INFLUENCE OF RIPARIAN VEGETATION ON THE KANSAS RIVER FLOOD OF 1993: AN ASSESSMENT OF STREAMBANK EROSION, DEPOSITION, AND CHANNEL MIGRATION

by

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ABSTRACT

This study explores the influence of woody riparian vegetation on the 1993 Kansas River flood. The extent of streambank erosion, deposition, and channel migration was compared between three landcover and five channel position classifications. Landcover was classified as forest land, non-forest land, and non-forest mix. Channel position was classified as straight, inside curve, outside curve, inside apex, and outside apex.

Researchers used 1992 and 1993 aerial slide photographs as the media for investigating the effects of the flood between landcover and channel position classifications. Photocopy reproductions of the slides were digitized and classified with LandCADD® R12 computer-aided design program. LandCADD® was used to organize, illustrate, and present the data. Data analysis was performed using a two-way analysis of variance with a 3 x 5 factorial design.

The greatest erosion occurred on non-forested streambanks, the least amount of erosion occurred on forested streambanks. Erosion on non-forest mix streambanks was less than non-forested streambanks and greater than forested streambanks. Findings of erosion attributable to channel position and interactions between channel position and landcover were not significant but demonstrated observed trends.

Results suggest that vegetation significantly affected the extent of streambank erosion caused by the 1993 flood. The lack of significant findings for the influence of channel position on streambank erosion shows that the flood was so large it caused extensive erosion at all channel positions. Investigation into the influence of riparian vegetation and channel position on erosion in smaller floods may be needed to provide significant results for both variables.

ACKNOWLEDGEMENTS

This thesis is an integral part of a larger project which is funded by the United States Forest Service, therefore I would first like to thank the Forest Service for their funding and support. Their assistance has enabled me to present the findings of this research at many conferences and meetings.

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Chapter 1

INTRODUCTION

Background studies

Studies indicate that woody riparian vegetation reduces streambank erosion during typical streamflow conditions. Researchers have found that vegetation reduces erosion by binding streambank soil and making it resistant to the erosive forces of water, by slowing streamflow velocity, and by trapping sediments in its stems and foliage. It is agreed that woody vegetation is the most effective vegetative type for stabilizing streambanks and reducing streambank erosion because of its typically dense root system (Hickin, 1984; Malanson, 1993; Turner, 1995; Wells, 1995). Some research also examines the effect of channel position on streambank erosion during normal streamflow conditions, indicating that some locations along a stream channel are more likely to erode than others (Leopold, Wolman, & Miller, 1964; Malanson, 1993).

While much research has examined the effects of riparian vegetation and channel position on streambank erosion during typical streamflow conditions, little research examines the effects of woody riparian vegetation and channel position on streambank erosion during flood conditions. It may be assumed that the same results would occur during flooding, but the lack of current research in this area gives reason to investigate

further. This thesis was developed to examine and provide evidence about the effects of riparian vegetation and channel position on streambank erosion during a flood.

Purpose of this study

This study investigates the influence of woody riparian vegetation and channel position on streambank erosion during the 1993 flood of the Kansas River. The primary research questions are: 1) What effect did woody riparian vegetation and channel position have on streambank erosion?, and 2) During the flood, did streambank erosion occur where it would have occurred under typical streamflow conditions?

To answer these questions, the author located areas of streambank erosion and deposition after comparing aerial photographic slide images of pre- and post-flood landscape conditions. The amounts of erosion and deposition were compared between different landcover types and channel positions to determine if those factors influenced amounts of erosion or deposition.

Statement of hypothesized relationships

The author developed and tested the following hypothesis:

1. Most erosion is predicted to have occurred along non-forested streambanks (Figures 1.1a & 1.1b), the next highest amount of erosion is predicted to have occurred along non-forest mix streambanks (Figures 1.2a & 1.2b), and the least amount of erosion is expected to have occurred along forested streambanks (Figures 1.3a & 1.3b). A forested streambank is defined as a 100 foot wide corridor next to a streambank in which

the dominant landcover type (>51%) is woody vegetation. A non-forested streambank is defined as a 100 foot corridor next to the streambank in which the dominant landcover type (>51%) is not woody vegetation (cropland, grassland, shrub/scrub land, or urban land). Finally, a non-forest mix streambank is defined as a 100 foot corridor next to the streambank in which there exists a single row of trees adjacent to a non-forest landcover type. Landcover classification for this thesis is based on the classification system used by the U.S.D.A. Natural Resource Conservation Service (N.R.C.S.) in their riparian classification project of Kansas riparian areas. A summary of their classification system is provided in Appendix A of this thesis.

2. In general, more erosion is expected to have occurred to the outside streambank than the inside streambank (Figure 1.4). Outside streambanks are defined as outside curve and outside apex. Inside streambanks are defined as inside curve and inside apex. The greatest amount of erosion is predicted to occur at the outside apex because research suggests that under typical streamflow conditions, more erosion occurs at the outside apex of a stream meander (Leopold, Wohlman, & Miller, 1964; Malanson, 1993).

3. Interaction between landcover type and channel position is expected. The greatest amount of erosion is expected to have occurred to areas classified as non-forest and defined as an outside apex.

Figure 1.1a: Diagrammatic sketch of non-forest land classification (from Kansas Water Office riparian survey definition).

Figure 1.1b: Photograph of non-forest land classification of a riparian area (photographed by Neppl).

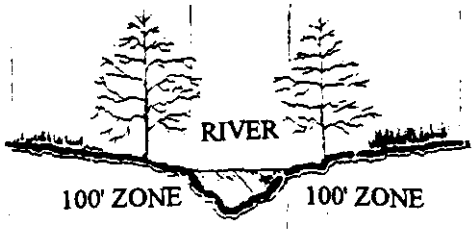


Figure 1.2a: Diagrammatic sketch of non-forest mix land classification (from Kansas Water Office riparian survey definition).

Figure 1.2b: Photograph of non-forest mix land classification of a riparian area (photographed by Neppl).

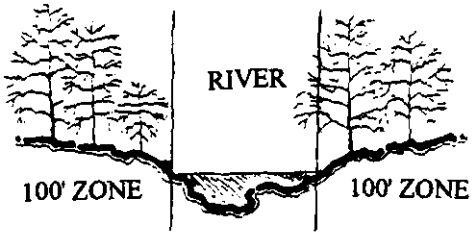


Figure 1.3a: Diagrammatic sketch of forest land classification (from Kansas Water Office riparian survey definition).

Figure 1.3b: Photograph of forest land classification of a riparian area (photographed by Neppl).

Significance of this research

This study is significant because it investigates the relationships between riparian vegetation on streambank erosion during a flood with a 100 to 500 year recurrence interval[1]. Little research exists about the effects of riparian vegetation on floods of such magnitude. This study expands on related research of Hickin (1984), Malanson (1993), Turner (1995), and Wells (1995), about streambank erosion and riparian vegetation.

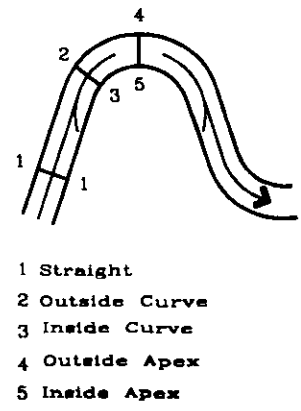


Figure 1.4: Diagram of channel position classification used for this study (based on channel position definitions by Leopold, Wolman, & Miller, 1964).

This study contributes to research in riparian landscapes and provides information beneficial to landowners in and around riparian corridors. Streambank erosion is a major resource management problem because it contributes to sediment loads in streams and causes extensive property damage. Land planners could take this information into consideration when planning land uses along riparian corridors. If results support the hypothesis, property owners will also benefit because they could learn that preserving or maintaining trees along riparian areas is beneficial. Other public agencies conducting work within riparian corridors would also benefit for the same reasons.

[1] A flood discharge that has a 100-year recurrence interval is so large that a discharge of equal or greater annual peak discharge is expected only once in any 100-year interval. In a given year, the annual peak discharge has a 1 in 100 (1%) chance of equaling or exceeding the 100-year recurrence interval.

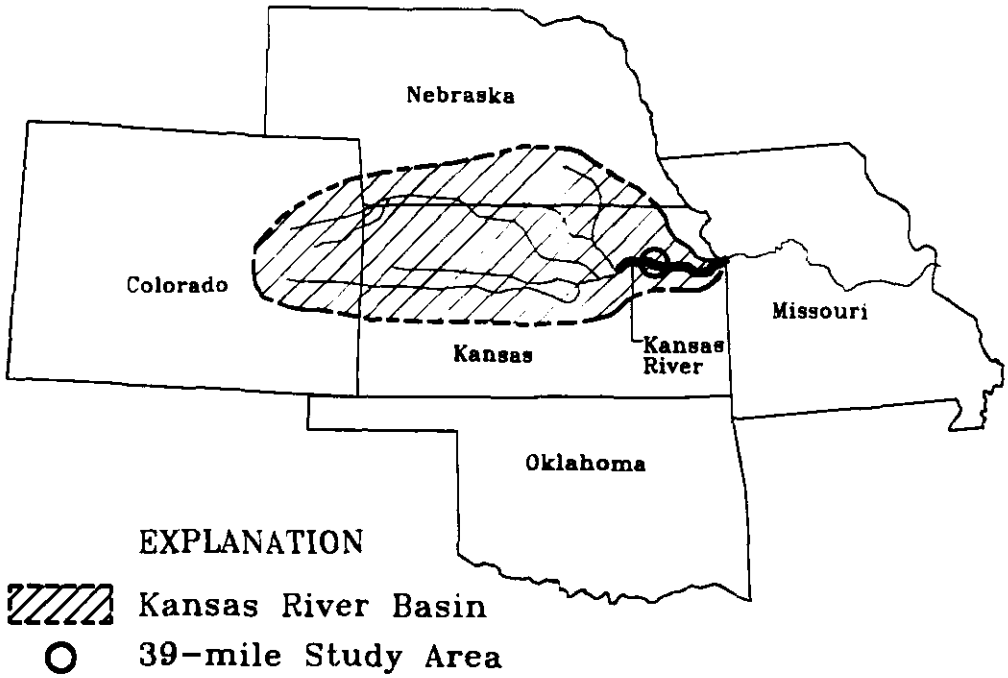


Figure 1.5: Regional map of the Kansas River Basin.

Study area

The Kansas River Basin (Figure 1.5) covers approximately 60,000 square miles of northern Kansas, southern Nebraska, and eastern Colorado. The Kansas River begins at the confluence of the Smoky Hill and Republican Rivers near Junction City, Kansas. The river then flows eastward to Kansas City, Kansas where it converges with the Missouri River at the Kansas/Missouri state line. The area of study is a 39 mile portion of the Kansas River near Manhattan, Kansas.

Physiographically, the Kansas River begins in the Flint Hills and flows eastward to the deciduous hardwood forests of eastern Kansas. Floristically, the riparian areas along the river consist of many woody plant species, including *Populus deltoides* (Eastern

Cottonwood, *Acer saccharinum* (Silver Maple), *Salix* species (Willows), *Celtis occidentalis* (Common Hackberry), and *Platanus occidentalis* (American Sycamore).

Key terms

A number of terms and phrases are used throughout this thesis which may not be common to all readers. A list of these terms, phrases, and their definitions is provided below.

1. **Riparian**: A riparian area is an area of land which is directly influenced by permanent water (rivers, for this study).
2. **Streambank**: Defined as the line where the river water level meets land.
3. **Streambank erosion**: Defined as the degradation of a streambank by soil erosion caused by the forces of streamflow. For this study, erosion is defined as the linear movement of the streambank upland and away from the river centerline.
4. **Streambank deposition**: Defined as the aggradation of a streambank by soil deposition caused by the forces of streamflow. For this study, deposition is defined as the linear movement of the streambank toward the river centerline.
5. **Channel migration**: Lateral movement of a stream or river channel across the floodplain caused by erosion and deposition of streambanks.
6. **Left/ right side of streambank**: While looking downstream, the left streambank is the bank to the left, the right streambank is the bank to the right.

The remainder of this thesis reviews relevant literature to the study, develops the basis for the experimental method, describes the research method, discusses results, and provides conclusions and recommendations based on the results.

Chapter 2

LITERATURE REVIEW

Effects of floods on the landscape

Flooding rivers have a great impact on the landscape, causing considerable change to both natural and human-influenced landscapes such as agricultural land and human dwellings (Figure 2.1). Much of the change is perceived as damage. Conflict arises when humans encroach on the natural system of rivers and floodplains. Many towns, cities, and agricultural fields are located in the floodplains of rivers and streams and are damaged when flooding occurs.

Figure 2.1: Aerial view of Mississippi River flooding along Highway 367, West Alton, Illinois (Cover photo, K.L. Wahl, K.C. Vining, G.J. Wiche, 1993).

Agriculture is an appropriate land use for the fertile fields of floodplains because during a flood, the loss of land and crops is less than that of human lives or structures. However, agricultural land is also greatly affected by floods. Flood waters drown crops, erode arable land, and deposit tons of sediment on fields often rendering them unusable for planting crops.

Crop inundation by flooding cannot be entirely prevented. During a flood, excess water floods crops within the floodplain and alters terrain by soil erosion and deposition. An example of the dynamic process of the riparian system, this occurrence is difficult to alter. Dikes and levees are built to prevent flooding of adjacent land and reduce damage to those areas. However, by constricting stream flow to the river channel and not the floodplain, dikes and levees may create greater problems downstream. Streamflow is increased to above what the natural floodplain can contain (Figure 2.2), resulting in greater flooding, erosion, and deposition downstream of the levee.

Sand and silt deposition in the floodplain and river channel is another process that cannot be entirely prevented. Streamflow deposits soil particles when the flow velocity can no longer suspend them. The dynamics of the riparian system are such that soil particles are eroded at one location and deposited downstream where velocities slow down. Finally, soil erosion by streamflow is another impact that can never be negated completely but can sometimes be reduced. Turner (1995) notes that although there are no practical methods to prevent streambank erosion, there are often ways to mitigate the full extent of the impacts.

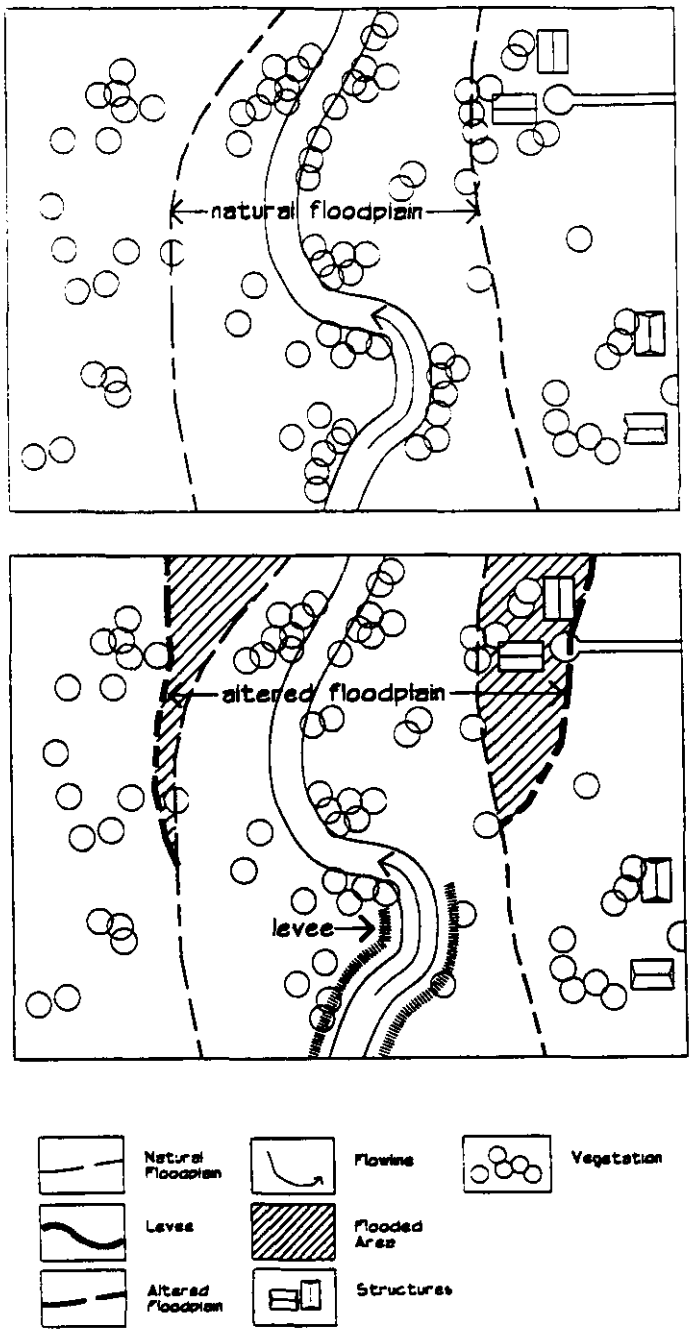


Figure 2.2: Levees alter the natural floodplain of rivers, causing greater erosion downstream than would have occurred under normal conditions.

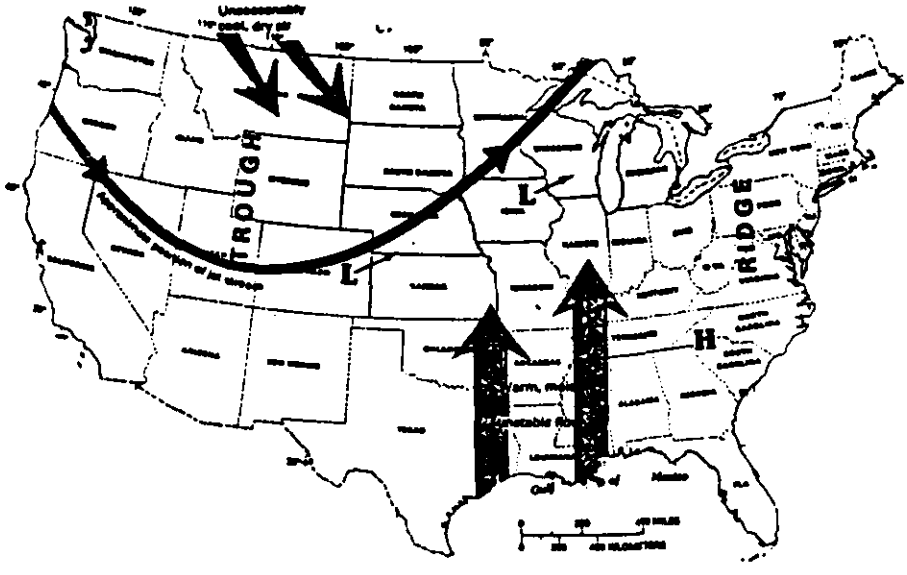
Impacts of the 1993 flood

The 1993 flood of the Kansas River (Figure 2.3) was devastating to the region. Flood damage in the Kansas River and the Mississippi River Basins was greater than in any other flood disaster in United States history. Property damage alone exceeded $10 billion. Many people suffered loss of property, disrupted business, and personal trauma (C. Parrett, N.B. Melcher, & R. W. James, Jr., 1994). Millions of acres of agricultural crop land were inundated for weeks during the summer of 1993.

Flooding inundated areas that had not been affected by previous floods. Record peak streamflow discharges were recorded by United States Geological Survey (U.S.G.S.)

Figure 2.3: Aerial view of the Kansas River flood during August, 1993 (Photograph courtesy of the Pottowatomie County Consolidated Farm Service Agency).

stream flow gaging stations throughout the upper Mississippi River Basin. From mid June through early August, 154 gaging stations recorded stream flows equal to or greater than the 10-year recurrence interval. Forty-one stations recorded peak discharges greater than their record discharges. Forty-five stations recorded peak discharges over the 100-year recurrence interval (Parrett, *et al.*, 1994).



EXPLANATION

□	Convergence zone: area of intense rainfall
TROUGH	Stationary upper atmospheric low-pressure area
RIDGE	Stationary upper atmospheric high-pressure area
H	Stationary surface high-pressure
L	Transient low-pressure storm system

Figure 2-4: Weather pattern responsible for causing the Midwestern floods of 1993 (Wahl *et al.*, 1993).

Climatic factors

The magnitude of the 1993 Kansas River flood was caused in part by persistent wet-weather patterns across the upper Midwest when weather fronts collided during that summer (Figure 2.4). An eastward-flowing jet stream extending from central Colorado northeastward across Kansas to northern Wisconsin caused the persistent wet-weather pattern (National Weather Service, cited in Parrett, *et al.*, 1994).

A weather-front convergence zone formed across the upper Midwest during the spring and summer of 1993. The jet stream carried moist, warm air from the Gulf of Mexico northward where it collided with cooler, dryer air from Canada. The collision created unstable air masses and heavy rains that persisted throughout the spring and summer of 1993. Heavy summer rains fell on soil already saturated from heavy spring rainfall and caused extensive flooding throughout the Kansas River Basin.

Reservoirs and flood control

The Kansas River Basin is the largest basin (by area) under flood control in the Mississippi River Basin. Flood-control reservoirs control streamflow from all of the major tributaries of the Kansas River basin and approximately 85 percent (50,840 square miles) of the total drainage basin area. Eighteen reservoirs with a flood control capacity of 7,390,000 acre-feet[2] provide flood protection for the Kansas River Basin and the Missouri River downstream (Figure 2.5). Sixteen reservoirs control streamflow along the Kansas River upstream from the 39 mile study area in this thesis.

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[2] An acre-foot is a volume of water that would cover one acre to a depth of one foot, equal to 43,560 cubic feet.

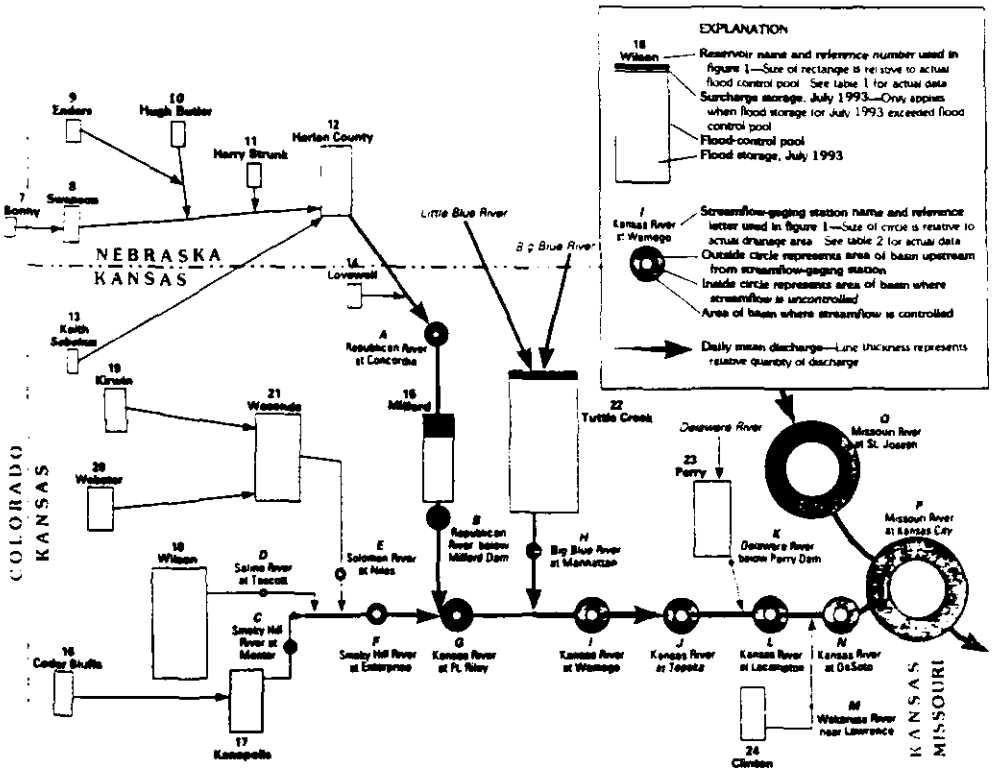


Figure 2.5: Sixteen flood-control reservoirs control streamflow above the Kansas River study area (USGS Circular 1120-B, 1994).

The US Army Corps of Engineers states that the reservoir system reduced the impacts of the flood. From April 1, 1993 through August 1, 1993, the Kansas River Basin reservoir system stored approximately 4,500,000 acre-feet of flood water. This resulted in lower peak discharges along the river, for example, the peak discharge at De Soto, Kansas was lower than it would have been without reservoir storage. The predicted uncontrolled peak discharge was 142,300 cubic feet/second compared to the observed peak discharge of 76,800 cubic feet/second (Perry, 1994) (Figure 2.6).

Flood control reservoirs stored large volumes of water and reduced flow discharges on the Kansas River at the time of peak rainfall. After peak flooding, water was released maintaining a higher flow during a longer time period than if the same flood

occurred with no flood control reservoirs. The purpose of flood control reservoirs is to reduce peak flood discharges and release stored flood water evenly across time, the net effect is reduced area of maximum flooding. Peak river flow levels could have been higher if no flood-control reservoirs existed.

The reservoir system may not have totally benefited the riparian landscape. It is possible that the reservoir system caused greater erosion than if no system existed. The prolonged release of flood waters after peak flooding resulted in increased streamflows of the Kansas River for months after peak flooding in the summer of 1993 (Figure 2.6). By releasing flood waters into the Kansas River long after the flood, greater volumes of water flowed in its channel possibly causing greater erosion to the already saturated streambanks.

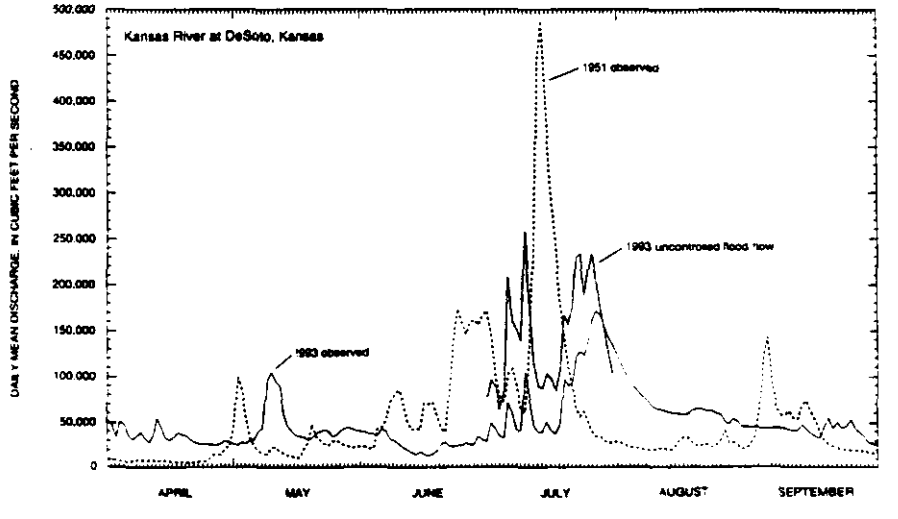


Figure 2.6: Observed and simulated uncontrolled discharges in the Kansas River at DeSoto, Kansas, July 1993 (Wahl, *et al.*, 1993).

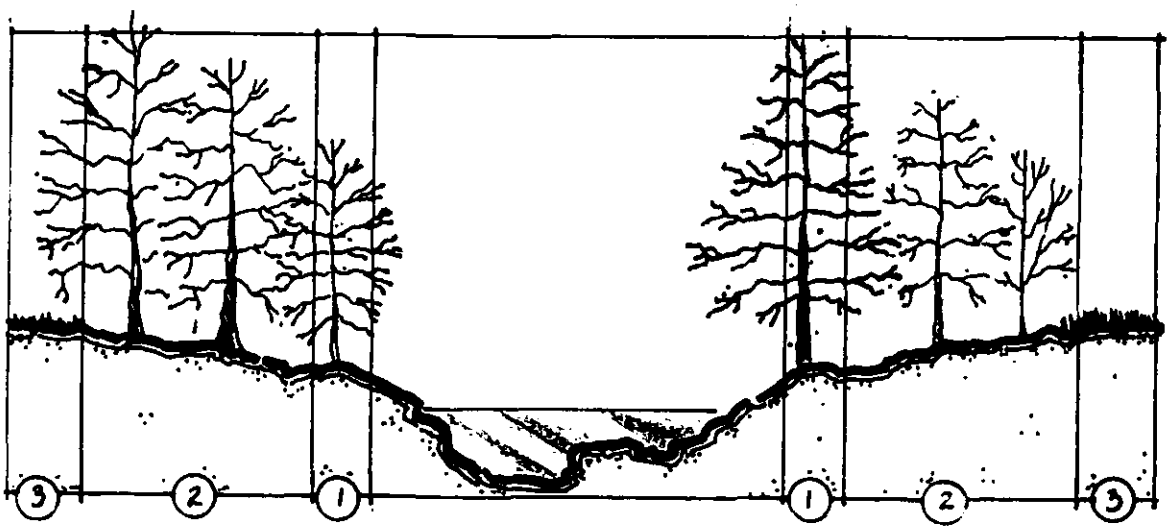
Riparian Vegetation

Riparian vegetation reduces streambank erosion and promotes streambank development. Much of the research has focused on streambank erosion under normal streamflow conditions, however, the effects of floods are less studied. While visual observations may suggest beneficial effects of trees on preventing streambank erosion during floods, there is a lack of information reported in the scientific literature about the effects of riparian vegetation on floods. Research on riparian vegetation, stream dynamics, and the relationship between riparian vegetation and stream dynamics was examined in development of this study.

Riparian vegetation corridors (Figure 2.7) are important landscapes. They serve as the interface between terrestrial and aquatic ecosystems and possess an unusually diverse array of species and environmental processes (Naiman *et al.*, 1993). In this study, riparian corridors are defined as the landscape which encompasses the stream channel and the part of the terrestrial landscape to the uplands where vegetation may be influenced by high water tables, flooding, and water retenting soils (Naiman *et al.*, 1993). Many plant and animal species flourish in riparian corridors and animals use them for movement within drainage basins (S.V. Gregory, F.J. Swanson, W.A. McKee, & K.W. Cummings, 1991). Riparian corridors are dynamic systems that adjust and evolve with changing land uses and climatic conditions. Healthy riparian corridors are beneficial to streams not only because they stabilize streambanks and reduce soil erosion, but they also filter agricultural pollutants from upland surface runoff. For example, when riparian vegetation is removed, more water flows into the stream channel increasing flow volumes which causes streambank erosion.

Recommended riparian vegetation corridor widths

Welsch (1991) describes recommended riparian forest buffer characteristics with the primary purpose of intercepting surface and ground waters for removing or buffering the effects of pollutants (Figure 2.8). The recommended widths are subdivided into two zones that begin at the streambank edge and move upland from the stream channel. The recommended zones are Zone 1, Undisturbed Forest: 15 feet wide consisting of maturing trees, and Zone 2, Managed Forest: 60 feet wide consisting of trees, shrubs, and groundcovers that remove the nutrients from ground and surface water before they enter



EXPLANATION

① Zone 1, Undisturbed Forest: 15' wide
② Zone 2, Managed Forest: 60' wide
③ Zone 3, Adjacent landuse

Figure 2-7: Diagram of a riparian corridor as defined in Welsch's study (1991).

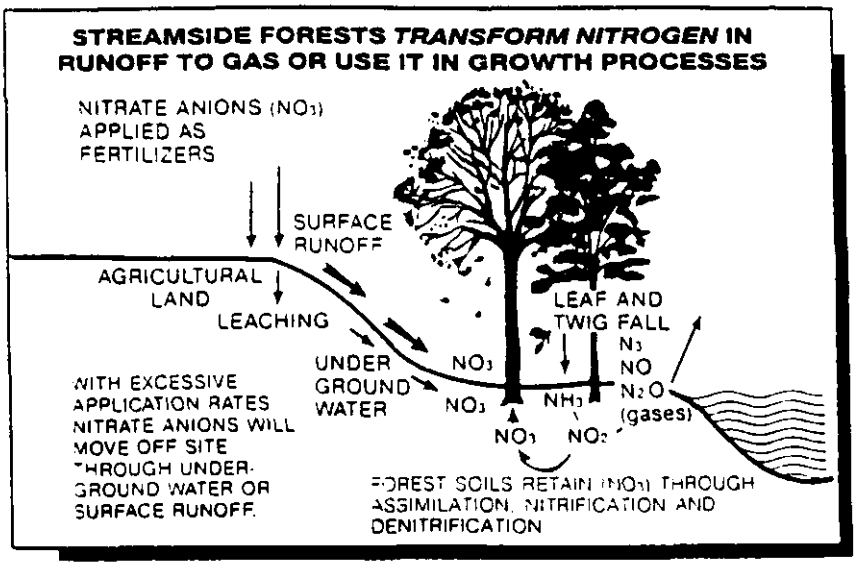


Figure 2-8: Roots of woody vegetation remove pollutants from agricultural runoff (from Welsch, 1991, p.8).

the stream. Welsch's study establishes guidelines about recommended riparian forest buffer widths for the purpose of removing agricultural chemicals from storm runoff, but does not examine their influence on streambank erosion.

Riparian vegetation and streambank erosion

Acres of arable land along the Kansas River eroded during the flood of 1993 resulting in a loss of both income to landowners and in total agricultural production. It would be beneficial to prevent or reduce similar losses when possible. Research shows one method of preventing extensive erosion is to revegetate the streambank (Roseboom, 1995; Turner, 1995; Wells, 1995).

Researchers have found that streambank vegetation reduces the erosive effects of streamflow and promotes deposition of suspended sands and silts, thus building and strengthening streambanks (Hickin, 1984; Meyers, 1989; Smith, 1976). Plants trap sediment with their leaves, stems, and exposed roots. Sediments collect and fill voids in the roots and stems allowing other plants to propagate in the deposited soils.

Malanson (1993) states that riparian vegetation protects streambanks from erosion by reducing the tractive force of water, protecting streambanks from the direct force of water, and inducing deposition of soil particles. These factors aid streambank development when they work together.

Other researchers have examined the effects of vegetation stabilizing streambanks. Hickin (1984, p. 111) found that "vegetation may exert significant control over fluvial processes and channel morphology through five mechanisms: flow resistance, bank strength, bar sedimentation, formation of log jams and concave-bank bench deposition." Hickin conducted an experiment in which the factors of water discharge, water surface slope, bend curvature, size of bank materials, and bank heights were held constant to compare the difference in erosion between a river migrating through an unvegetated or cultivated floodplain and one meandering through a naturally forested floodplain. Results show that a river migrating through an unvegetated or cultivated floodplain eroded streambanks at almost twice the rate as one meandering through a naturally forested floodplain.

Smith (1976) studied the relationship between vegetation and streambank erosion by simulating natural erosion conditions in a specially designed box allowing examination

of the effect of roots of herbaceous and woody plants on erosion. Results suggest that plant roots stabilized the soil enough to provide 20,000 times the resistance to erosion than non-vegetated banks (Smith, 1976).

Meyers (1989) also studied the effects of vegetation on streambank stability. Four factors of vegetation that contributes to streambank stability are identified in Meyers' work: density of plant material, species diversity, vigor of plant material, and reproductivity of plant material. It is explained that riparian vegetation has an unlimited supply of water to support its growth and therefore develops thick mats of roots that bind the soil. Root mats increase in density with proximity to the channel therefore providing maximum protection from streambank erosion in areas where streamflow is most constant.

Stream dynamics

Rivers and streams are dynamic in nature, migrating across their floodplains over long periods of years. Stream dynamics has been greatly documented and can be observed by comparing aerial photographs of riparian landscapes from successive years (Hickin, 1984; Kalliola and Puhakka, 1988; Naiman *et al.*, 1993). The dynamic nature of streams and rivers limits the feasibility of locating certain land uses in floodplains. Any land use located in a floodplain runs the risk of being damaged by flood waters. For example, the record floods of 1993 inundated much of the Mississippi and Kansas River basins and caused property damage greater than $10 billion throughout the Midwest (Parrett *et al.*, 1994).

Several authors report factors influencing streambank erosion and suggest that it can be predicted. Malanson (1993) discusses the meandering process of river bends noting that meanders migrate because of the hydrology of the bends. Extensive erosion typically occurs at the outside bend where flow velocities are greatest; therefore meanders migrate outwardly forming cutbanks at the outside bends. Along the inside bends where flow velocities are slower, soil particles deposit and form sandbars. This research provides the base from which predictions of streambank erosion and deposition were made for this study.

Alonso and Combs (1990) conducted research on streambank erosion caused by bed degradation. They define bed degradation as erosion of the river bed that causes instability and collapse or mass failure of the banks (Figure 2.9). They also found that vegetative protection is a principal factor affecting streambank stability, indicating that vegetated streambanks erode less than unvegetated streambanks.

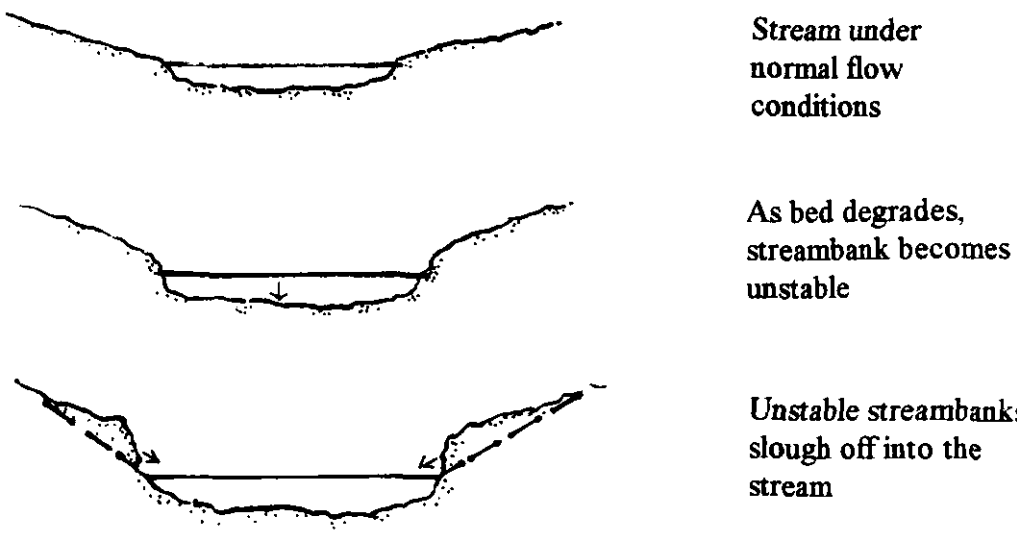


Figure 2-9: Diagram of streambank erosion caused by bed degradation (Alonso and Combs, 1990).

Chapter 3

METHODOLOGY

Tools of investigation

The author used aerial photographic slides as the media to examine the effects of the 1993 Kansas River flood (Refer to Appendix B for an example of an aerial photographic slide image of the Kansas River). Aerial photos were chosen because they provide an historical record of the condition of riparian areas along the river. Changes can be assessed by comparing photos taken at subsequent dates (Hickin, 1984). Aerial photographic images are the chosen media by which pre- and post-flood conditions can be compared because features such as riparian vegetation and streambank edge can be identified.

The Consolidated Farm Service Agency[3] (C.F.S.A.) offices of Riley and Pottowatomie Counties provided slide images of the Kansas River study area. Slides photographed in December 1992 and 1993 were chosen so that the effects of the 1993 flood could be examined. A benefit of using aerial slide images photographed in the winter is the lack of foliage on the trees allows the streambank edge to be easily seen. Each slide covers approximately two one-mile sections (Figures 3.1 & 3.2). For organization purposes and cross referencing, slides are classified by township, range, and section.

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[3] Images of approximately 20 per cent of the Kansas River in Riley County was provided by the Riley County C.F.S.A. and approximately 70 per cent of the river was provided by the Pottowatomie County C.F.S.A.

Two methods of using the slides were compared. The first method was projecting the images onto a 24" x 36" mylar sheet and tracing the streambank edges. The process is as follows: the sheet of mylar tracing film was first taped to a firm vertical surface and the projector was placed so that the projected slide image fit onto the mylar sheet. The author traced the following information from the image: street/ road centerlines and intersections, land section lines, and streambank edges. Vegetation types and corridor edges were also noted. The information was labeled on the mylar accordingly, for example: road names, landcover types, and prominent landmarks were identified and noted. Road centerlines were traced because they allow accurate calibration of the digitized slide image to the base mylar sheet during the digitization process.

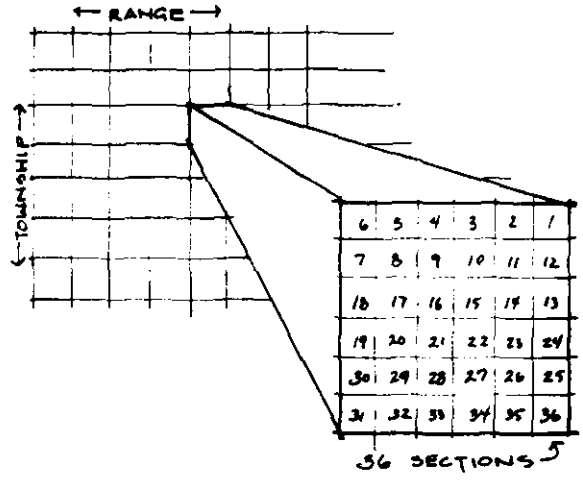


Figure 3.1: The public land survey divides land into ranges, townships, and sections.

The traced images were then digitized with a Calcomp® digitizing tablet into a LandCADD® R12 computer aided drafting and design (C.A.D.) environment. The C.A.D. program was chosen because it allows accurate organization and graphic presentation of spatial data.

Figure 3.2: Example of an aerial photographic slide used in this study. Refer to the United States Geologic Survey topographic quad map for comparison.

The primary benefit of this method was that the images were relatively large (approximately 24" x 36") therefore great detail about the streambanks was accurately digitized. The negative aspects of this method are listed below:

1. It is time consuming. The entire process of tracing and digitizing takes approximately forty-five minutes per slide image.
2. The slide images were out of focus around the edges making it more difficult to distinguish different landcover types and delineate the streambank edge within that portion of the image. Tracing accuracy, therefore, can not be guaranteed.
3. The slide projector must be placed perpendicular to the tracing surface otherwise the image is distorted. It is very difficult to align the projector correctly.
4. If the projector is disrupted, the image shifts out of alignment and is difficult to realign.
5. The mylar sheets are large and difficult to handle and store.
6. After tracing, the only record of the slide image is the hand-drawn mylar copy of street/ road information, landcover types, and streambank edges. If questions arise about a particular slide image, the researcher must go to the C.F.S.A. office to obtain the original slide. This requires a lot of time and effort and is not an efficient way of getting further information about a particular slide.

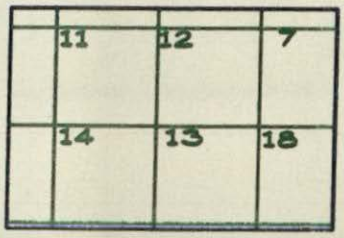
The second method of investigation involved digitizing an 11" x 17" color photocopy of the slide image into the C.A.D. system. This method proved to be much more cost-efficient than the first because it takes less time to perform and requires less expensive materials. Benefits of this method are:

1. Digitizing the photocopies took fifteen minutes per slide image.
2. This method is also more accurate because the photocopied image is clearer than the projected image and is easier to digitize.
3. Photocopies are much easier to handle and store than the large mylar sheets.
4. Photocopies serve multiple purposes as they were used both as the image to be digitized, reference for landcover classification, and as maps for field work. The photocopies were labeled according to the date they were photographed and their public land survey location by range, township, and section.

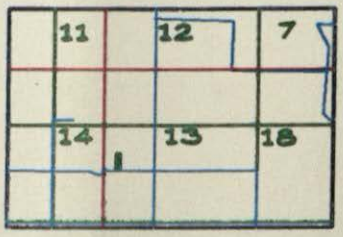
To ensure the most accurate information possible, only those slides which contained the river in the center of the image were used because the center of the image is generally the most accurate. The edges of the image tend to be distorted and not to scale because of the curvature of the surface of the earth and the tendency for photographic lenses to have poor focusing power in the margins of the view field.

Because the photocopies are not to a given scale, it is necessary during the digitization process to calibrate them to a standard base map to enable accurate analysis of the images. The process is outlined on the following page.

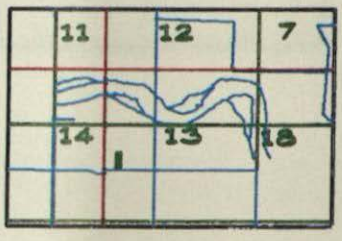
Data collection process



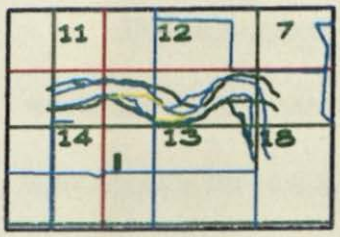
1. A basemap for digitizing the slide images was created by drawing section, range, and township lines in C.A.D. Square mile sections were created by drawing red section lines 5,280 units (representing one mile) on center to create the square mile grid. Range and township lines were differentiated from section lines by coloring every sixth section line yellow. Sections, range, and township lines were labeled according to the area to be digitized.



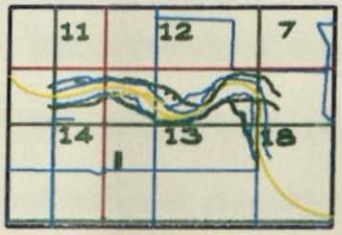
2. United States. Geologic Survey 7.5 minute topographic quadrangle maps were digitized to serve as base information for digitizing slides. Only information useful in calibrating slide images was digitized including roads, railroad tracks, and mile section lines.



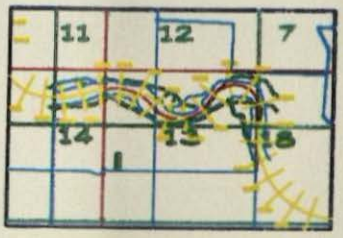
3. 1992 slide images of the Kansas River were securely placed on the digitizing tablet and calibrated to the C.A.D. base map. The streambank edges were then digitized.



4. The same process was followed for the 1993 slide images and streambanks. Notes as to landcover and channel position conditions were made on the drawing as needed at the time the images were digitized.



5. Once all 1992 and 1993 slide images were digitized a river centerline was interpolated on the C.A.D. drawing of the streambanks using the 1992 streambanks as a guide. The centerline is used as a reference line for landcover and channel position classification. The 1992 streambanks were chosen as the guide because classification was based on pre-flood conditions.



6. Data collection points were created by inserting line segments at regular 500 foot intervals along the centerline. The line segments were labeled in numerical order starting at the west end of the centerline. A total of 174 line segments were inserted along the centerline in the study area. Landcover and channel position classification was done using the aerial photographs as a guide. Erosion and deposition amounts were estimated by measuring the perpendicular distance from the 1992 streambank to the 1993 streambank along the inserted line segments. Data was collected for both the left and right side streambanks and inserted as attributes (a function of C.A.D.) at every data collection point. Attribute information was then extracted from C.A.D. and inserted into the SAS statistical program for analysis.

C.A.D. drawing organization

Digitized images were organized by separating graphic information into layers within the C.A.D. environment. For example, 1992 streambanks were placed on their own layer to allow the various components of the images to be manipulated independently. Streambank information from a 1992 image can be colored differently than the 1993 streambank information allowing the two to be easily distinguished when analyzing an image. Different layers can be turned on or off depending on what information is needed. Overlaying different layers of digitized information allows relationships between variables of landcover, channel position, streambank erosion and deposition to be determined.

Chapter 4

ANALYSIS OF RESULTS

Data was collected from a total of 204 (103 right side and 101 left side) streambank points (Tables 4.1 & 4.2). Analysis was conducted by two way analysis of variance (ANOVA) with a 3 by 5 factorial design. Data from each side of the river was examined separately generating results for both the left and right side streambanks. In Tables 4-1 and 4-2, class is defined as the independent variables of position and landcover. Levels define the number of each independent variable, each of which is given a value as illustrated in column labeled *values*.

General Linear Models Procedure Class Level Information *Right side of stream*						
Class (Independent variable)	Levels	Values				
Position	5	1	2	3	4	5
Landcover	3	1	2	3		
Number of observations in data set = 103						

Table 4.1: This table illustrates the information for right streambank.

General Linear Models Procedure Class Level Information *Left side of stream*						
Class (Independentvariable)	Levels	Values				
Position	5	1	2	3	4	5
Landcover	3	1	2	3		
Number of observations in data set = 101						

Table 4.2: This table illustrates the data for the left streambank.

Analysis of separate right and left streambank data sets

Each side of the streambank was analyzed independently because paired observations exist for the left and right streambanks at every data collection point. Paired observations are defined using the following example: In a channel meander, water flows faster at the outside curve than the inside curve (Figure 4.1). Although the observations at each side of the curve are not identical, they are somewhat related because of the fluvial dynamics of streamflow. Because they are related, they are considered paired observations.

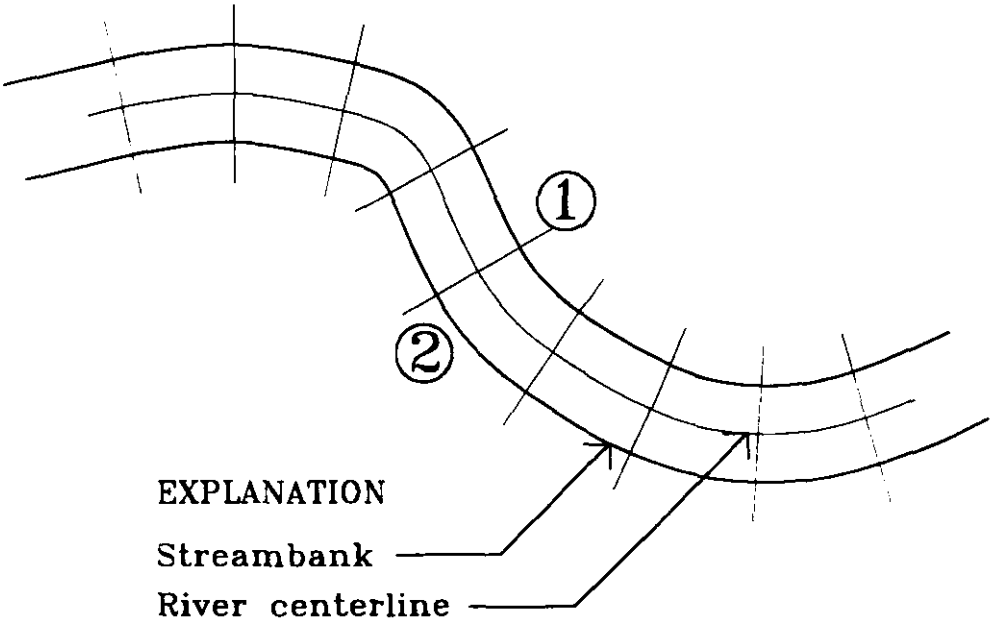


Figure 4.1: ① and ② are paired observations.

Left side analysis

One hundred one data points were collected from the left side of the river (Table 4.3). The results were classified as follows: 37 points were classified as forest land, 46 points were classified as non forest land, 18 points were classified as non forest mix. Channel position for the left side data was classified as follows: 43 points were classified as straight, 23 points were classified as outside curve, 17 points were classified as inside curve, 15 points were classified as outside apex, and 3 points were classified as inside apex. Refer to Table 4.4 for a summary of the left side analysis for landcover, channel position, and interactions of the two.

Landcover Results for the left streambanks indicate that 99% of the time the hypothesis (forest land eroded less than non-forest land and non-forest mix) was supported. Results indicate that 1% of the time, (p=0.01), the hypothesis was supported due to random error. These findings are highly significant to the p=0.05 level which is the standard for biological studies.

Channel position Results for channel position on left streambanks were not significant to the level of p=0.05. It was found that 11% of the time, the hypothesis (outside apex eroded more than the other channel positions) was supported. Eighty nine percent (89%) of the time, (p=0.89), the hypothesis was supported due to random error.

Interaction between landcover and channel position Results for interaction were found not significant to the level of p=0.05. Twenty five percent (25%) of the

time the hypothesis was supported. Seventy five percent (75%) of the time ($p=0.75$), the hypothesis was supported due to random error.

Erosion/Deposition Data by Position and Landcover (Left Side)

	n	mimimum	maximum	mean	std. dev. std. dev.	mean less std. dev.	mean plus std. dev.
straight							
forest	24	-149	405	28.25	107.83	-79.58	136.08
non-forest	18	-270	207	-88.06	105.92	-193.98	17.86
mix	1	-39	-39	-39	NA	-39	-39
outside curve							
forest	7	-176	122	-48.71	94.48	-143.19	45.77
non-forest	9	-683	163	-165.4	244.29	-409.69	78.89
mix	7	-99	175	72.14	87.94	-15.8	160.08
inside curve							
forest	4	-78	94	-25.75	80.68	-106.43	54.93
non-forest4	12	-613	304	-149.1	216.14	-365.24	67.04
mix	1	-20	-20	-20	NA	-20	-20
outside apex							
forest	1	77	77	77	NA	77	77
non-forest	6	-161	-11	-83.83	64.07	-147.9	-19.76
mix	8	-239	123	28.62	120.66	-92.04	149.28
inside apex							
forest	1	139	139	139	NA	139	139
non-forest	1	-147	-147	-147	NA	-147	-147
mix	1	-119	-119	-119	NA	-119	-119

Table 4.3: Summary of left streambank data analysis.

LEGEND

n	Number of Observations
Min	Minimum amount of erosion (linear feet) observed
Max	Maximum amount of erosion (linear feet) observed
Mean	Average amount of erosion (linear feet) observed
StDev	Standard Deviation from the mean
NA	No Standard Deviation
	A positive value indicates streambank deposition
	A negative value indicates streambank erosion

Summary of the analysis of the left side					
Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Significance of F
Position	4	21368.85	5342.21	0.27	0.89
Landcover	2	183842.92	91921.46	4.67*	0.01
Position* Landcover	8	98899.58	12362.45	0.63	0.75

*p<0.05

Table 4.4: Summary of the analysis of the left side

Right side analysis

103 data points were collected from the right side of the river (Table 4.5). The results were classified as follows: 59 points were classified as forest land, 38 points were classified as non-forest land, 6 points were classified as non-forest mix. Channel position for the left side data was classified as follows: 51 points were classified as straight, 24 points were classified as outside curve, 13 points were classified as inside curve, 3 points were classified as outside apex, and 12 points were classified as inside apex. Refer to Table 4.6 for a summary of the analysis of the right side.

Landcover Results for the left streambanks indicate that 93% of the time the hypothesis (forest land eroded less than non-forest land and non-forest mix) was supported. Results indicate that 7% of the time, (p=0.07), the hypothesis was supported due to random error. These findings are not quite significant to the p=0.05 level which is the standard for biological studies, but are considered to be approaching significance for the purposes of this study.

Channel position Results for channel position on left streambanks were not significant to the level of p=0.05. It was found that 74% of the time, the hypothesis (outside apex eroded more than the other channel positions) was supported. Twenty six percent (26%) of the time, (p=0.26), the hypothesis was supported due to random error. These findings are considerably more significant than for the left streambank.

Interaction between landcover and channel position Results for interaction were found not significant to the level of p=0.05. Sixty eight percent (68%) of the time the hypothesis was supported. Thirty two percent (32%) of the time (p=0.32), the hypothesis was supported due to random error, which is considerably more significant than for the left streambank.

Erosion/Deposition Data by Position and Landcover (Right Side)

	n	mimimum	maximum	mean	std. dev.	mean less std. dev.	mean plus std. dev.
straight							
forest	29	-181	190	-14.69	78.29	-92.98	63.6
non-forest	20	-397	90	-74.5	122.44	-196.94	47.94
mix	2						
outside curve							
forest	16	-143	281	56.19	107.55	-51.36	163.74
non-forest	7	-309	-52	-129	86.36	-215.36	-42.64
mix	1	-4	-4	-4	NA	-4	-4
inside curve							
forest	3	-54	30	-22.33	45.65	-67.98	23.32
non-forest	9	-505	0	-137.22	154.39	-291.61	17.17
mix	1	-77	-77	-77	NA	-77	-77
outside apex							
forest	1	0	0	0	NA	0	0
non-forest	1	-80	-80	-80	NA	-80	-80
mix	1	-28	-28	-28	NA	-28	-28
inside apex							
forest	10	-51	82	15.4	47.15	-31.75	62.55
non-forest	1	2	2	2	NA	2	2
mix	1	33	33	33	NA	33	33

Table 4.5: Summary of right streambank data analysis.

LEGEND

n	Number of Observations
Min	Minimum amount of erosion (linear feet) observed
Max	Maximum amount of erosion (linear feet) observed
Mean	Average amount of erosion (linear feet) observed
StDev	Standard Deviation from the mean
NA	No Standard Deviation
	A positive value indicates streambank deposition
	A negative value indicates streambank erosion

Summary of the analysis of the right side					
Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Significance of F
Position	4	53824.14	13456.03	1.32	0.27
Landcover	2	56098.11	28049.06	2.75	0.07
Position* Landcover	8	95535.94	11941.99	1.17	0.32

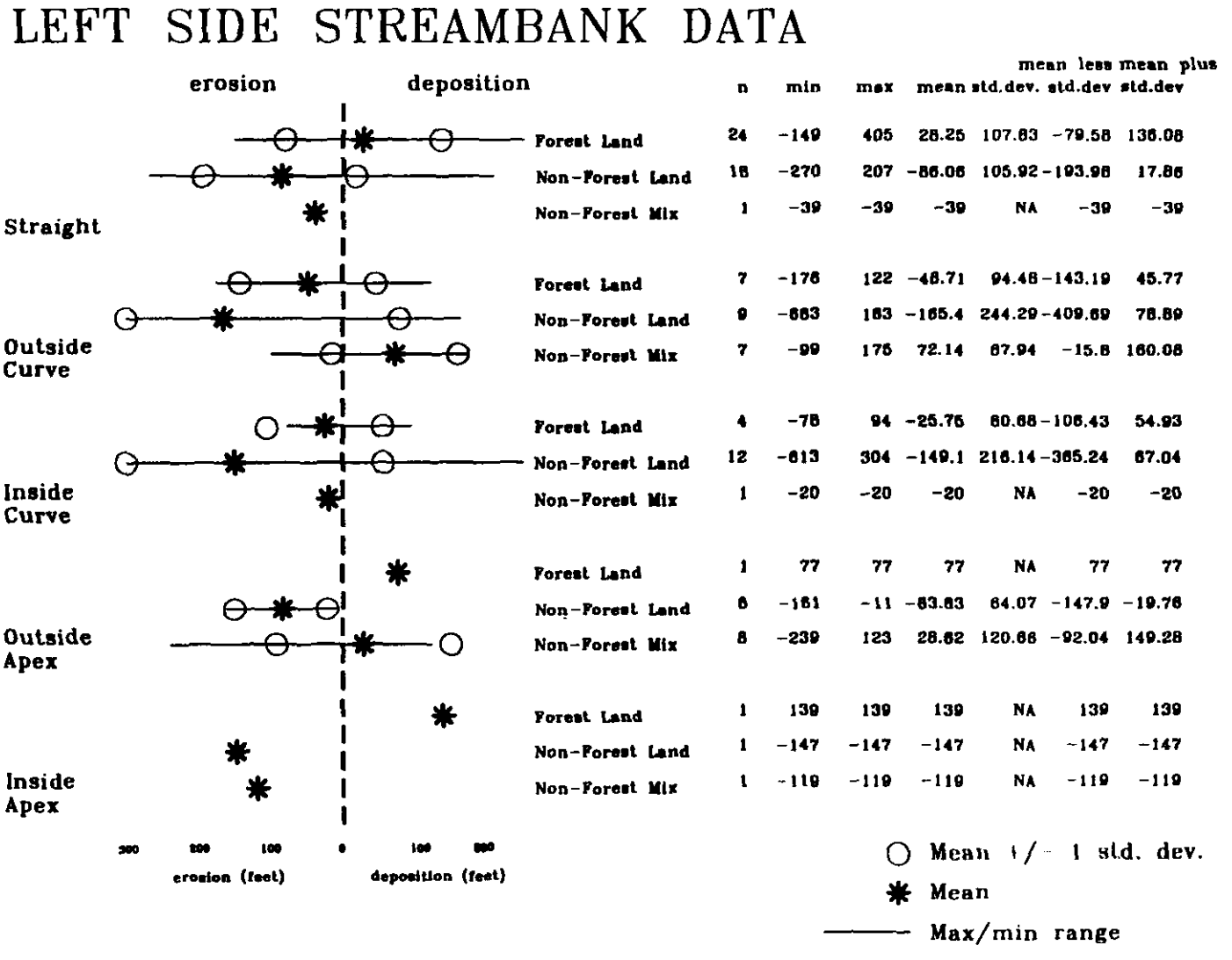
Table 4.6: Summary of the analysis of the right side

Results

Graphic interpretation of left and right side data analysis is provided in Figures 4.2 and 4.3. Results indicate that woody riparian vegetation did reduce the extent of streambank erosion caused by the flood of 1993. Forested areas on both sides of the river sustained less erosion than those areas which had little to no woody vegetation cover.

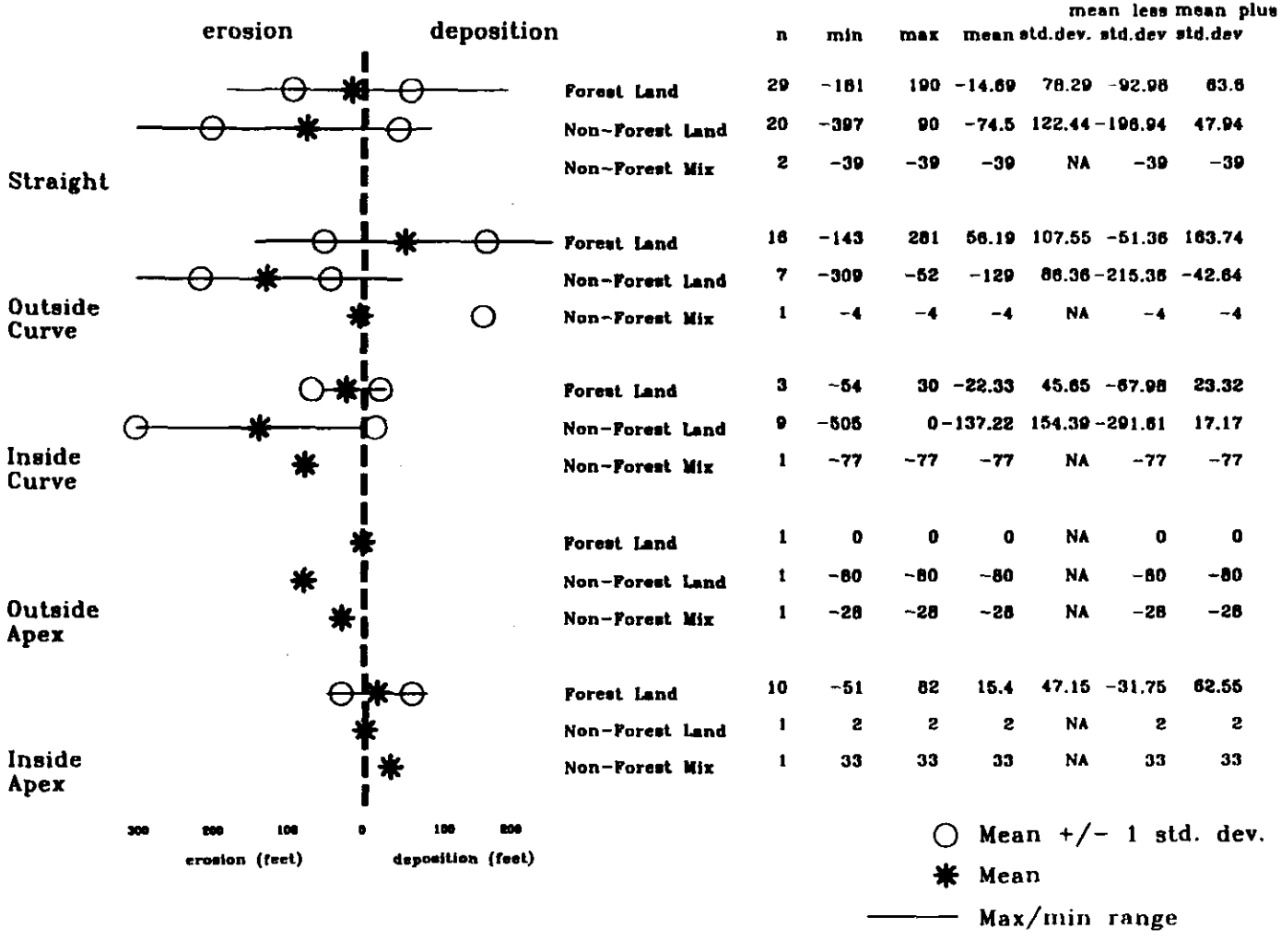
Results for channel position were not significant but were approaching significance in many instances. Extensive erosion occurred at all channel positions, therefore no assumptions about the relationship between channel position and streambank erosion can be made based on these results.

The interaction between landcover and channel position were also not significant. This is likely due to the fact that the findings for channel position were not significant. As with channel position, no assumptions about a significant relationship between channel position and streambank erosion can be made based on these results.



		n	min	max	mean	mean less std.dev.	mean plus std.dev
Straight	Forest Land	24	-149	405	28.25	107.83	-79.58	136.08
	Non-Forest Land	15	-270	207	-86.06	105.92	-193.98	17.86
	Non-Forest Mix	1	-39	-39	-39	NA	-39	-39
Outside Curve	Forest Land	7	-176	122	-48.71	94.48	-143.19	45.77
	Non-Forest Land	9	-663	183	-165.4	244.29	-409.69	78.89
	Non-Forest Mix	7	-99	175	72.14	87.94	-15.8	160.08
Inside Curve	Forest Land	4	-75	94	-25.75	80.68	-106.43	54.93
	Non-Forest Land	12	-613	304	-149.1	216.14	-365.24	67.04
	Non-Forest Mix	1	-20	-20	-20	NA	-20	-20
Outside Apex	Forest Land	1	77	77	77	NA	77	77
	Non-Forest Land	6	-161	-11	-83.83	64.07	-147.9	-19.76
	Non-Forest Mix	8	-239	123	28.62	120.66	-92.04	149.28
Inside Apex	Forest Land	1	139	139	139	NA	139	139
	Non-Forest Land	1	-147	-147	-147	NA	-147	-147
	Non-Forest Mix	1	-119	-119	-119	NA	-119	-119

Figure 4.2: Graphic interpretation of left side streambank data analysis.



		n	min	max	mean	std.dev.	mean less std.dev	mean plus std.dev
Straight	Forest Land	29	-161	190	-14.69	78.29	-92.98	63.6
	Non-Forest Land	20	-397	90	-74.5	122.44	-196.94	47.94
	Non-Forest Mix	2	-39	-39	-39	NA	-39	-39
Outside Curve	Forest Land	16	-143	281	56.19	107.55	-51.36	163.74
	Non-Forest Land	7	-309	-52	-129	86.36	-215.36	-42.64
	Non-Forest Mix	1	-4	-4	-4	NA	-4	-4
Inside Curve	Forest Land	3	-54	30	-22.33	45.65	-67.98	23.32
	Non-Forest Land	9	-505	0	-137.22	154.39	-291.61	17.17
	Non-Forest Mix	1	-77	-77	-77	NA	-77	-77
Outside Apex	Forest Land	1	0	0	0	NA	0	0
	Non-Forest Land	1	-80	-80	-80	NA	-80	-80
	Non-Forest Mix	1	-28	-28	-28	NA	-28	-28
Inside Apex	Forest Land	10	-51	82	15.4	47.15	-31.75	62.55
	Non-Forest Land	1	2	2	2	NA	2	2
	Non-Forest Mix	1	33	33	33	NA	33	33

Figure 4.3: Graphic interpretation of right side streambank data analysis.

The results suggest extensive streambank erosion and deposition in many areas. As noted in Chapter 1, erosion and deposition are defined (for this study) as the linear movement of the streambank away from or toward the river centerline. This definition indicates how erosion and deposition would appear from above the ground, as in an aerial view. The definition was developed because aerial photographs were chosen as the media to compare pre- and post-flood landscape conditions, and is the most effective way to estimate the extent of erosion and deposition.

The definitions of erosion and deposition for this study do not account for the volume of soil eroded and deposited. It is difficult to determine the volume of soil erosion and deposition caused by the flood because it requires accurate information about the topography of the streambanks prior to and directly after the 1993 flood. This information is not available for the study site, therefore no accurate estimations of the volume of soil erosion or deposition can be made. The author, however, predicts that the volume of soil erosion and deposition would be similar in comparison to the extent of streambank movement. It is likely that the volume of soil eroded is considerably greater than the volume of soil deposited.

IMPLICATIONS AND DISCUSSION

This chapter discusses the implications of the results, outlines methods of erosion prevention and assistance, and provides recommendations for further study.

Implications of results

Significant results from this study indicate that forested streambanks erode less than streambanks with no forest vegetation. These findings support current research (Hickin, 1984; Malanson, 1993; Naiman *et al.*, 1993; Turner, 1995; Wells, 1995) about the effects of woody vegetation on streambank erosion.

Based on the results of this study, one method to reduce streambank erosion is to establish a zone of riparian vegetation along streambanks. Results show that although a single row of trees was better at reducing erosion than no trees at all, a better solution is to establish at least a 100 foot zone of trees along a streambank. This width is chosen because it is the corridor width examined in this study. Zone widths less than 100 feet were not examined in this study, however they may prevent erosion better than a single row of trees. Comparing the effects of various corridor widths is a subject worthy of future study.

Streambank restoration

A number of methods of streambank restoration exist (Turner, 1995; Wells, 1995). Each erosion problem is unique and therefore requires a unique solution. This section is not intended to provide technical assistance about streambank restoration, but serves as a review of two methods and resources available to landowners.

An important first step in preventing streambank erosion is stabilizing the streambank. Even if a wide corridor of trees exist along a streambank, if the streambank is not protected from the water, erosion could occur and undercut the trees causing them to fall into the channel.

Extensive erosion occurred on forested land in some locations of the study area. It is likely that erosion occurred there because the streambank eroded beneath their roots. As the soil beneath their roots eroded, the trees lost support and fell into the river. When this happens, the roots of the tree carry large amounts of the streambank soil with them and greatly increase the amount of erosion. This finding may reinforce the need for future study of the effects of bank height on streambank erosion.

If the streambank is unstable because of a steep slope, it is necessary to establish a stable slope. A preferred slope angle is 1:1, which means that for every one foot of horizontal distance, the vertical change is one foot. Once the preferred slope angle is achieved, the streambank must be protected from erosion using one of many mitigation strategies (Wells, 1995). A brief review of two vegetative strategies is provided according to Wells (1995).

Vegetative strategies

A common method of bank stabilization is the **cedar tree revetment**. This method can be applied to streambanks which are very steep and therefore difficult to alter. Live cedar trees (*Juniperus* species) are selected with crown diameters equal to two-thirds (⅔) of the height of the exposed streambank: For example, if the exposed streambank is ten feet high, a tree with a diameter of six to seven feet should be selected. If the bank is too high, a number of trees can be placed on top of each other until two thirds of the bank is covered. The entire length of the exposed and eroding streambank should be covered with the revetment.

The method of **willow pole revetments** consists of planting dormant willow poles into an eroding bank at regularly spaced intervals. The goal is that the willows will root into the streambank and revegetate. This type of revetment has been widely used on smaller streams, however it has generally not been used on larger streams or rivers.

Before applying this method, the streambank should be stable, at a 1:1 maximum slope, and there should be no evidence of down cutting or aggradation of the channel. The bank should be less than 15 feet high. This method is used to prevent lateral streambank erosion, the type examined in this thesis, and to establish a permanent cover of woody vegetation on the streambank. Willow poles are generally 10 to 15 feet long and are buried to the depth of the water table. The poles require a constant supply of water to propagate, therefore this is very important.

Summary

To summarize the streambank restoration methods previously outlined, it is important to remember that every erosion problem is unique and therefore requires a unique solution. Cost, availability of materials and labor, and the severity of erosion are factors to consider when choosing a restoration method.

Involvement of Landscape Architects

The results of this study indicate that woody riparian corridors reduced streambank erosion caused by the 1993 flood. This information can benefit agencies and individuals involved in land development, land-use planning, and others participating in the restoration and preservation of riparian landscapes. This information may also assist professionals, including landscape architects, in projects dealing with land restoration, land-use planning, and land-use impact assessments of riparian areas.

The landscape architect can also work with landowners, natural resource managers, and state agencies in coordinating streambank restoration efforts. Landscape architects and planners may become involved in the issue of streambank restoration in various ways. He or she may become active in local planning in their community and advocate for the restoration or preservation of riparian areas in their community. This issue is particularly important in developing communities.

As areas are developed, rain is intercepted at the ground surface by rooftops and pavement. The rain is usually directed through a municipal storm water conveyance system and discharged into nearby swails, streams, or rivers. Prior to development, much

of the rain would infiltrate the ground's surface and little of it would runoff. However, after development runoff is greatly increased. Increased flows of water in streams and rivers cause greater erosion, therefore in developed areas it is possible that rates of streambank erosion could be accelerated.

The landscape architect and planner could mitigate increased runoff by implementing strategies such as "zero runoff" in the developments they design and build. The zero runoff concept means that no increase in runoff occurs as a result of land development: the amount of runoff from a site after development equals the amount of runoff from a site prior to development. Detention and retention basins are tools used in achieving zero runoff.

Another way in which landscape architects and planners may become involved in streambank restoration is to protect existing riparian areas on sites which are to be developed. Maintaining a vegetated buffer zone, such as the 100 foot zone identified in this study, along a riparian area will help reduce many problems related to development. Streambank erosion is likely to be reduced if riparian vegetation is maintained. Riparian vegetation also removes soil and other pollutants from storm runoff. One of the problems associated with land development is surface soil erosion: riparian vegetation removes eroded soil from surface runoff before it enters the stream channel.

A number of state and federal agencies provide technical assistance in streambank restoration projects. In some cases the cost of materials and labor is shared between the landowner and agency. Some agencies providing technical assistance in Kansas are:

- *Natural Resource Conservation Service*
- *Kansas Department of Health and Environment*
- *Kansas State and Extension Forestry*
- *Consolidated Farm Service Agency*
- *State conservation agencies*

Recommendations for further study

The finding that less erosion occurred to forested streambanks than non-forest mix streambanks indicates that a substantial woody vegetation buffer is needed to protect streambanks. A protective buffer width of 100 feet seemed to greatly reduce the erosive effects of the Kansas River. Areas classified as non-forest mix had a single row of trees which protected the streambank more than in non-forested areas, however, there was substantially more erosion which occurred to non-forest mix streambanks than forested streambanks.

Because no significant results for either channel position or the interaction between channel position and landcover were obtained, further research is needed to determine if a relationship exists between these variables and streambank erosion. No significant results for channel position were obtained because extensive erosion occurred at all positions: no pattern or hierarchy of erosion amounts exists. This is likely due to the magnitude of the 1993 flood. The amount of water flowing in the Kansas River channel was so great that it flowed out of its streambanks and into the floodplain.

Evidence of this exists in aerial photographs of post flood conditions. Large deposits of sand in the floodplain provide a record of the extent of flooding. The velocity was much higher than normal and therefore more erosive. Because the channel was full, erosion occurred at all points along the streambank.

To determine the relationship between streambank erosion with channel position and the interaction of channel position and landcover, further examination of normal streamflows is necessary. A longitudinal study could be created to study the effects of these factors on streambank erosion under normal streamflow conditions and under less intensive floods (10, 20, and 50 year floods). The study could focus on a portion of the Kansas River (or any other river) with various channel characteristics including straight runs and meanders. A similar method of classification of both channel position and land cover types could be used. The study would provide evidence as to the annual changes which occur to riparian systems during both normal flow conditions and flood conditions. Such a study would be useful because it would provide evidence about more common occurrences than the flood of 1993.

Future research efforts should coordinate with local, state, and federal agencies active in the protection and preservation of riparian areas. Currently, several agencies are coordinating their efforts in Kansas to address the issues and needs of wetland and riparian areas conservation through the Kansas Wetland and Riparian Areas Project (WRAP). The project was approved by the Kansas Water Authority and is coordinated by the Kansas Water Office. Several documents have been published by the WRAP team which define the goals and strategies of the team's efforts and list resources and

guidelines for local planning agencies. Full citations of the following documents are provided in the *References Cited* chapter: Brooks & Deines, 1993; Kansas Water Office, 1993; Miller, *et al.*, 1993; Monda, *et al.*, 1992, Monda, *et al.*, 1993; Monda, *et al.*, 1993; Steiner, *et al.*, 1991.

The author will continue this research project by examining the effects of the flood on the Republican River in northeast Kansas. The study will be changed slightly by reclassifying landcover to differentiate between cropland and grassland. The format of the study will remain relatively similar to the format of this thesis research, however specific effort will be made to obtain a better distribution of data.

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APPENDICES:

A. Summary of landcover classification categories
B. Photocopy of aerial photographic slide image
C. Streambank erosion/ deposition data

APPENDIX A:

The following categories of land uses were mapped by Wetland and Riparian Areas Project (WRAP) teams as part of a wetland and riparian inventory project for Kansas. These landcover classifications served as the basis for the thesis landcover categories:

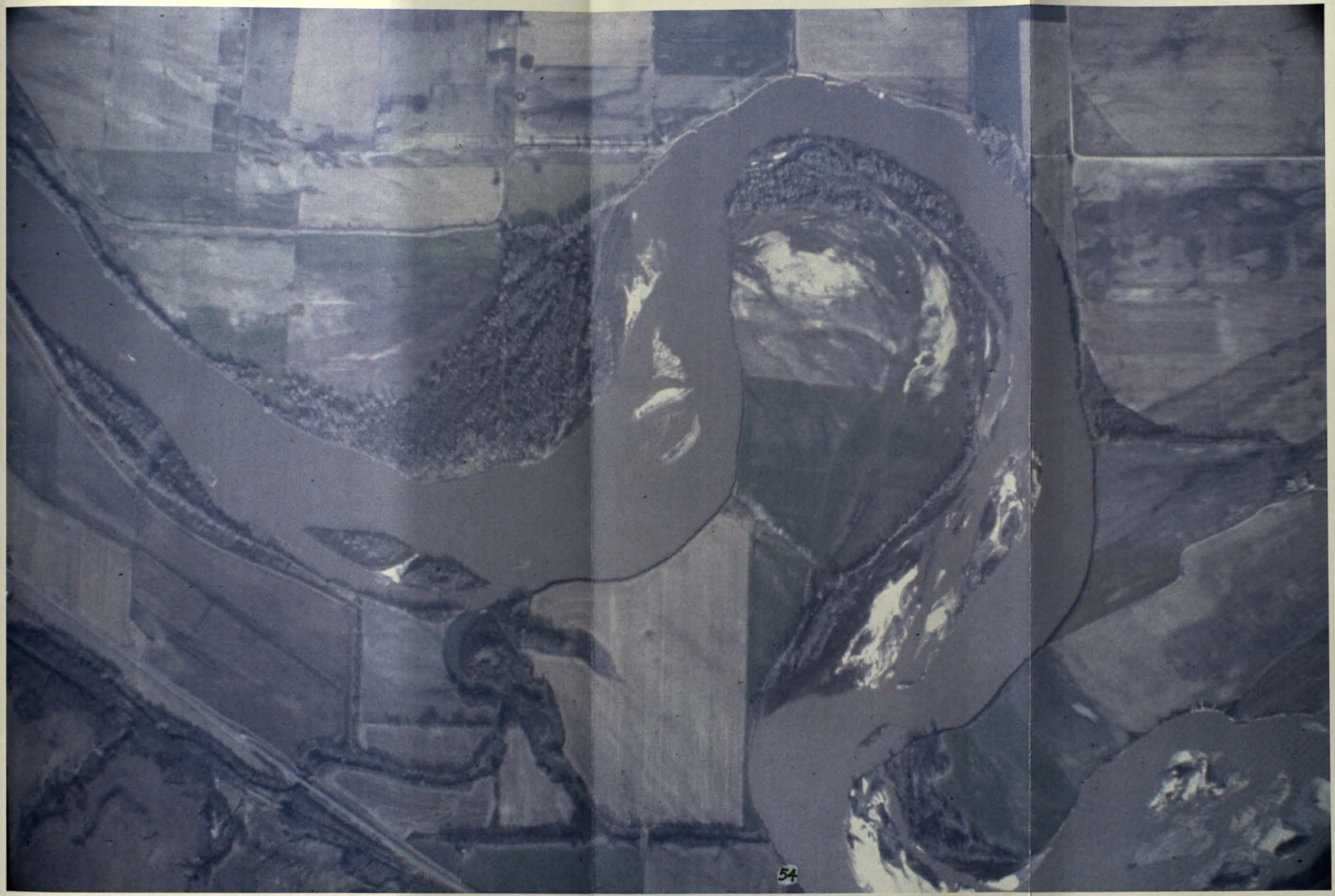
1. Forest land: Areas adjacent to a stream that contain trees with a canopy cover greater than 51% of the 100 foot buffer zone.
2. Crop land: Areas adjacent to a stream where no trees are present an in which 51% or more of the 100 foot buffer is planted or was planted during the previous growing season to a row crop, small grain, or legume.
3. Grass land: Areas adjacent to a stream where 51% or more of the 100 foot buffer contain native or cool season grasses.
4. Urban land: Areas adjacent to a stream where 51% or more of the 100 foot buffer contains dwellings or is located in an urban area and no trees are adjacent to the stream.
5. Shrub/ Scrub land: Areas adjacent to a stream which contain shrubs or brush/ scrub vegetation with a canopy cover greater than 51% of the 100 foot buffer zone.
6. Grass/ Tree mix: Grass with a single row of trees next to the stream.
7. Crop/ Tree mix: Crop land with a single row of trees next to the stream.
8. Urban/ Tree mix: Urban areas with a single row of trees next to the stream.

The WRAP categories were reclassified for thesis research. Forest land remained the same; crop land, grass land, urban land, and shrub/ scrub land were reclassified as non-forest land; grass/ tree mix, crop/ tree mix, and urban/ tree mix were reclassified as non-forest mix.

APPENDIX B:

This is a photocopy of an aerial photographic slide image of the Kansas River similar to those used in this project. The image was photographed in December 1992 southeast of Manhattan, Kansas.

Source: Pottowatomie County Consolidated Farm Service Agency, Westmoreland, Kansas



APPENDIX C:

The following pages include the data collected for this project. Data is summarized in tabular format. The first three tables include data for the left streambanks, the remaining four tables include data for the right streambanks.

Each table gives the data point identification number, landcover classification category, channel position classification category, and the amount of erosion or deposition. Summaries of landcover and channel position classification categories are:

LANDCOVER

Category	Description
1	Forest Land
2	Non-forest Land
3	Non-forest Mix

CHANNEL POSITION

Category	Description
1	Straight
2	Outside Curve
3	Inside Curve
4	Outside Apex
5	Inside Apex

Please refer to Chapter One for definitions of landcover and channel position categories. In reference to erosion and deposition, those figures which are negative indicate streambank erosion (in linear feet), and those figures which are positive indicate streambank deposition (in linear feet).

Left Streambank Data Points

Data Point	Landcover Classification	Channel Position Classification	Erosion/ Deposition
11	2	2	-291
12	3	4	-239
13	2	4	-153
14	2	4	-161
15	2	3	-65
16	3	5	-119
17	1	5	139
18	2	5	-147
19	3	1	-39
20	3	3	-20
39	1	2	122
40	2	2	163
41	3	2	115
42	1	4	77
43	3	4	84
44	3	4	72
45	3	4	59
46	1	1	34
47	3	4	63
48	2	4	-11
49	3	4	-51
50	2	4	-29
76	2	2	-253
77	1	2	-53
78	1	1	-6
79	1	1	30
80	1	1	0
81	2	1	-37
82	2	1	-133
83	2	1	-192
84	2	1	-126
85	3	2	-99
86	3	2	131
87	3	2	44
88	3	2	84
89	3	2	55
90	3	2	175
91	3	4	118
92	3	4	123

Left Streambank Data Points

Data Point	Landcover Classification	Channel Position Classification	Erosion/ Deposition
100	2	4	-100
101	2	4	-49
102	1	3	94
104	2	1	-31
105	2	2	-53
124	1	3	-50
125	1	3	-78
126	1	3	-69
127	2	3	-106
128	2	3	-49
129	2	3	-90
130	2	3	-243
131	2	1	-270
132	2	2	-275
133	2	2	-48
134	2	2	-31
135	2	2	-18
136	1	2	-49
137	1	1	-14
138	1	1	-43
139	1	1	-60
140	1	1	-42
141	2	1	-21
142	2	1	-10
143	2	3	-8
144	2	3	-191
145	2	3	-216
146	2	1	-227
147	1	1	-28
148	1	1	-43
153	1	1	20
154	2	1	207
155	2	1	-124
156	2	1	-58
157	2	3	-175
158	2	3	-613
159	2	2	-683
160	1	2	0
162	1	1	405

Left Streambank Data Points

Data Point	Landcover Classification	Channel Position Classification	Erosion/ Deposition
163	2	1	-95
164	2	3	-337
181	1	1	151
182	1	1	29
183	1	1	60
185	1	1	105
186	1	1	93
187	1	1	151
188	2	1	-63
189	2	3	304
196	1	1	-149
197	1	2	-176
198	1	2	-61
199	1	2	-124
200	1	1	-70
201	1	1	-44
202	1	1	-7
203	2	1	-122
204	1	1	0
205	2	1	-194
206	2	1	-72

Right Streambank Data Points

Data Point	Landcover Classification	Channel Position Classification	Erosion/ Deposition
10	1	2	267
11	1	2	281
12	1	1	190
13	1	1	81
14	1	1	112
15	1	1	56
16	2	1	38
17	2	3	-67
18	1	3	-54
19	1	3	30
20	2	1	-100
21	2	1	-397
22	2	3	-505
39	2	1	-147
40	1	1	-83
41	1	1	-98
42	1	1	-45
43	1	1	-116
44	1	1	-120
45	1	1	-22
46	1	1	-49
47	1	1	-41
48	1	1	-35
49	1	1	2
50	1	1	25
51	1	1	-34
53	2	1	-285
54	2	1	-244
55	2	1	-120
56	2	1	-59
57	2	5	2

Right Streambank Data Points

Data Point	Landcover Classification	Channel Position	Erosion/ Deposition
78	1	1	-47
79	1	1	-70
80	1	1	-71
81	1	1	0
82	1	1	-13
83	1	1	-22
84	1	1	40
85	2	1	31
86	2	1	7
87	2	1	-25
88	3	4	-28
89	2	2	-52
90	2	2	-69
91	2	2	-95
92	2	2	-143
93	2	2	-93
94	1	2	0
100	1	5	0
101	1	5	-49
102	1	5	-30
103	3	5	33
104	1	1	-9
123	1	2	-30
124	1	2	56
125	1	2	78
126	1	2	103
127	1	2	50

Right Streambank Data Points

Data Point	Landcover Classification	Channel Position	Erosion/ Deposition
128	1	2	105
129	1	2	95
130	1	2	28
131	1	2	18
132	1	2	67
136	2	3	-58
138	3	3	-77
139	2	3	-143
140	2	3	-143
141	1	3	-43
142	1	5	-51
143	1	5	20
144	1	5	82
145	1	5	27
146	1	5	32
147	2	1	-30
153	3	1	-126
154	3	1	-248
155	2	3	-212
156	1	5	66
157	1	5	57
158	1	4	0
159	2	3	0
160	2	3	0
161	2	4	-80
162	1	2	-10
182	1	1	-181
183	2	1	-38
184	2	1	-69
185	2	1	-82
186	2	3	-107

Right Streambank Data Points

Data Point	Landcover Classification	Channel Position	Erosion/ Deposition
189	1	2	-143
190	1	2	-66
191	3	2	-4
192	2	2	-142
193	2	2	-309
194	1	1	-11
195	1	1	0
196	2	1	-83
197	1	1	0
198	2	1	90
199	2	1	90
200	2	1	-87
201	2	1	20
202	1	1	135