface
Light-duty road, hard or improved surface
Secondary highway, hard surface
Unimproved road
Interstate Route
U. S. Route
State Route
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1971. Field checked 1972
SILOAM SPRINGS NW, OKLA.
N3607.5—W9437.5/7.5
1972
PHOTOREVISED 1982
ILLINOIS
RIVER
OKLAHOMA
QUADRANGLE LOCATION





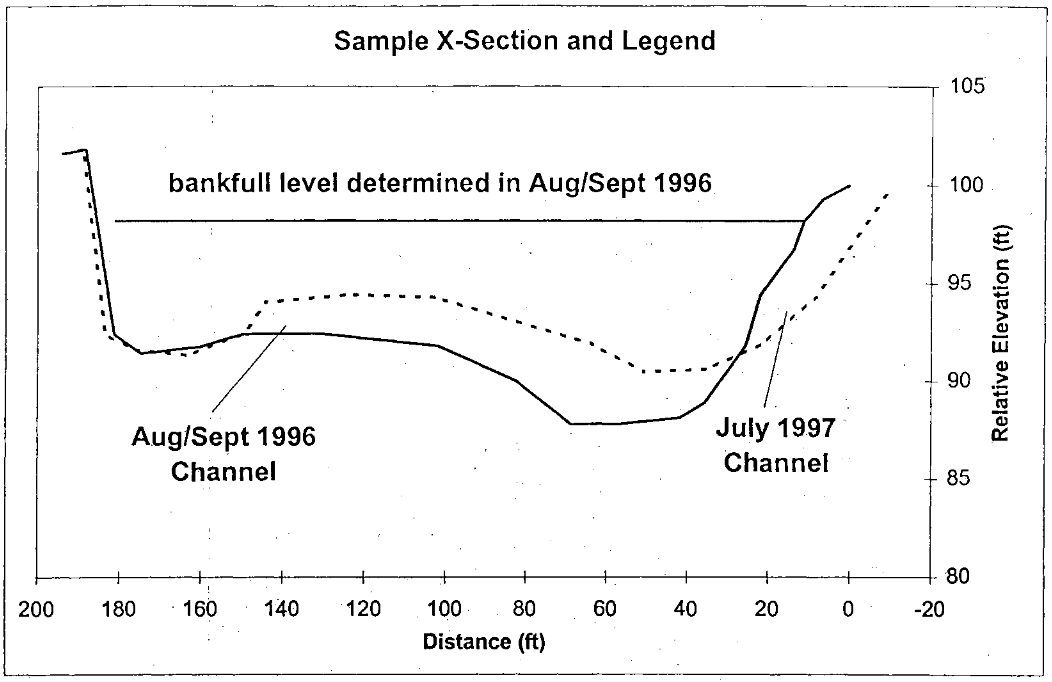
War Eagle Landing
Pumpkin Spring
Briggs
Illinois
Illinois River


TAHLEQUAH
10
PROCTOR
ILLINOIS
RIVER


57°30"
ID AND 1982 MAGNETIC NORTH
IATION AT CENTER OF SHEET
CONTOUR I
NATIONAL GEODETI
THIS MAP COMPLIES WITH N
FOR SALE BY U. S. GEOLOGICAL SURVEY, DEN
AND BY THE OKLAHOMA GEOLOGI
A FOLDER DESCRIBING TOPOGRAPHIC M
Welling
Turner Ford Camp
ILLINOIS
H
L
L

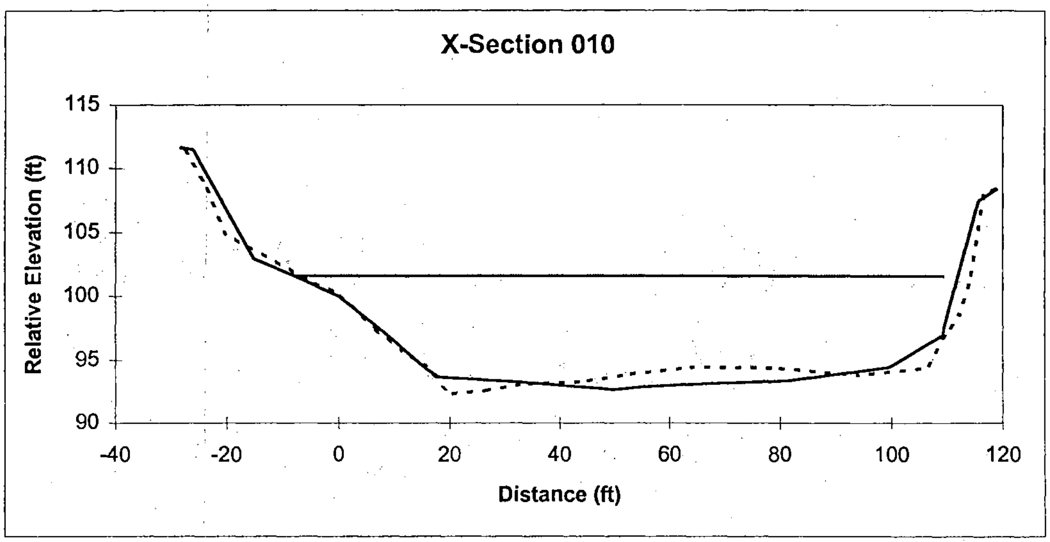
APPENDIX D

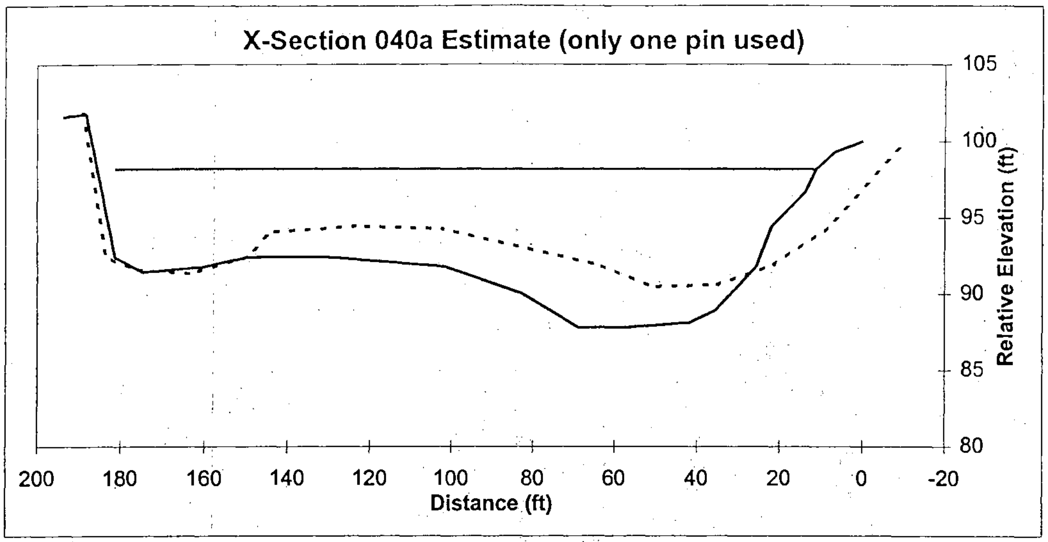
1996 AND 1997 CROSS SECTIONS OF SITES SELECTED FOR DETAILED STUDY



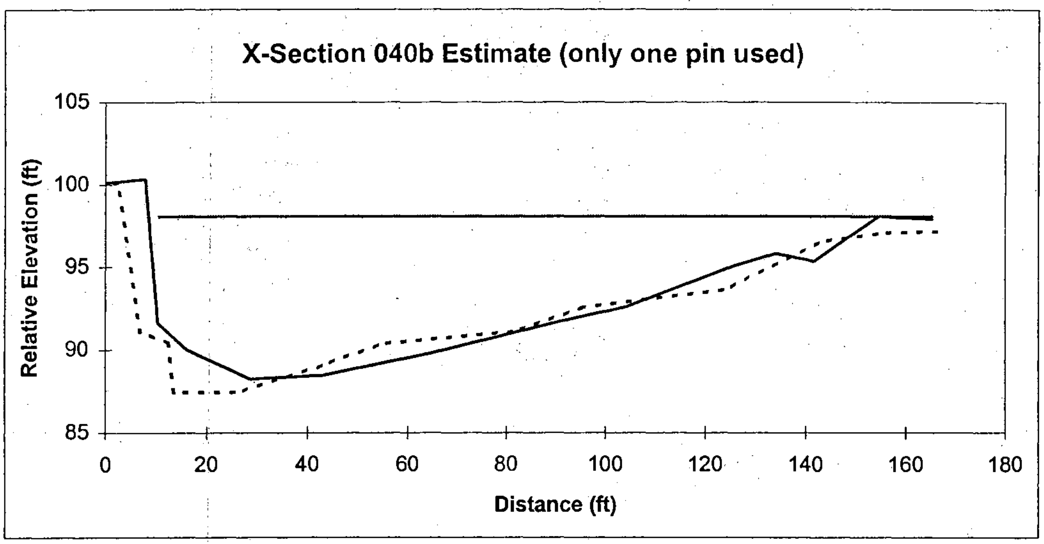
cross sections are presented in the downstream view

all vertical scales are exaggerated for presentation purposes

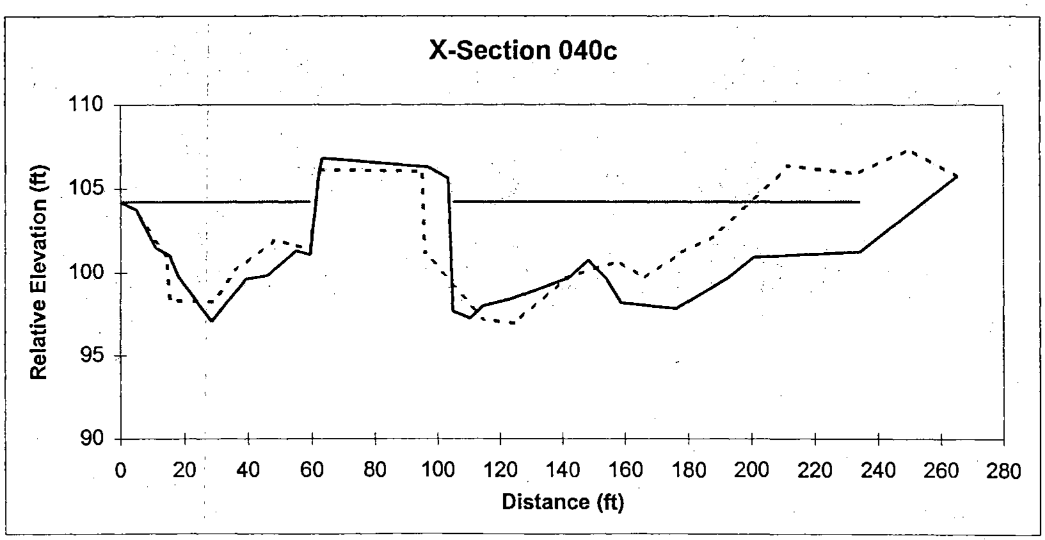




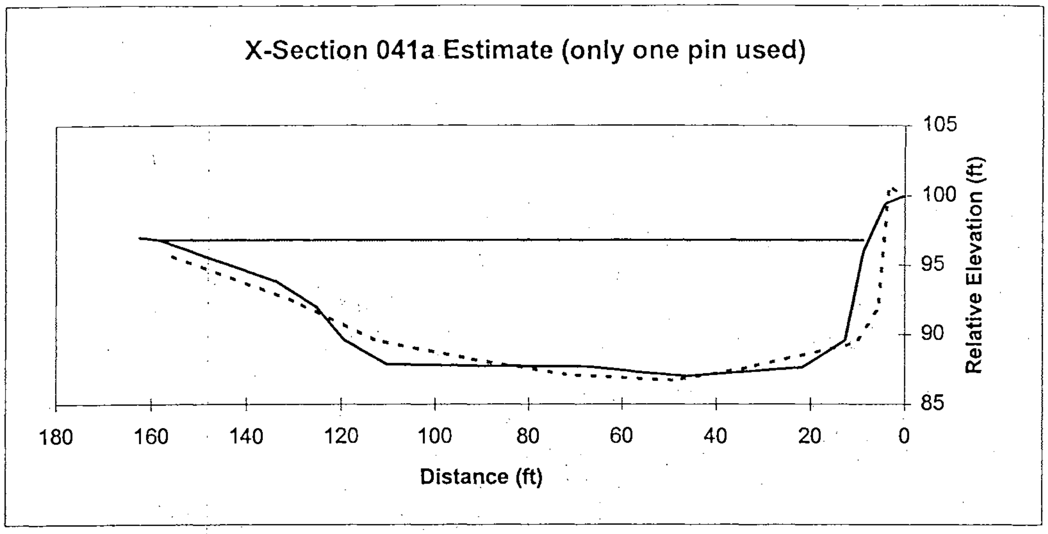
X-Section 040a Estimate (only one pin used)
105
100
95
90
85
80
Relative Elevation (ft)
200
180
160
140
120
100
80
60
40
20
0
-20
Distance (ft)

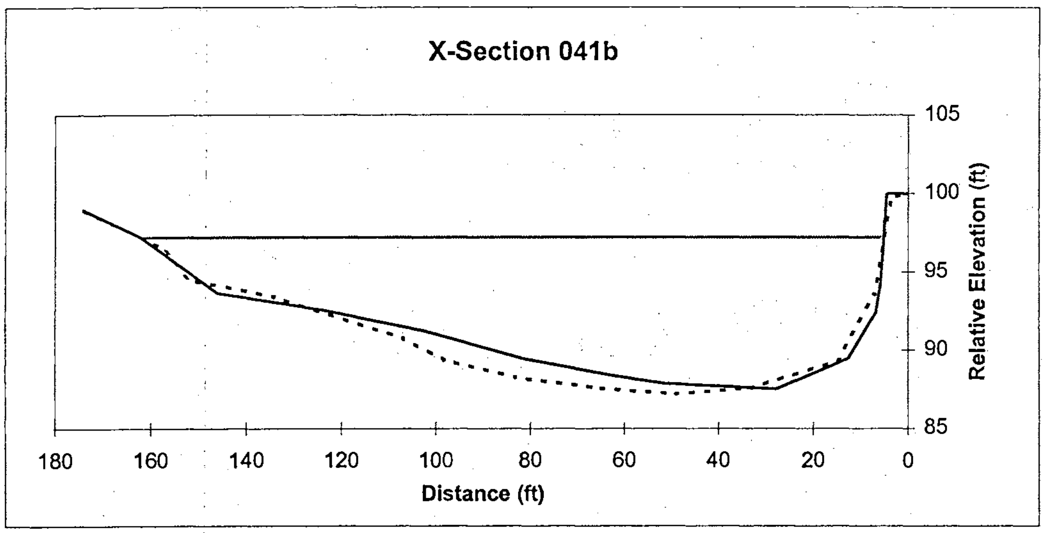


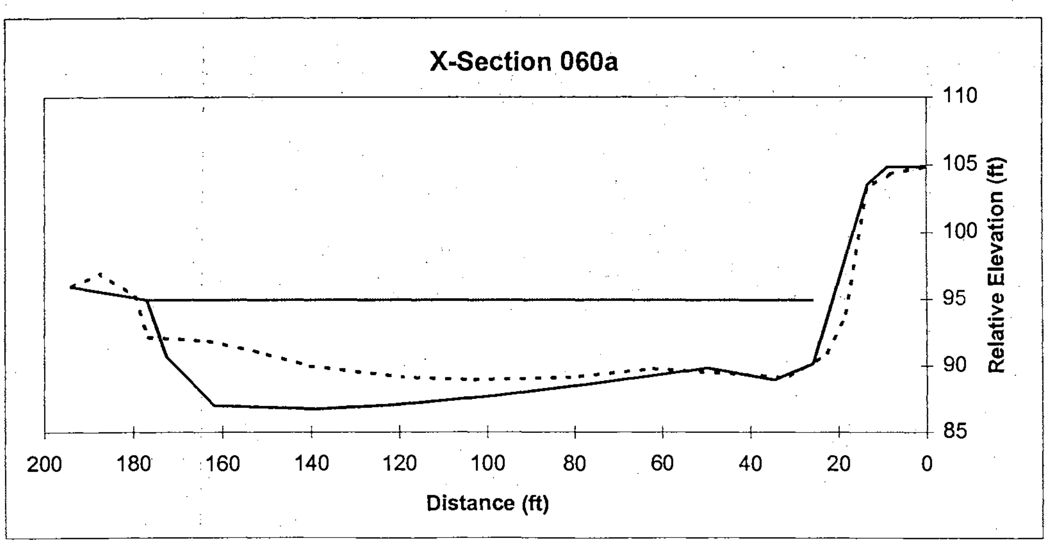
X-Section 040b Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
0
20
40
60
80
100
120
140
160
180
Distance (ft)

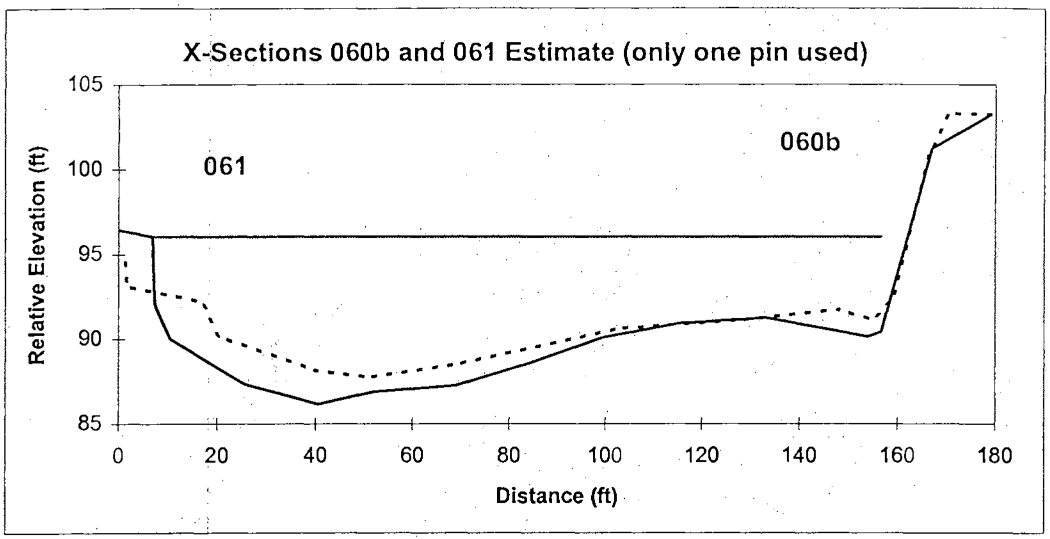


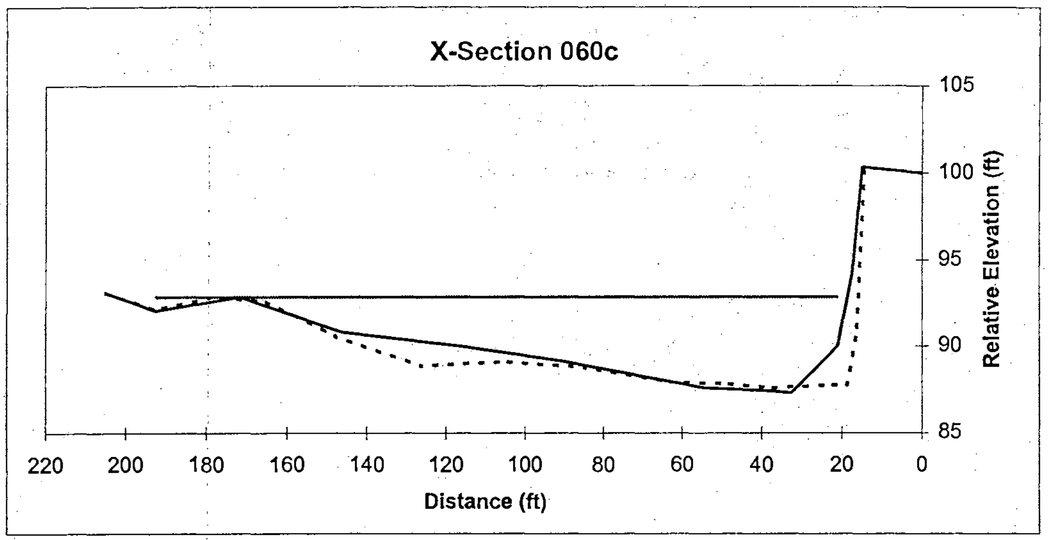
X-Section 040c
110
105
100
95
90
Relative Elevation (ft)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
Distance (ft)

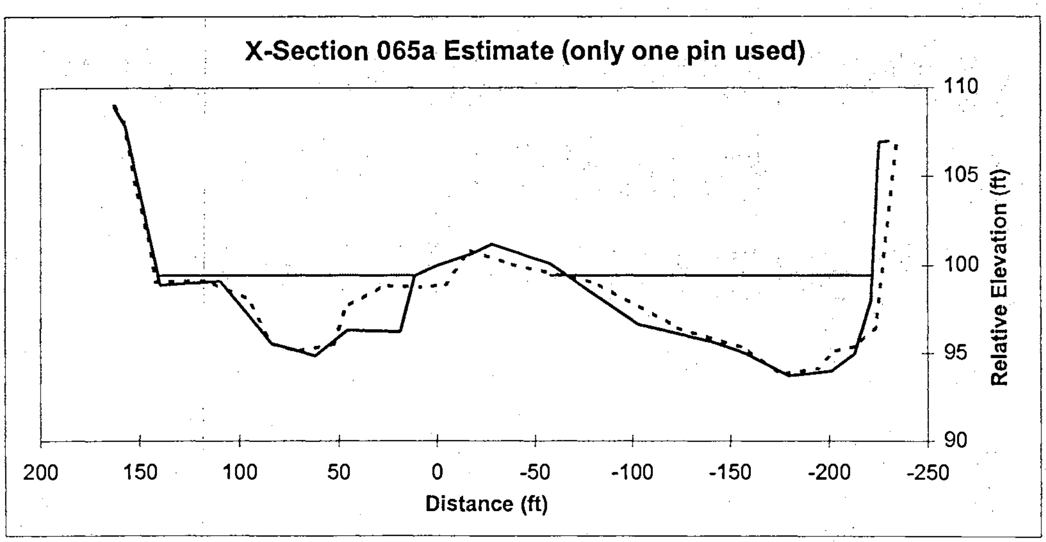

X-Section 041a Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
180
160
140
120
100
80
60
40
20
0
Distance (ft)

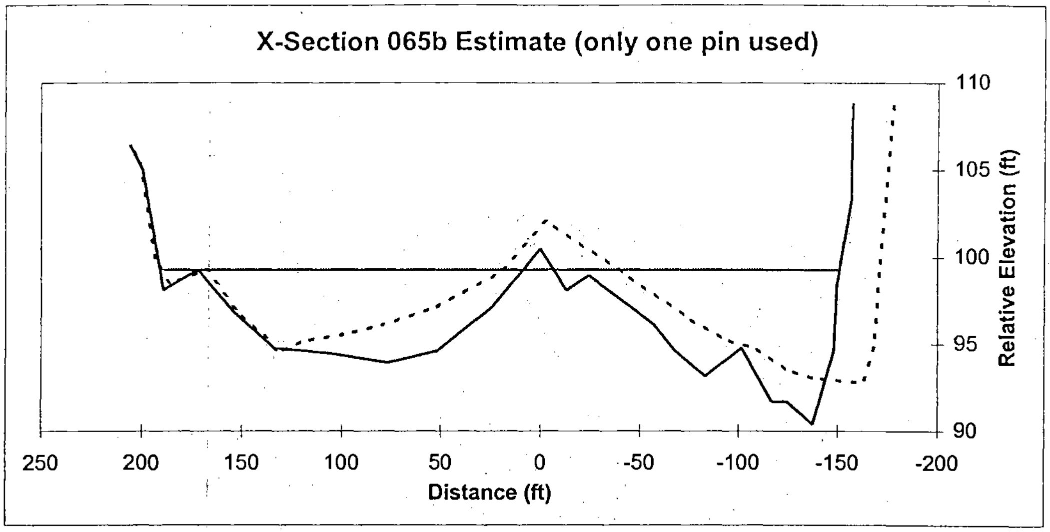

X-Section 041b
105
100
95
90
85
Relative Elevation (ft)
180
160
140
120
100
80
60
40
20
0
Distance (ft)

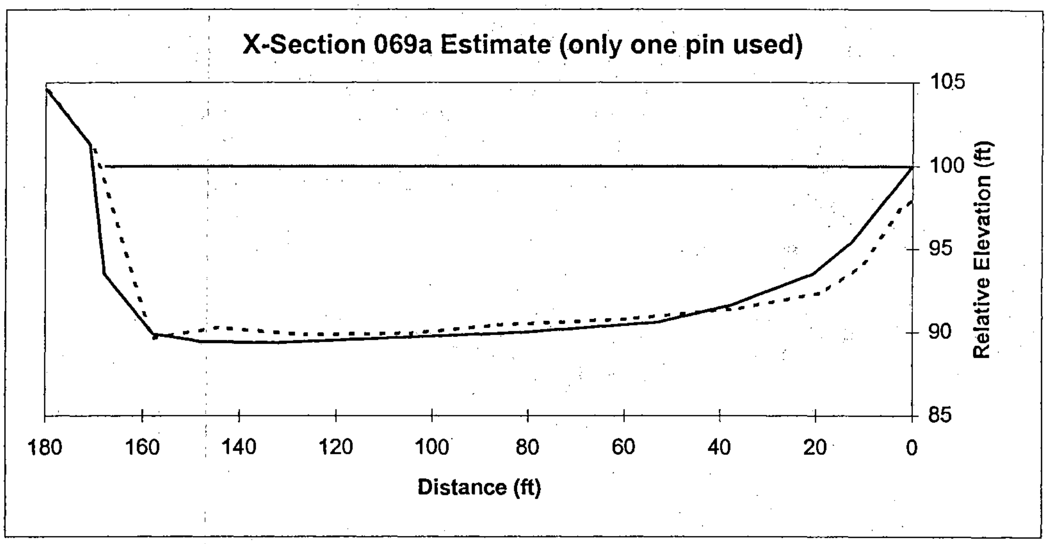

X-Section 060a
110
105
100
95
90
85
Relative Elevation (ft)
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)

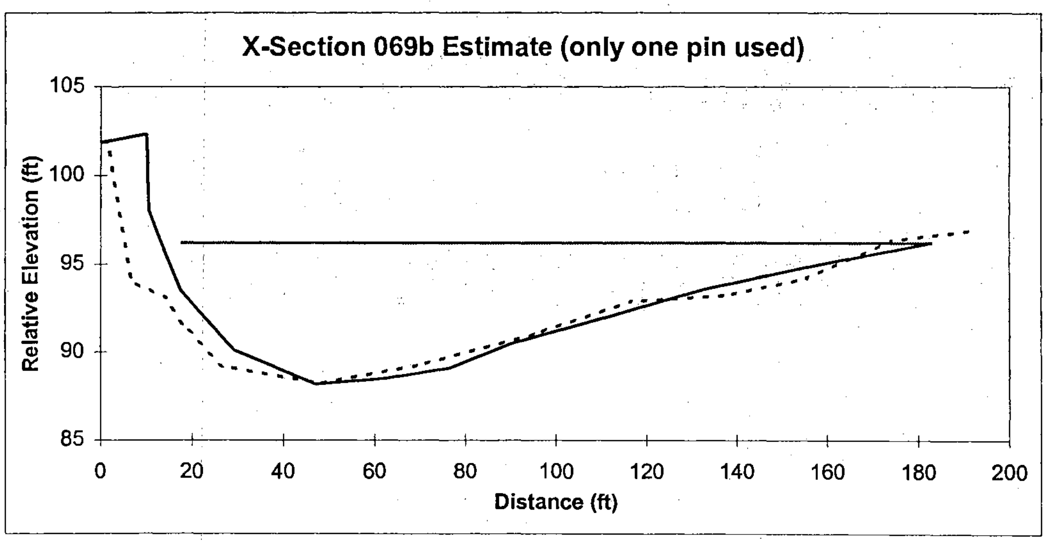

X-Sections 060b and 061 Estimate (only one pin used)
061
060b
Relative Elevation (ft)
105
100
95
90
85
0
20
40
60
80
100
120
140
160
180
Distance (ft)

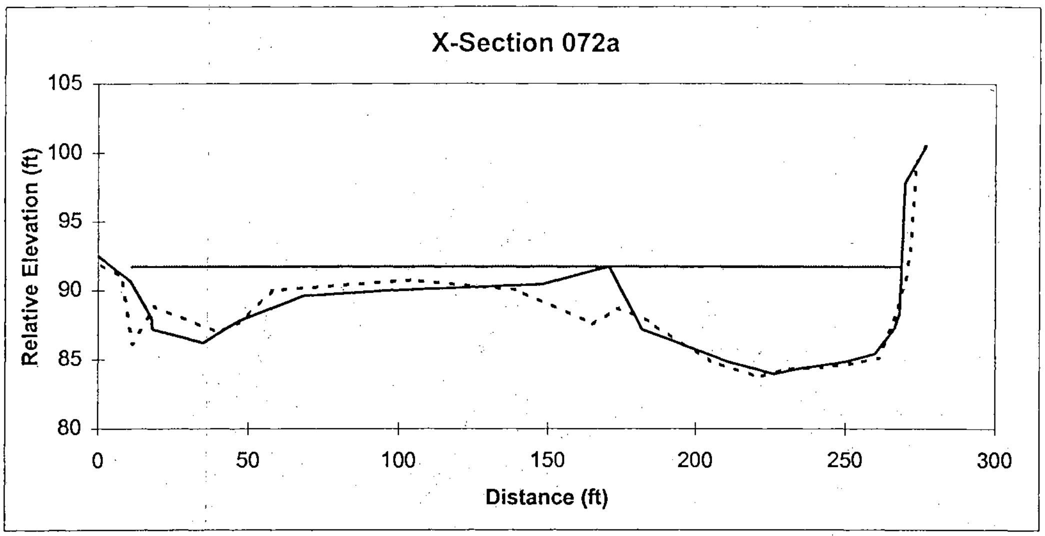

X-Section 060c
Relative Elevation (ft)
105
100
95
90
85
220
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)

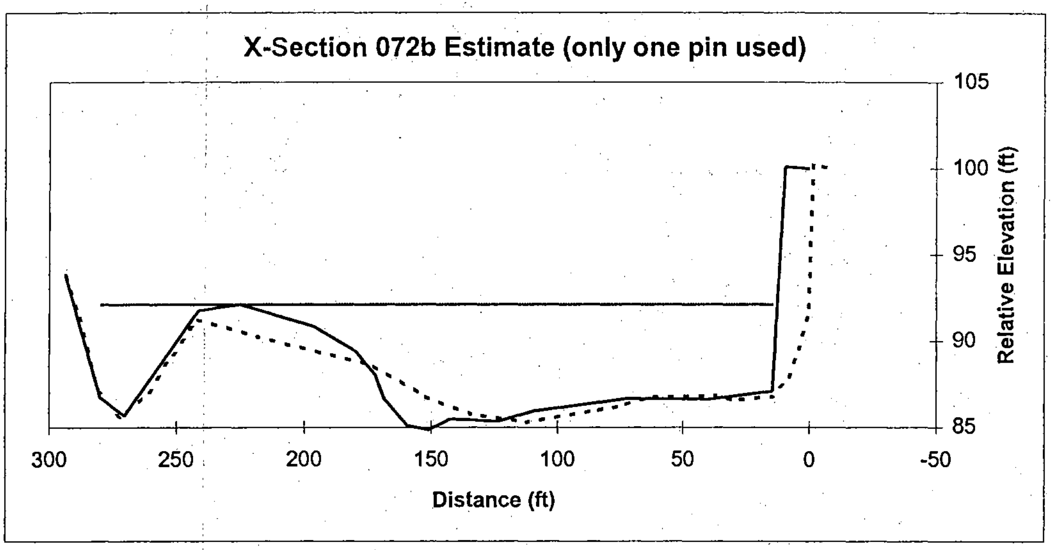

X-Section 065a Estimate (only one pin used)
Relative Elevation (ft)
110
105
100
95
90
200
150
100
50
0
-50
-100
-150
-200
-250
Distance (ft)

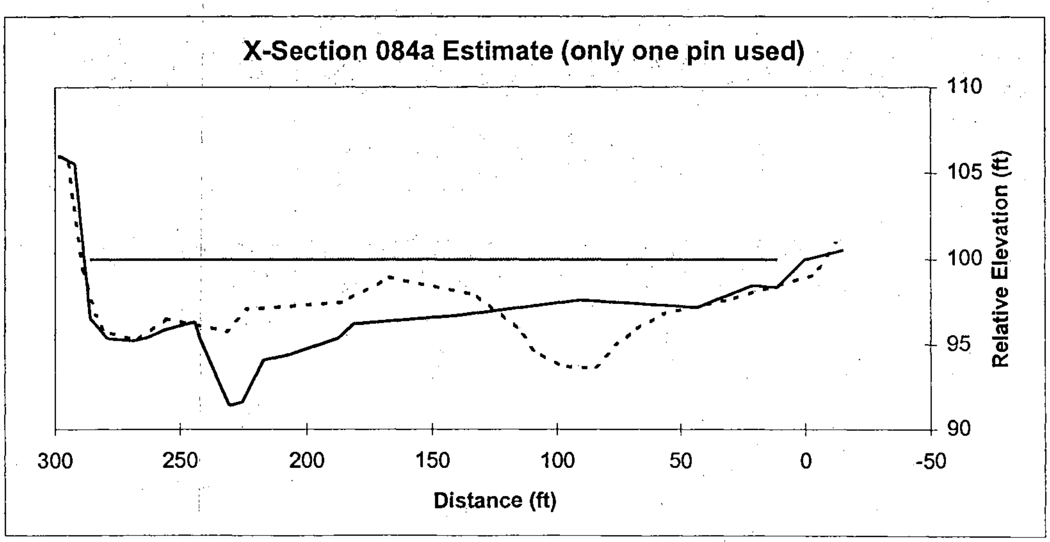

X-Section 065b Estimate (only one pin used)
Relative Elevation (ft)
110
105
100
95
90
250
200
150
100
50
0
-50
-100
-150
-200
Distance (ft)

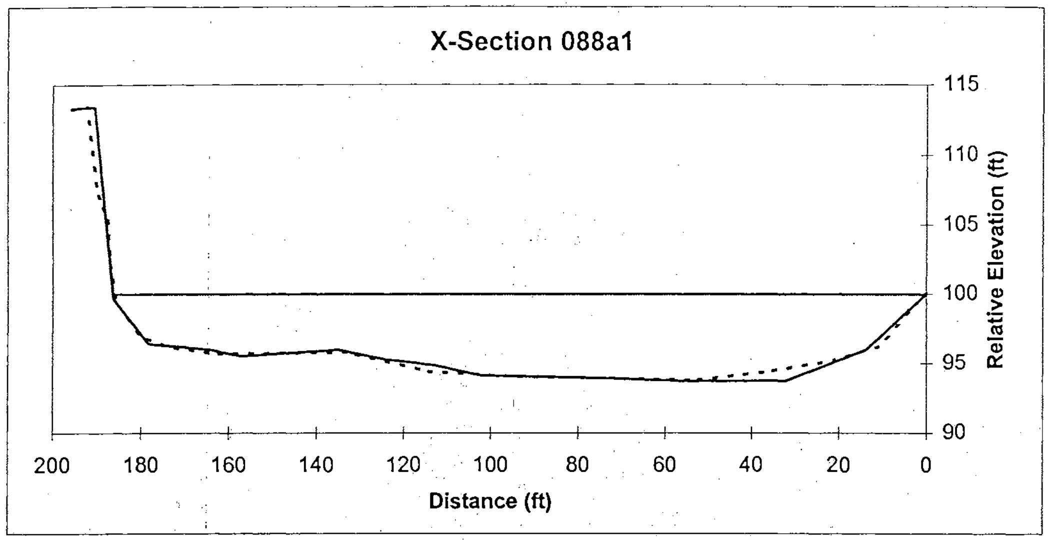

X-Section 069a Estimate (only one pin used)
Relative Elevation (ft)
105
100
95
90
85
180
160
140
120
100
80
60
40
20
0
Distance (ft)

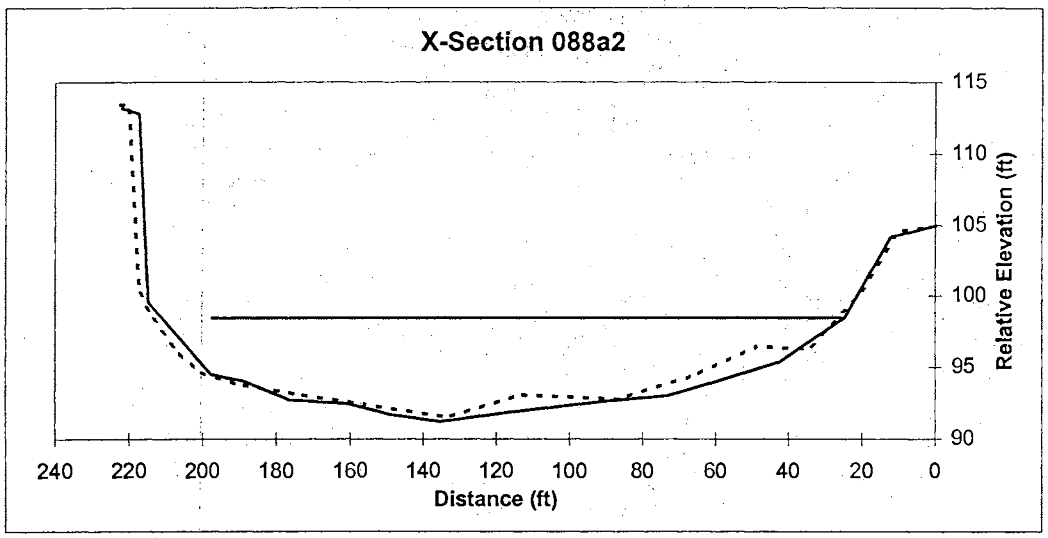

X-Section 069b Estimate (only one pin used)
Relative Elevation (ft)
105
100
95
90
85
0
20
40
60
80
100
120
140
160
180
200
Distance (ft)

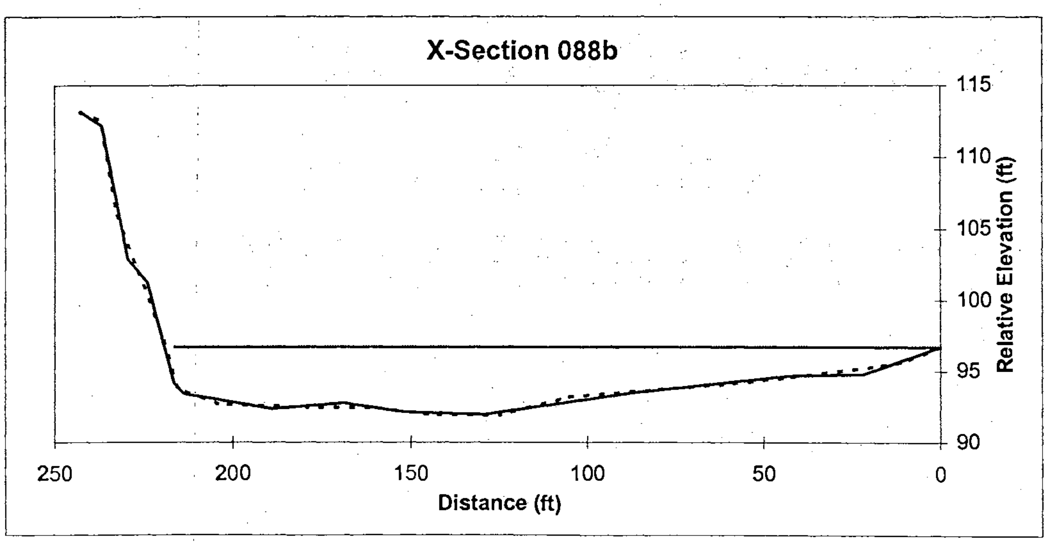

X-Section 072a
Relative Elevation (ft)
105
100
95
90
85
80
0
50
100
150
200
250
300
Distance (ft)

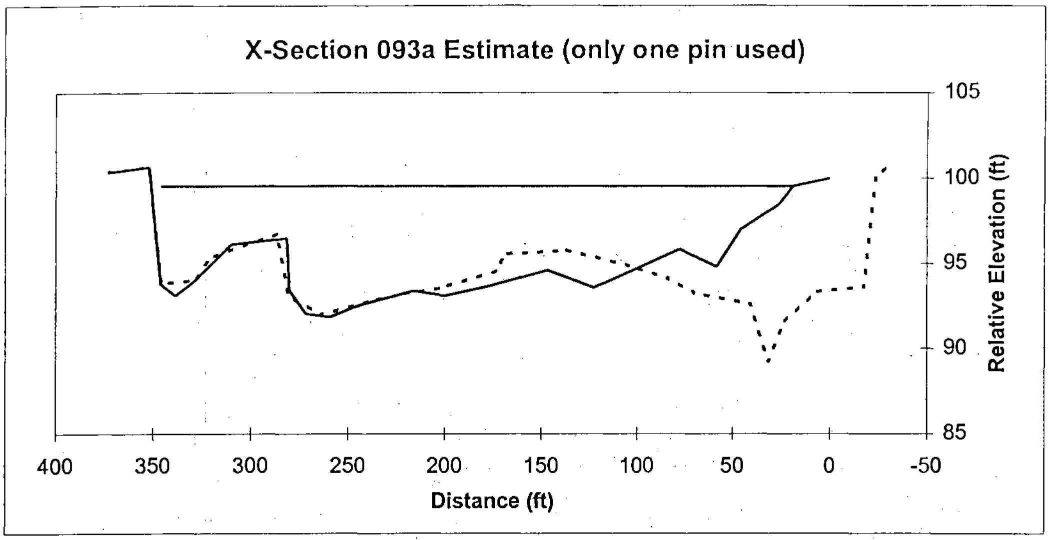

X-Section 072b Estimate (only one pin used)
Relative Elevation (ft)
105
100
95
90
85
300
250
200
150
100
50
0
-50
Distance (ft)

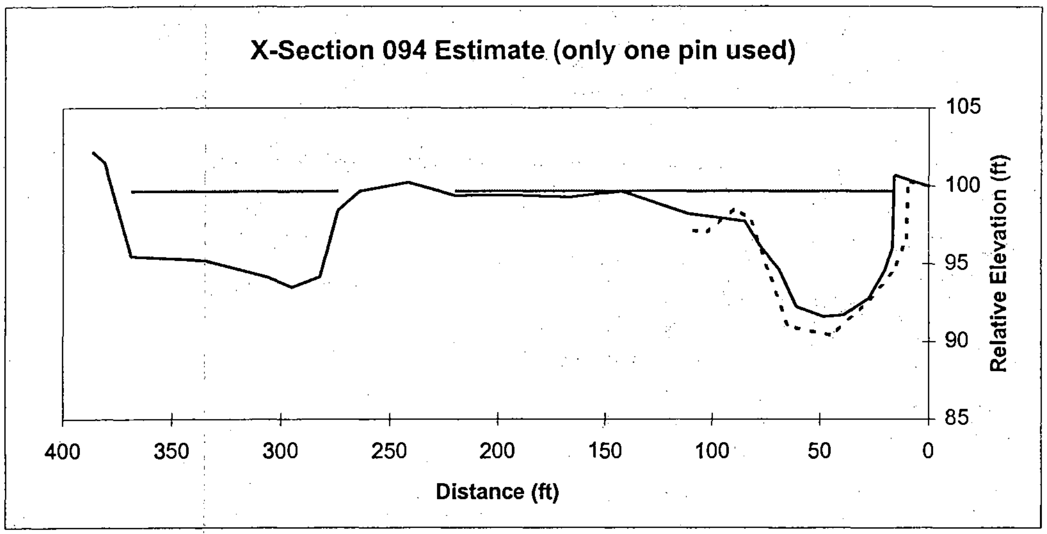

X-Section 084a Estimate (only one pin used)
Relative Elevation (ft)
110
105
100
95
90
300
250
200
150
100
50
0
-50
Distance (ft)

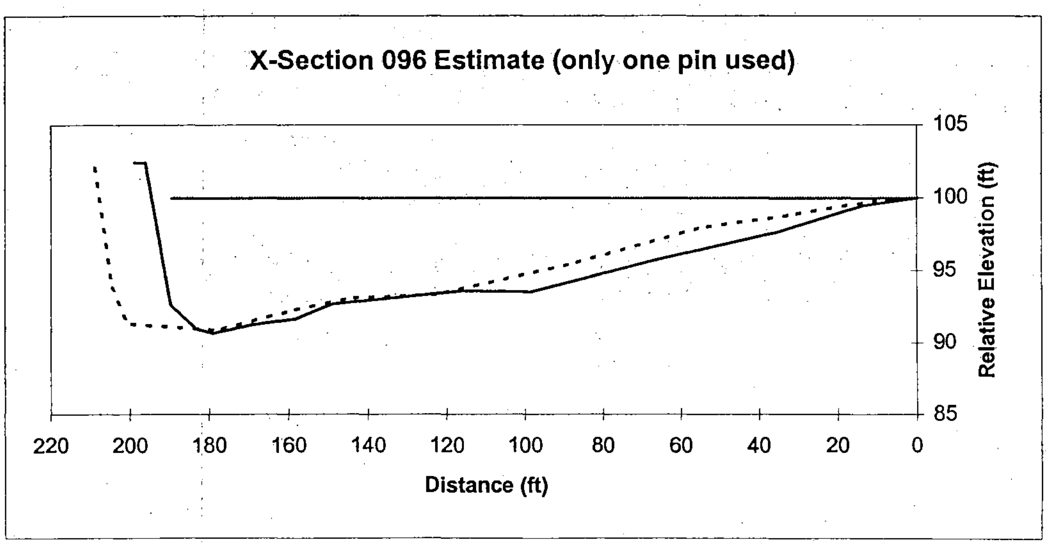

X-Section 088a1
115
110
105
100
95
90
Relative Elevation (ft)
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)

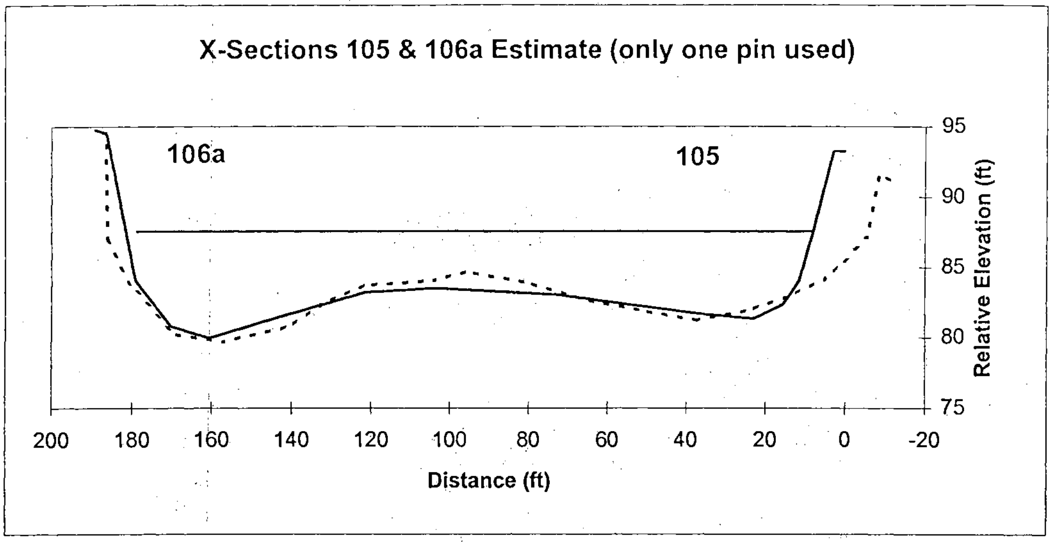

X-Section 088a2
115
110
105
100
95
90
Relative Elevation (ft)
240
220
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)

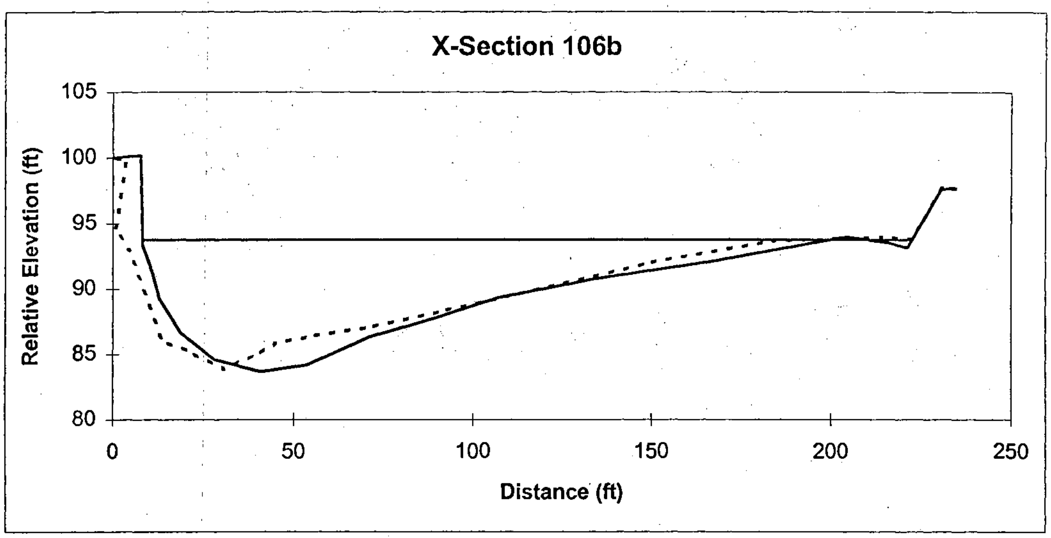

X-Section 088b
115
110
105
100
95
90
Relative Elevation (ft)
250
200
150
100
50
0
Distance (ft)

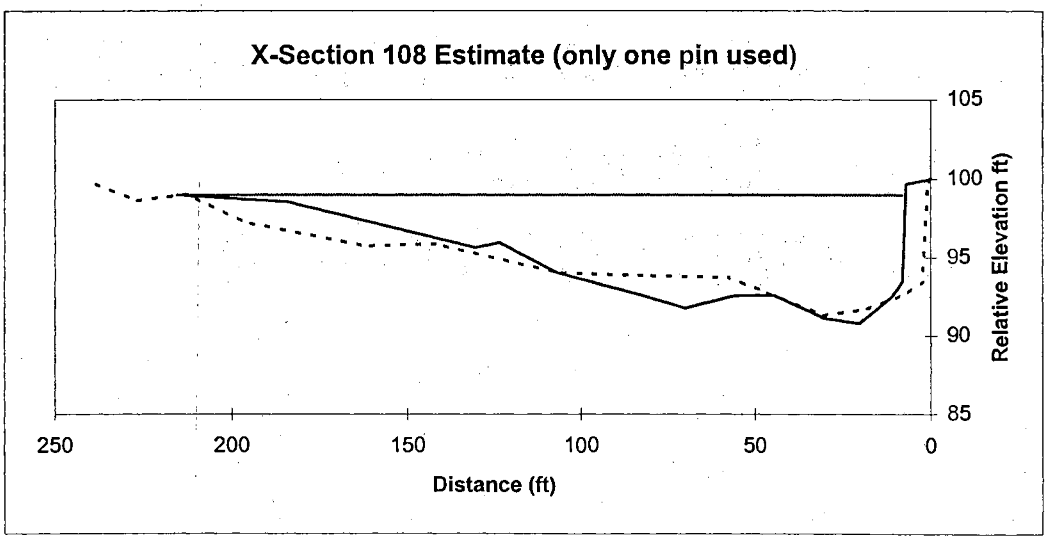

X-Section 093a Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
400
350
300
250
200
150
100
50
0
-50
Distance (ft)

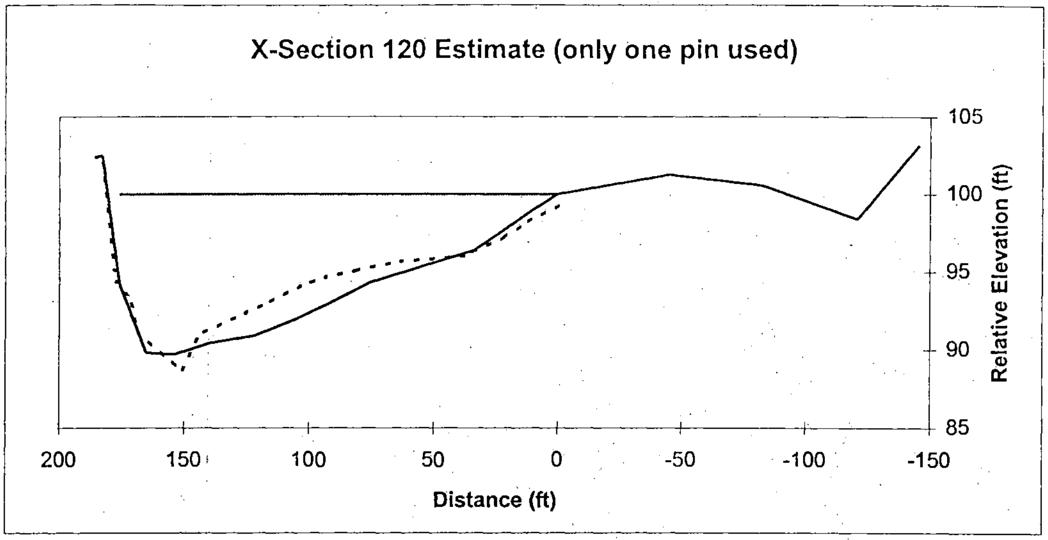

X-Section 094 Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
400
350
300
250
200
150
100
50
0
Distance (ft)

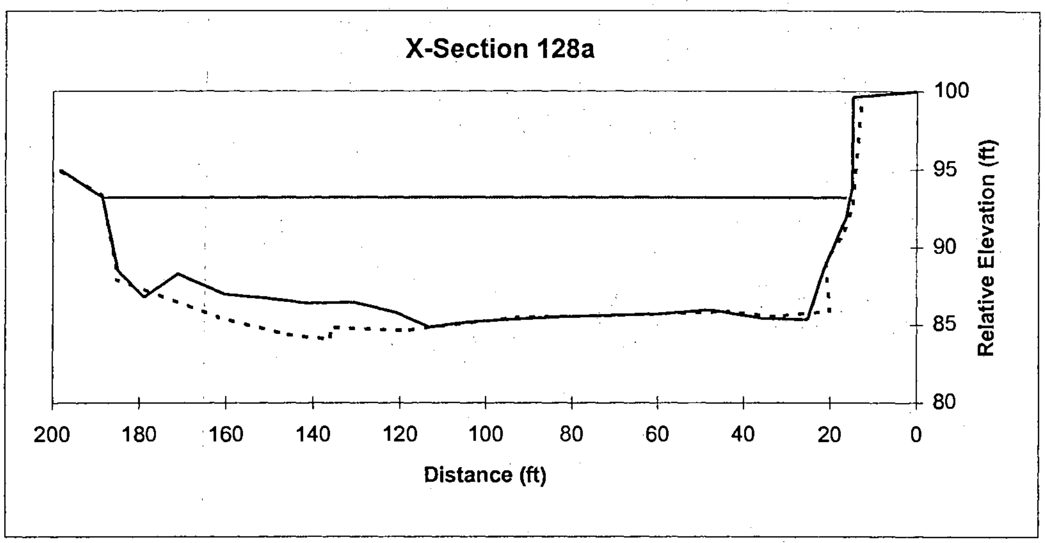

X-Section 096 Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
220
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)

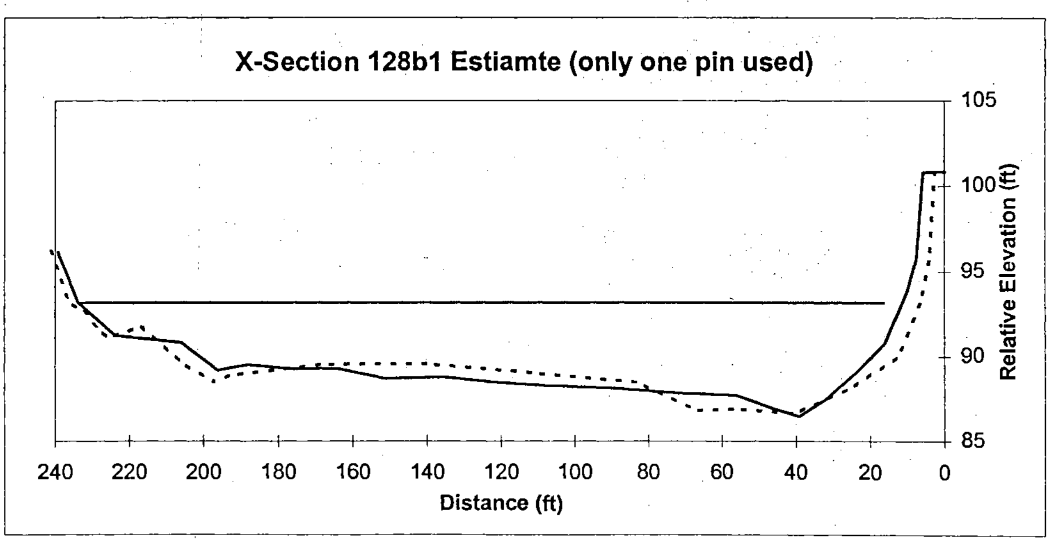

X-Sections 105 & 106a Estimate (only one pin used)
106a
105
95
90
85
80
75
Relative Elevation (ft)
200
180
160
140
120
100
80
60
40
20
0
-20
Distance (ft)

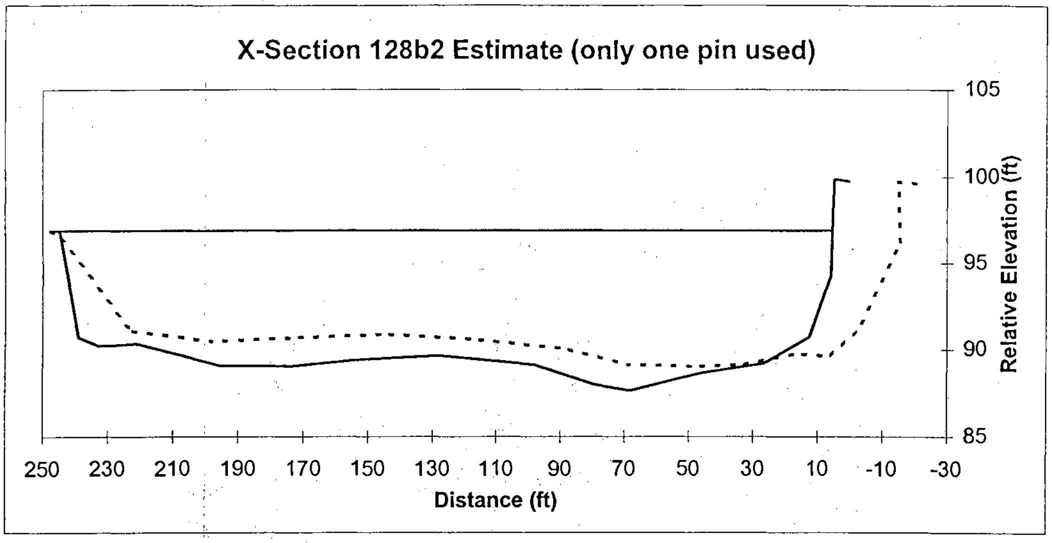

X-Section 106b
105
100
95
90
85
80
Relative Elevation (ft)
0
50
100
150
200
250
Distance (ft)


X-Section 108 Estimate (only one pin used)
105
100
95
90
85
Relative Elevation ft)
250
200
150
100
50
0
Distance (ft)


X-Section 120 Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
200
150
100
50
0
-50
-100
-150
Distance (ft)

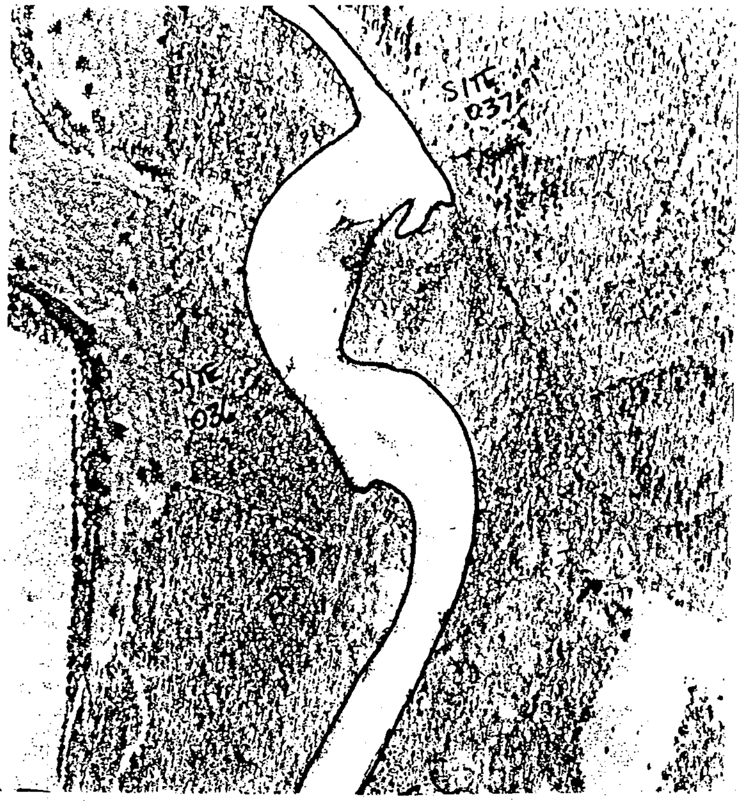

X-Section 128a
100
95
90
85
80
Relative Elevation (ft)
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)


X-Section 128b1 Estiamte (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
240
220
200
180
160
140
120
100
80
60
40
20
0
Distance (ft)

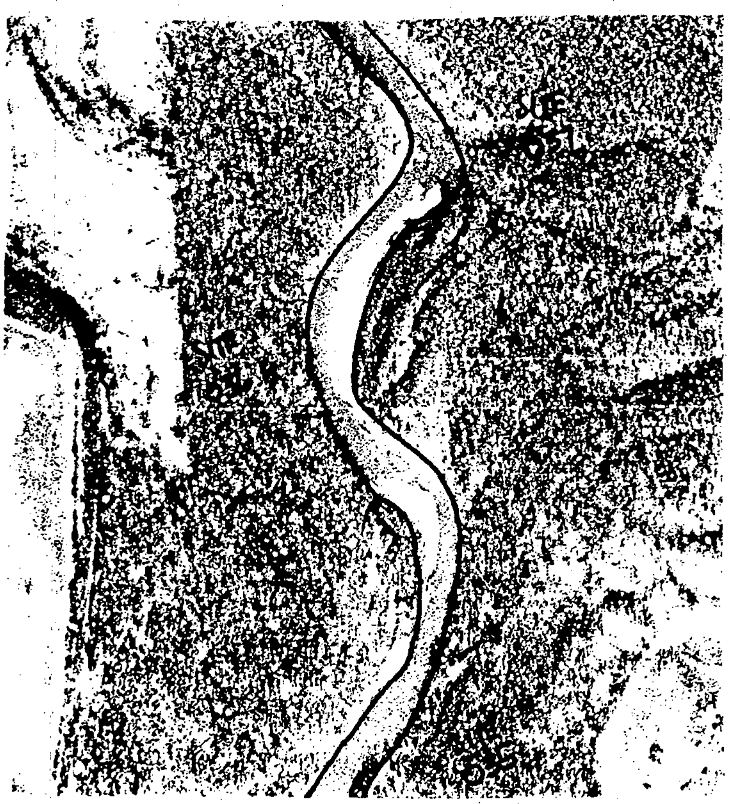

X-Section 128b2 Estimate (only one pin used)
105
100
95
90
85
Relative Elevation (ft)
250
230
210
190
170
150
130
110
90
70
50
30
10
-10
-30
Distance (ft)

APPENDIX E

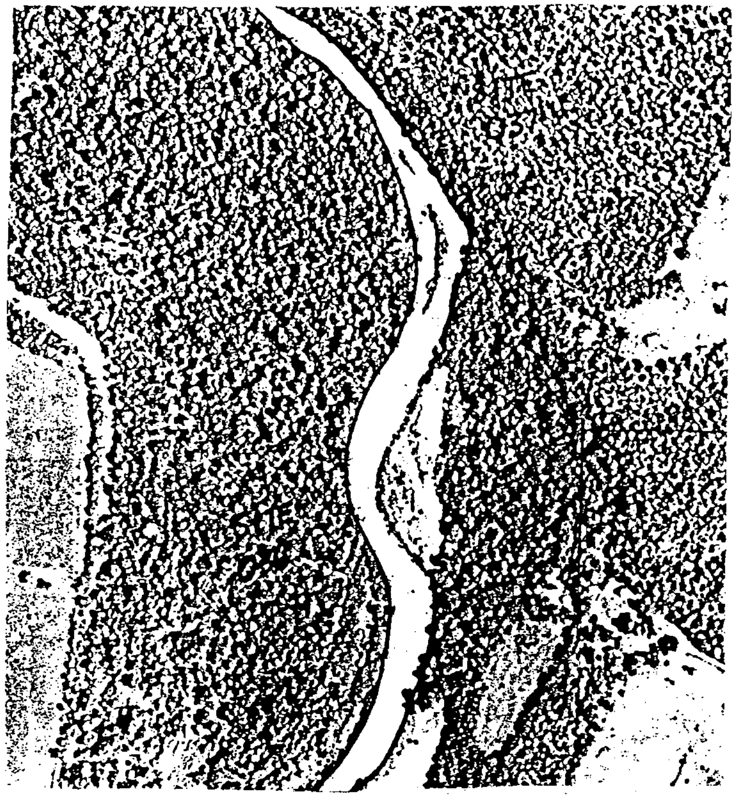
EXAMPLE OF CHANNEL CHANGES FROM 1958 TO 1979



Aerial Photograph of Illinois River in 1991



Aerial Photograph of Illinois River in 1979



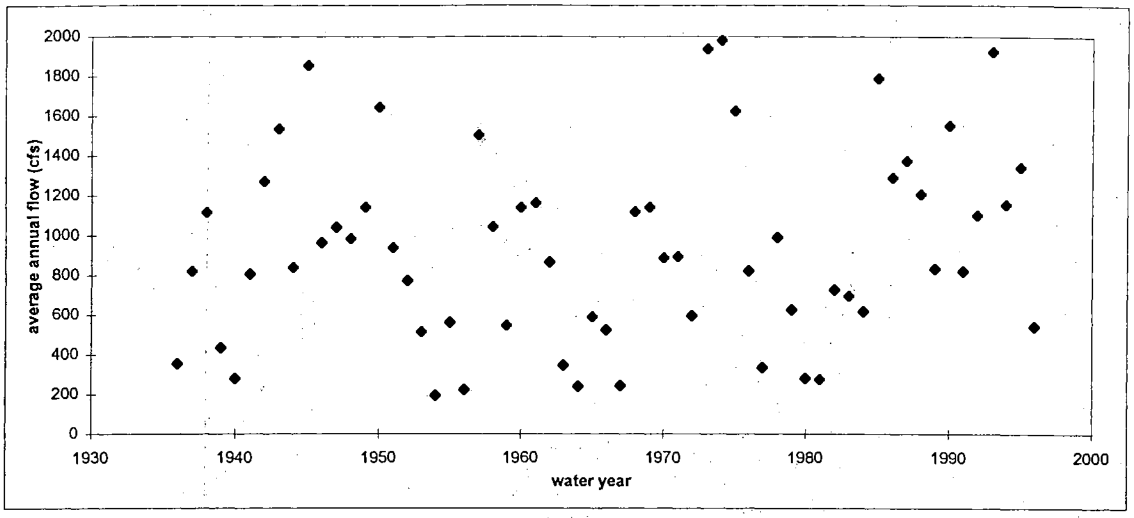
Aerial Photograph of Illinois River in 1958

APPENDIX F

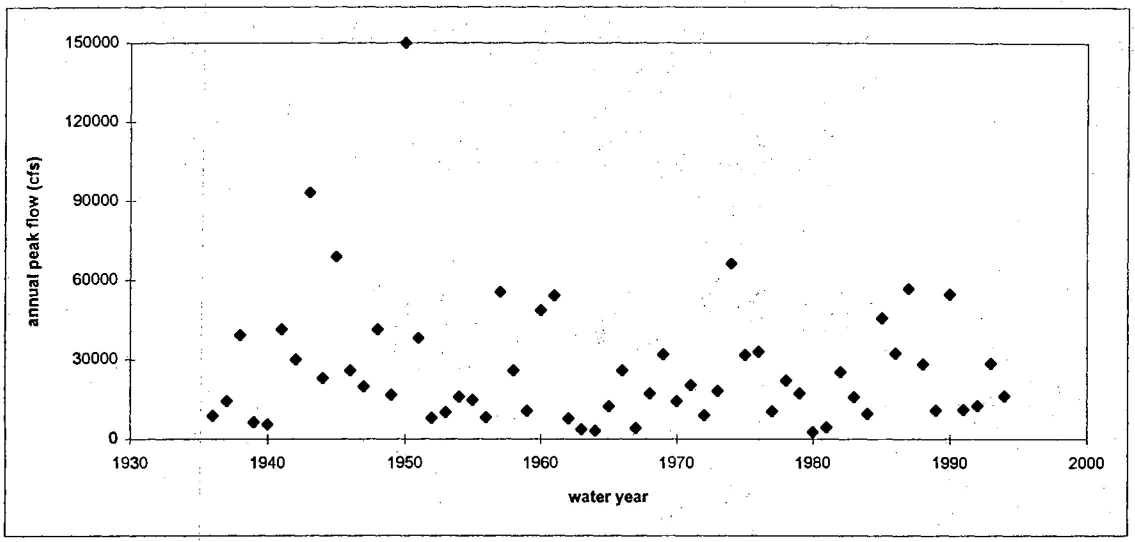
AVERAGE ANNUAL FLOWS AND ANNUAL PEAK FLOWS

FOR THE TAHLEQUAH GAGE STATION

FROM 1936 TO 1994



Average Annual Flow for Water Years 1936 to 1996



Annual Peak Flows for Water Years 1936 to 1994

Regression Statistics *** neither regression is significant at p = 0.05. ***

Average Annual Flow (cfs) Versus Time (yr)		coefficient	st error	t stat	P value
R square = 0.02	slope	803.2	123.8	6.49	2.0E-08
	intercept	4.25	3.47	1.22	0.23

Annual Peak Flow (cfs) Versus Time (yr)		coefficient	st error	t stat	P value
R square = 0.02	slope	32829	6598	4.98	6.3E-06
	intercept	-201.5	191.3	-1.05	0.30

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VITA

R. Daren Harmel

Candidate for the Degree of

Doctor of Philosophy

Dissertation: ANALYSIS OF BANK EROSION ON THE ILLINOIS RIVER IN NORTHEAST OKLAHOMA

Major Field: Biosystems Engineering

Biographical:

Personal Data: Born in Wichita Falls, Texas on October 13, 1969, the son of Dr. Bob Harmel and Mrs. Mary Ellen Harmel.

Education: Graduated from Rider High School, Wichita Falls, Texas in June 1988; received Bachelor of Arts degree in chemistry from Central College, Pella, Iowa in May 1992; received Masters of Science degree in soil physics from Texas Tech University, Lubbock, Texas in August 1994. Completed the requirements for the Doctor of Philosophy degree with a major in hydrology at Oklahoma State University in December 1997.

Experience: Reared in Wichita Falls, Texas; employed on the R.M. Harmel Ranch during summers; interned for the Soil Conservation Service, Knoxville, Iowa in 1992; employed as a graduate research assistant by Texas Tech University, Lubbock, Texas from 1992 to 1994; employed as a graduate research fellow by Oklahoma State University, Stillwater, Oklahoma from 1995 to 1997; served as the technical coordinator for the OSU Technical Staff of the Oklahoma Riparian Management Program to Protect Water Quality, Stillwater, Oklahoma from 1995 to 1997.

Professional Membership: American Water Resources Association, American Society of Agricultural Engineers, Alpha Epsilon (The Honor Society of Agricultural Engineering), Gamma Sigma Delta (The Honor Society of Agriculture).