Stream Bank Erosion and Land Use/Land Cover along the Gun River, Allegan County, Michigan

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Kenneth James Sexton
The Gun River, located in Allegan County, MI, is experiencing profound erosion and sedimentation due to past channel modifications and current land use activity. The Gun River historically has been dredged and straightened to drain water faster and more effectively for agricultural production. Additionally, human land use activities in the watershed influence the current land cover and riparian vegetation. The purpose of this study was to determine if variations in land use (residential, agricultural, and forested) and vegetative cover along the banks of the Gun River influence erosion. Additionally, the study provided a unique opportunity to compare the upper portion of the Gun River, which primarily flows through agricultural land and functions as an inter-county drain, with the lower section of the River that has visible characteristics of a natural river, such as vegetative riparian cover, meanders, and the presence of large woody debris. Using an index based on riparian vegetation and stream bank erosion, as well as channel measurements of the Gun River, data collected from the Gun River and riparian corridor revealed that residential land management results in more bank erosion and sedimentation in the Gun River. Data also revealed that there are differences between the upstream and downstream portions of the Gun River, primarily because most of the residential property along the Gun River is located in the downstream reach.
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CHAPTER I

INTRODUCTION

Rivers and streams are dynamic systems that carve and shape the Earth as they meander across the landscape. The morphology of a river is the result of gradation by erosional and depositional processes due to the massive energy and force of flowing water. These processes direct a stream’s course by eroding the landscape at a cut-bank and creating point bars as the stream meanders across the landscape.

Although a stream naturally loses bank material and deposits it downstream, human activities adjacent to rivers and floodplains have made stream bank erosion a problem in many areas. Alteration of a stream’s natural course and land use activities in riparian areas increases soil erosion that contributes to the degradation of the stream’s ecosystem. A net increase in erosion can have negative effects on a river by increasing sediment load in the river, thus, decreasing water quality as well as aquatic habitat, submerging and destroying some productivity of microhabitats. In addition, soil erosion along a riverbank may result in the loss of property, leaving property owners worried about the encroachment of the river, regardless of specific land use type or management.

Residents and stakeholders, in the Gun River watershed, in southwest Michigan, are currently concerned about the water quality and water resources of their watershed. Increased erosion, sedimentation, and pollution is occurring in the Gun River and on its banks as a results of direct and indirect, past and present land use activities. The Gun River historically was a sinuous river that had been straightened
through channelization and dredging projects in 1903, 1914, and again in 1945 (Allegan County, n.d.a., n.d.b., n.d.c.). Like many channel modification projects in the past, the purpose of the channelization project was to drain water faster and more effectively from the wetland areas of the Gun Plain so that the land could be developed for agricultural activity.

Unfortunately for riparian landowners in the watershed today, the Gun River is experiencing profound erosion along the channel banks due to past and current land use activities and management procedures, which influences the current land cover and riparian vegetation. For instance, channelization, agricultural, and urban/residential land use activities often involve the removal of stream bank vegetation, which in turn promotes further erosion and sedimentation (Wang et al., 1997; Mensing et al., 1998; Lyons et al., 2000; Simon and Rinaldi, 2000; Freeman and Ray, 2001).

Stakeholders are troubled about the erosion that is occurring along the Gun River since soil erosion is resulting in the loss of their property, increasing sedimentation and pollution, as well as threatening the lotic biota of the stream. At present, a watershed management plan for the Gun River is in the beginning stages of development, headed by the Allegan Conservation District (ACD).

Problem Statement

It is generally accepted that vegetation along stream banks aids in slope stability by preventing channel widening and also helps to prevent sediment and pollution from entering streams through direct and indirect sources (Parsons, 1963;
Apmann and Otis, 1965; Shields et al., 1995; Forman, 1995). The purpose of this study is to determine if variations in land use as well as the presence of vegetation along the Gun River influence erosion. Essentially, are there measurable relationships between land use/land cover and stream bank erosion? In addition, the Gun River provides an unusual opportunity to compare the upper portion of the river, which primarily functions as an inter-county drain (ACD, 2000) with the lower section of the river that has visible characteristics of a natural river, such as vegetative riparian cover, meanders, and the presence of large woody debris. Therefore, this study also answers the question, are there differences in the stream bank vegetative and erosional conditions between the upper and lower portions of the Gun River?

It was expected that variations in land use and land management as well as the presence of vegetation along the Gun River influence erosion and water quality. Therefore, collecting data from the Gun River channel and riparian corridor was used to assess bank conditions and slope stability.
Anthropogenic Impacts on Rivers and Water Quality

Human activities and land use practices in the past have shaped the current physical, environmental, and cultural landscape (Mensing, et al., 1998). For example, humans in the conterminous United States since the 1600s have cleared large tracts of forests and drained over half of the Nation's wetlands for urban and agricultural land uses (Mensing et al., 1998; Finkenbine et al., 2000). Additionally, in the past 200 years, more than 80 percent of North America's riparian corridors have been removed due to land development (Mensing, et al., 1998; Freeman and Ray, 2001). Human activities, such as agriculture, forestry, ranching, construction, resource extraction, and flood control projects have directly and indirectly impacted river channels and riparian ecosystems by increasing upland and floodplain inputs of nutrients, sediments, water, and energy to streams (Karr and Dudley, 1981; Walling, 1999; Freeman and Ray, 2001). Unrestrained development and improper land use practices, therefore, can negatively impact the "physical, chemical, and biological character of streams" (Henshaw and Booth, 2000, 1219).

Human activities can threaten rivers and riparian ecosystems in two ways: indirectly, by non-point pollution sources such as surface runoff and erosion from agricultural and urban areas, and directly, by point source pollution such as storm-water runoff from drains or bank failure (Silva and Williams, 2001; Lenat and
Crawford, 1994). At present, most efforts and research focus on non-point sources because there is less direct dumping of pollutants into waterways today, as a direct result of the 1972 Clean Water Act (Karr and Dudley, 1981). The effort to detect non-point sources of pollution is also important because it has become increasingly clear that agricultural and urban land uses have produced long-term, cumulative damage to river ecosystems (Wang et al., 1997; Thomann and Linker, 1998).

On the other hand, pollution from point sources, such as bank failures and anthropogenic impacts like channelization and the removal of vegetation are important because river health and riparian habitat ecosystems are directly affected from these impacts (Nakamura et al., 1997; Mensing et al., 1998). These impacts often change the physical, biological, and chemical functions of streams and adjacent floodplains, usually with negative consequences for both humans and river ecosystems (Wang et al., 1997; Mensing et al., 1998; Henshaw and Booth, 2000; Simon and Rinaldi, 2000; Freeman and Ray, 2001).

**Channelization and Bank Stability**

Bank erosion is often a consequence of human alterations to streams. Although a stream naturally, and variably, erodes bank material upstream and deposits it downstream, human activities, such as channelization and dredging in rivers and floodplains, have made stream bank erosion a problem in many areas (as discussed in Chapter I). Channelization often involves modifying natural river patterns, which completely restructures and sometimes relocates the streambed and banks (Brookes, 1985; Harvey and Watson, 1986; Simon and Hupp, 1986).
According to Brookes (1985), channelization involves four fundamental types of channel modifications. They are: (1) widening, deepening, and straightening a channel; (2) clearing vegetation and logs from the banks and channel; (3) diking, which increases bank height through levees to increase channel depth; and (4) bank stabilization (Brookes, 1985).

The first three types of channel modifications have direct effects on the channel morphology and hydraulic characteristics (Harvey and Watson, 1986). Type one involves straightening a channel, which shortens a river’s length, increases net flow gradient, increases flow velocities, amount and rate of scouring along the bed and banks, erosion and sedimentation, and widens the channel (Brookes, 1985; Harvey and Watson, 1986; Simon and Hupp, 1986; Mensing et al., 1998). The additional sediments and nutrients introduced to the river system from increased erosion can have negative impacts on aquatic organism such as plants, fish, and insects (Karr, 1981; Lenat and Crawford 1994; Rice et al. 2001). Suspended soil particles can increase turbidity reducing light penetration necessary for aquatic plant growth (Center for Watershed Protection [CWP], 2003). Sedimentation can damage fish gills, making respiration difficult and increasing the risk of infection and sickness (Robertson and Pierce, 1985; CWP, 2003; Michigan Department of Environmental Quality [MDEQ], 2003). Sedimentation can harm aquatic habitats by depositing in spawning areas or changing the natural continuum of bed sediment and pools and riffles (Rice et al., 2001; MDEQ, 2003). Deposited sediment can also reduce channel capacity, intensifying bank erosion and flooding downstream.
The second type of channel modification often involves the removal of riparian vegetation. Riparian vegetation is an important component for maintaining the health and quality of streams. Vegetation along streams helps to filter non-point source pollution and prevents excess nutrients and sediments from entering the streams from surrounding land use activities. Removal of riparian vegetation in the river corridor also results in the loss of wildlife habitat, root structure for slope stability, shade, and flood control. The functions and importance of riparian vegetation as buffer strips along a stream’s length are discussed in depth in the “Importance of Vegetation and River Corridors” section.

The third type of channel modification, according to Brookes (1985), involves diking. Increasing bank height through diking or levees is the least harmful type of channel modification, given that “the original channel is not modified and the vegetation is undisturbed” (Harvey and Watson, 1986, p 360). However, increasing bank height by depositing dredged channel material on top of banks can have negative impacts. For instance, the deposited material destroys existing vegetation, increases bank slope angle, and increases gully development further exacerbating erosion and bank instability (Simon and Hupp, 1986).

**Impacts of Anthopogenic Channel Modification and Public Awareness**

Worldwide, human modifications to fluvial systems have created unforeseen and often undesirable effects to river channels, riparian floodplains, and associated ecosystems. In northern Japan, a channelization project on the Kuchoro River straightened approximately 10 km of the naturally sinuous river to drain water faster
and more effectively (Nakamura, et al., 1997). The project had changed the hydraulic conditions in such a way that increased flow velocities upstream (from the channelized reach) degraded the channel and made the bed slope steeper, which in turn increased erosion, sedimentation, and flood events downstream.

In the Po Plain region of northern Italy, human alteration and containment of drainage networks since the 16th century has also increased flood events and their magnitude (Marchetti, 2002). More recently, in the 1960s and 1970s, problems from industrialized dredging and in-channel extraction of gravel for construction materials in the upstream catchment have increased bed and bank erosion along the River Po, and as a consequence, have damaged bridges and dams.

In the midwestern United States, human development on floodplains and modification to river channels has also changed the morphology and hydraulic conditions of many fluvial systems. As a result, unstable channels decrease water quality as erosion and sedimentation increase and in some cases infrastructure and property adjacent the river is also damaged (Simon and Hupp, 1986; Simon, 1989; Simon and Rinaldi, 2000). In west Tennessee, for example, a channelization project on Cane Creek straightened and shortened the creek from 36.5 km (22.7 mi) to 26.6 km (16.5 mi) in length. The project was intended to improve flood plain drainage, but also stimulated major erosion (up to 46 m [150 ft] at one location between 1970-83), gully development, loss of fertile land, and is assumed responsible for local bridge failures (Simon and Hupp, 1986).
Other areas of the Midwest have also undergone channelization projects for the purpose of wetland and floodplain drainage. In the Kankakee River watershed, located in northern Illinois and Indiana, modification to the River and its tributaries, through channelization projects accomplished by 1917, straightened roughly 161 km (100 mi) of the River's meanders to drain the area known as the Grand Marsh (Indiana Department of Environmental Management [INDEM], 2001). The channel alteration directly endangered aquatic organisms by reducing microhabitat diversity and sedimentation from increased erosion further threatened the remaining biota (Kwak, 1993). Similar to other channelization projects in the Midwest, changing the morphology of the Kankakee River ultimately posed a threat to public and private property downstream by increasing erosion, channel widening, and flooding events.

Although channelization directly alters the structure and stability of river systems, human activity in the watershed can also indirectly affect watershed hydrology and channel conditions as well. For instance, in urbanized watersheds, buildings, roads, parking lots, and other impermeable surfaces prevent infiltration and increase runoff (Hammer, 1972; Hollis, 1975; Finkenbine et al., 2000). During intense or long durations of rainfall, increased runoff from urban areas enters natural or man-made drainage systems and intensifies peak flows, which also intensifies bank and bed erosion (Hammer, 1972; Booth, 1991; Finkenbine et al., 2000; Bledsoe and Watson, 2001). Moreover, runoff may carry chemical pollutants and nutrient-rich sediment that enters waterways and further degrades water quality and habitat (Heggem et al., 2000).
Agriculture and forestry activities can also have indirect (and direct) effects on drainage systems. Just as urban areas increase runoff, vegetation removal and topsoil exposure from agriculture and forest activities also increase runoff and sedimentation since little vegetative covering is present (Booth, 1991; Mensing et al., 1998). Additionally, overuse of ground and surface water for agriculture and urban areas can exceed ground water recharge, drop the water table, and lower a stream’s local base flow. A lower base level can cause channel adjustments, increase sediment loads, and degrade riverbeds (Harvey and Watson, 1986). Therefore, both direct and indirect impacts from anthropogenic activities can have negative consequences for river ecosystems by accelerating erosion and sedimentation, increasing flood events, degrading biotic integrity, and diminishing overall functions of riparian habitats (Hammer, 1972; Olsen et al., 1997; Bledsoe and Watson, 2001).

Public awareness of degraded waterways and riparian ecosystems due to human impacts has led to an array of programs from community-orientated “grass-roots” organizations and watershed programs to national and international legislative policies (U.S. Environmental Protection Agency [EPA], 2003; Cobourn, 1999; McGinnis, 1999). In 1972, Congress enacted the Federal Water Pollution Control Act (amended in 1977 as the Clean Water Act) as a direct response to public concern about managing water resources (EPA, 2003). The Act prevented the discharge of industrial pollution (without permits) into many streams and lakes for the larger goal of restoring and maintaining “the chemical, physical, and biological integrity of the
nation’s waters” for the preservation and continuation of aquatic and terrestrial wildlife and recreational purposes (EPA, 2002a).

Additionally in 1972, Canada and the United States signed the Great Lakes Water Quality Agreement to help reduce the amount of toxic pollutants released in the Great Lakes (Environment Canada, 2001). The international law required the two countries to work together to improve the Great Lakes water quality and provided a working model for bordering countries and communities.

Public involvement and concern over water quality is not limited to national and international projects or federal legislation. In regional and local communities, property owners, watershed citizens, scientists, and interest groups (e.g. recreation users and activities) are involved in developing management programs to meet certain goals for streams, lakes, and watersheds (Cobourn, 1999; McGinnis, 1999). For example, the Truckee River Watershed in California and Nevada, a large watershed that encompasses over 7000 km$^2$ (2700 mi$^2$), has seen local, county, and state agencies working together to manage and improve watershed quality through Integrated Watershed Management (IWM) (Cobourn, 1999). IWM involves “interorganizational coordination” in which watershed management plans are created at local levels or sub-watersheds instead of the entire watershed (Cobourn, 1999). In this way, IWM helps to devise manageable, attainable projects in sub-watersheds based on a community’s social, cultural, and political values. As a result, management plans are not developed to be all-inclusive for the entire watershed. Instead, strategies are designed to accommodate local environment(s) and
ecosystem(s), which meet community needs, which ultimately are beneficial for the entire watershed (Heaney, 1993).

In northern Indiana and Illinois, public concern in the late 1970s and early 1980s about the quality and integrity of the Kankakee River ecosystem (as a response to the channel modification mentioned above) led to a comprehensive study of environmental and human impacts on aquatic life in the watershed (Kwak, 1993). Data from 1979 and 1980 revealed that sedimentation was a problem as “an estimated average of 733,000 metric tons of sediment” was transported each year (Kwak, 1993, 127). Recommendations of the study suggested that modifying land use activities in the watershed would help to reduce levels of sediment and pollution. More recently, a Kankakee River Watershed Restoration Action Strategy (WRAS) has been developed to address management strategies for activities in the watershed effecting water quality (INDEM, 2001). WRAS has met cooperation from citizens, planners, activists, educators, and governmental agencies, such as “IDEM, IDNR, USDA-Natural Resources Conservation Service, Ohio River Valley Water Sanitation Commission, Purdue University, Indiana University, Indiana Geologic Survey, and the US Geological Survey” (INDEM, 2001, 5).

Public concern for water quality in southwestern Michigan is representative of the above examples in which communities along with regional and local government agencies have developed and implemented strategies to protect water resources. For example, the Little Rabbit River watershed, a sub-watershed of the Rabbit River Watershed, part of the larger Kalamazoo River watershed, provides a successful
model where the implementation of best management plans (BMPs) proved effective. In the early 1990s, stakeholders in the watershed created a watershed management project focusing on BMPs to reduce surface runoff, sedimentation, erosion, and nutrients from entering the Little Rabbit River (Clean Water Action Plan [CWAP], 2000). BMPs included stream bank stabilization, the creation of sediment detention basins and erosion control structures, the planting of 18 acres of vegetative buffer strips, and restoring more than nine acres back to wetland (EPA, 2002b). During the three years of the project, the total amount of pollutants that were kept from entering the stream was “19,852 tons [20,170 metric tons] of sediment, 19,706 pounds [8,938 kg] of phosphorus, and 39,321 pounds [17,840 kg] of nitrogen” (EPA, 2002b, 4).

Importance of Vegetation and River Corridors

A vegetative riparian corridor plays a key role in supporting healthy, stable stream systems (Abernethy and Rutherfurd, 1998). A riparian corridor includes all trees, shrubs, and herbaceous plants that extend along both sides of a stream bank and can include the adjacent floodplains and slopes (Forman, 1995). This corridor acts as a buffer strip to protect a stream’s physical, chemical, and biological functions (Henshaw and Booth, 2000; Boon et al., 1992). River corridors and vegetative buffer strips along banks “...slow water velocity during floods, provides organic matter to soil, absorbs some lateral inputs from surrounding land use activities (such as erosion and runoff from agricultural and urban areas), and provides a route for terrestrial species that can tolerate wet soils and periodic flooding” (Forman, 1995, 214). In addition, wooded corridors provide habitat for wildlife and, depending on the size of
the corridor (wider and larger versus narrow and smaller), may provide a great source of biodiversity for recreational and educational uses.

Protection of a stream bank and the control of erosion are enhanced when vegetation is present because vegetation can prevent changes to the channel by acting as a stabilizing force to reduce lateral widening through bank erosion (Henshaw, 1999). Where there is little or no vegetation the stream bank is not stable and loose soil is easily washed away by rain and flowing water. The lack of vegetative cover also increases surface runoff because nothing is present to slow surface flow or help absorb the precipitation. Excess water flowing across the surface towards the river channel loosens and removes top particles of the soil surface (Hackett, 1972).

A canopy of trees and shrubs is very important because they too help to reduce erosion. Vegetation can intercept rainfall before it hits the ground and evaporation may occur directly from the surface of the leaf, branch, or stem (Henderson et al., 1999). Rain that does manage to reach the ground can be taken up through the roots of plants and the process of transpiration can remove surprisingly large amounts of the water (Hackett, 1992).

In addition to absorbing water in the soil, plant roots greatly increase slope stability by holding soil particles together. In a study conducted by Schuppener (2001, 175), in which plants were used to reinforce slope stability, root development from the vegetation resulted “in a four to fivefold increase in the bond strength over several years”. Riparian plant roots can also protect water quality by absorbing nutrient and contaminants in the soil (Cheng et al., 2002).
Vegetative cover near the ground, termed “contact cover” by Prosser et al. (1995), is especially efficient in reducing sedimentation (Siepel et al., 2002, 113). Whereas canopy can intercept rain before it hits the ground, contact cover shields soil from overland flow, reduces runoff velocity, helps trap nutrients and contaminants, and prevents sediment from entering the stream (Pearce et al., 1997; Lyons, et al., 2000; Siepel et al., 2002). Thus, vegetation on the slope and in the adjacent floodplain helps moderate non-point source pollution from adjacent land use activities, operating as filters to improve water quality by decreasing sediment load, toxins, and high nutrient input by depositing and storing sediments on the floodplains, before these materials enter the stream channel (Forman, 1995; Brooks et al, 1997).

Stream corridors and vegetation in the adjacent floodplain and adjoining wetlands also aid in flood control. Adjacent wetlands, large wooded debris, and forest vegetation in first order streams help reduce runoff and flow velocity (Brooks et al, 1997). “Vegetated large patches...are the mega sponges that absorb, hold, and slowly disperse water toward streams” (Forman, 1995, 213). Thus, the removal of vegetation upstream may be detrimental to communities downstream, and may increase the number and magnitude of floods near the mouth of rivers.

Trees along a river’s edge also contribute to the habitat of aquatic organisms. In stream networks, form and source of energy is important for ecosystem characteristics and biological populations (Karr and Dudley, 1981). The River Continuum Concept (RCC) describes the framework and transition of biological communities along river systems as linear gradients in response to the energy inputs,
exchanges, storage, and consumption processes in stream ecosystems (Vannote, et al., 1980).

The RCC was adopted from Leopold and Maddock’s (1953) principle of dynamic equilibrium theory, which suggested that river morphology (width, depth, velocity, and carrying load) and channel adjustments are direct responses to continuous nutrient and kinetic energy transfers (Vannote, et al., 1980). Vannote and colleagues (1980) hypothesized that an ecological continuum exists longitudinally along rivers on the basis of interactions between geomorphologic and biologic processes (Carpenter, 2001).

In the RCC, one of the main concepts is that stream size effects ecosystem networks such that organic material, aquatic organisms, fish populations, and energy exchange change along a continuum from small to large reaches (Vannote et al., 1980). Organisms in headwater streams (stream orders 1-3) are heterotrophic, meaning they rely on nutrient sources outside themselves (Carpenter, 2001). Riparian vegetation in headwater streams is therefore important because coarse particulate organic matter (CPOM), such as leaves, twigs and other organic material from the corridor (allochthonous material) provide the main source of food and habitat for invertebrates (Vannote et al., 1980; Karr and Dudley, 1981; Takashi et al., 2002). This is vital for the food chain because larger prey, such as fish, consume the invertebrates. Additionally, narrow stream widths in low-order streams allow greater canopy closure over the stream. The canopy helps to prevent sunlight penetration
keeping streams cool and allochthonous material can fall in the stream (Bernthal, 1997).

As rivers become larger (stream orders 4-6) the dominant organisms are autotrophic, or capable of self-nourishment (Vannote et al., 1980). In this portion of the continuum, streamside vegetation is less important for energy as incoming allochthonous material is mainly fine particulate organic matter (FPOM) from upstream that is insignificant as a food source (Vannote et al., 1980; Karr and Dudley, 1981). Instead, as stream widths expand and sunlight penetrates the water increasing temperature and photosynthesis production, invertebrates in this section of the continuum feed on algae and plants (Vannote et al., 1980; Karr and Dudley, 1981; Bernthal, 1997).

In the largest streams (stream order greater than six), the stream again becomes heterotrophic primarily because depth and turbidity limit photosynthesis, although free-floating algae (phytoplankton) do occur (Vannote, et al., 1980; Karr and Dudley, 1981). In this portion of the continuum, FPOM from upstream is the primary food source for invertebrates (Vannote, et al., 1980).

The RCC has undergone criticism because it was developed in the framework of ideal river ecosystems and neglects to consider disruptions (human or natural) along the river (Ward and Stanford, 1983; Carpenter, 2001; Rice et al., 2001). For instance, impoundments such as dams and confined headwaters disconnect upstream and downstream portions (Ward and Stanford, 1983). Others suggest that tributaries and significant bank erosion can also disrupt the continuum (Ward and Stanford,
Additionally, the RCC is limited geographically because the model was developed in the context of forested watersheds in Pennsylvania, and is not always appropriate for all environments.

Although the RCC has gained criticism because it fails to consider interruptions that disrupt the continuum and is geographically limited, it still offers a valuable model for testing in other regional settings (such as the Midwest) to help comprehend the dynamic network of inputs, exchanges, storage, and consumption processes in stream ecosystems. Additionally, the RCC demonstrates the importance of riparian vegetation in stream corridors as part of the network that makes a healthy stream ecosystem. Other models have been developed to determine the physical, chemical, and biological conditions and integrity of streams and riparian ecosystems. However, before discussing other biotic and physical indices and techniques used to assess the condition of streams and riparian ecosystems, it is important to continue discussing the importance of riparian corridors, as well as the vegetative characteristics of effective corridors.

The size and density of an effective riparian corridor is a subject of considerable debate. The literature reveals conflicting viewpoints as to the proper width, height, density, and vegetation type for a riparian buffer strip to be considered effective (Smith, 1992; Dosskey et al., 1996; Schultz, et al., 1997; Abernethy and Rutherford, 1998; Foley and Ridgway, 2000). For example, Dosskey et al. (1996) proposed that a narrow corridor of 7.6 to 10 m (25 to 30 ft), with slopes less than fifteen percent, may be effective in filtering sediments and nutrients from agricultural
runoff. On the contrary, studies conducted on Iowa State University test plots found that a buffer strip of at least 20 m (66ft) is necessary for filtering sediment and chemicals from surface runoff (Schultz et al., 1997). Results from that study also indicated that a minimum buffer width of 15 m (50 ft) (with slopes less than 5 percent) is required if the only purpose is to remove sediment from surface runoff.

In a study conducted in Virginia, a 4.6 m (15 ft) wide vegetative filter strip was effective in removing 55 percent of total nitrogen and 60 percent of the phosphorus from run off water (Smith, 1992). Another experiment in northeast Iowa performed on both seven and twelve percent slopes revealed "70 percent of sediments from fields were removed within the first [3.1 m] 10 ft of a vegetative filter strip and more than 95 percent removed within [10 m] 30 ft" (Smith, 1992, 2).

Adjacent land uses must also be considered in determining the effectiveness of buffer strips since different land uses impact streams in various ways (Schultz et al., 1997). For streams surrounded by or bordering agricultural lands, Schultz et al. (1997) suggest that an effective riparian buffer strip should be approximately 18.3 m (60 ft) and consist of at least three zones with varying heights and vegetation types. According to these authors, the first zone closest to the stream channel must be a minimum of 10 m (30 ft) and be comprised of fast and slow growing trees. The middle or second zone should be at least 4 m (12 ft) in width, comprised of shrubs that are adaptable to dry and wet soil conditions. The third zone, farthest from the stream next to the cropland, is a minimum of 6 m (20 ft) and consists of native grasses and forbs.
While Schultz et al. (1997) propose a multi-story, multi-zoned corridor is the ideal type of buffer strip, others suggest that buffer length is more important that buffer height (Pearce et al., 1997; Lyons et al., 2000). Lyons et al. (2000) proposed that grassy or herbaceous buffer strips in some situations are, in fact, more suitable and provide advantages over forested corridors. Their results suggested that grassy vegetation in agricultural watersheds was more effective in preventing bank erosion and filtering chemicals and nutrients from sediment. Similarly, in a study conducted by Pearce et al. (1997), the efficiency of grass buffer strips and height was studied instead of distribution, density, and diversity of vegetation. It was concluded that the buffering length of grass strips was more important that buffer height for filtering sediments from runoff.

Most researchers agree that an effective width is dependent on location, site conditions, and the objectives of community and landowner management (Forman, 1995; Dosskey et al., 1996; Schultz et al., 1997; Foley and Ridgeway, 2000). Similarly, Forman (1995) suggests that three issues should be addressed when considering how wide a corridor should be. They are (1) delineation of ecological processes and purposes performed (i.e. effects of nutrients, species, and energy movement through the corridor); (2) identification of the spatial structure (i.e. stream order: low-order streams require more corridor width because of allochthonous detritus and chemical input from surrounding matrix); and (3) a combination of the previous two steps, “by linking the most sensitive ecological processes with the spatial structure” (Forman, 1995, 243). Thus, the ideal stream corridor width is
dependent on a number of factors including environmental, physical, and human interactions, as well as community and regional perspectives and concerns.

In summary, a riparian corridor is important because it performs many functions and operates as part of the overall stream ecosystem. First, trees along stream banks provide shade, which helps to maintain cooler water temperatures, and are essential to cool water fish such as trout and salmon (Forman, 1995; Bernthal, 1997). Second, over-hanging and fallen branches help to slow stream velocity, which is beneficial in providing areas for fish to hide or rest. Third, vegetation along a stream provides organic material for organism consumption, and also provides cover for insects that are also a source of food for fish (Forman, 1995, Takashi, et al., 2002). Fourth, vegetative corridors absorb nutrient and chemical input from surrounding land use activities. Lastly, vegetation along streams helps to slow surface runoff, absorbs floodwaters, protects soil from erosion, and ultimately reduces sedimentation in streams.

Assessing Erosion, Water Quality, and River Health

In addition to the RCC discussed above, several techniques and protocols have been developed to determine the condition, quality, and integrity of streams and riparian ecosystems, (Karr, 1981,1999; Simonson et al., 1994; Wang et al., 1997; Mensing et al., 1998; Hawkins et al., 2000, Scholz and Booth, 2001). These methods include a wide range of water quality parameters including physical and chemical indicators that measure and assess water quality. The examples and models that follow mainly focus on physical indicators, such as stream channel morphology as
well as bank and vegetative corridor conditions, since physical characteristics have a greater effect on water quality and riparian ecosystems than chemical factors (Scholz and Booth, 2001).

Physical indicators may include the assessment of biological variables, such as species (flora and fauna) population and diversity. The presence of pools, riffles, and woody debris in many low order streams are also good physical indicators of healthy rivers because they represent the dynamic equilibrium of a river’s natural process while providing habitat for biological communities (Leopold and Maddock, 1953; Vannote et al., 1980). The presence (or absence) of bank erosion is used to assess slope stability, and in some instances, visual estimations of erosion can be manipulated to provide quantitative measurements for evaluating river conditions (Scholz and Booth, 2001). In addition, extracting physical and biological information from riparian corridors can also be used to assess and gauge erosion, water quality, and river health (Gurnell et al., 1996; Forman, 1995; Scholz and Booth, 2001).

Models for Measuring River Ecosystem Health and Integrity

The following models are representative of the techniques and protocols used to physically assess and determine the condition of river systems. They include the Index of Biological Integrity (IBI), Habitat Quality Rating (HQB), and methods for quantifying channel conditions based on vegetation and erosion, hereafter called the Erosion Index (Appendix A).

The IBI developed by James Karr (1981), also known as the multimetric approach, uses biological indicators such as fish species and communities to assess
the quality of streams. Biological conditions and ecological processes are examined to discover human impacts that threaten natural and biological processes. As Karr (1999, 226) states, "The core principle of the multimetric IBI is to detect divergence from biological integrity—divergence attributed to human actions".

Others have adapted Karr's IBI to explore the interactions and relationships between riparian ecosystems and human activities. For example, Mensing et al. (1998) used Karr's IBI to explore relationships between riparian wetland communities and anthropogenic disturbances and Wang et al. (1997) incorporated the IBI (as well as a Habitat Quality Rating, discussed below) to examine watershed land use effects on the health of streams and riparian habitats. Both studies concluded that biodiversity assessments were feasible and reliable methods to determine human land use impacts on riparian ecosystems.

Hawkins et al. (2000) and Simpson and Norris (2000) have adapted a format that compares the observed taxa of a site to those predicted to occur at that site if there were no human alteration. Predictive Models, as they are called, are built from biological and environmental data collected from reference sites that are minimally impacted by human disturbances (Norris and Hawkins, 2000). These reference sites are then used as an empirical basis to compare the relative conditions of other sites (Hawkins, et al., 2000). Norris and Hawkins (2000, 15) claim that Predictive Models are superior to multimetric approaches (such as Karr's IBI) in three ways:

"(1) It provides site-specific prediction of the composition of biota at test sites and thus allow direct measurements of an easily understood component of biological integrity (loss of biodiversity), (2)
assessments require no assumptions regarding the specific types of stresses affecting biota, and (3) predictive models use independent data for matching test sites with reference sites for producing assessments”.

The Habitat Quality Ranking system is used to assess and rank the quality of riparian habitat. This method adapted by Simonson et al. (1994) and used in conjunction with the IBI by Wang et al. (1997) standardizes a framework for evaluating fish habitats in Midwestern streams. Habitat variables that are used to determine healthy stream ecosystems include channel morphology characteristics, cover for fish, bank conditions, and riparian vegetation (Wang et al., 1997).

Lastly, Scholz and Booth (2001) have developed strategies and protocols that recognize six channel features that they feel are of particular importance when monitoring urban streams. These include (1) channel geometry, (2) stream corridor vegetation, (3) channel erosion and bank stability, (4) large woody debris, (5) channel-bed sediment, and (6) in stream physical habitat. Of these six channel features, only two (stream corridor vegetation and channel erosion) are discussed in this literature review since they directly relate to the erosive conditions and sedimentation concerns of the Gun River.

Stream Corridor Vegetation

Scholz and Booth’s (2001) method for assessing water quality involves describing the amount of vegetation adjacent to the stream. The parameters used to
measure the corridor vegetation include canopy, shade percentage, ground cover, and shrub layer. The approach is essentially qualitative, ranking canopy, ground cover, and shrub layer as low, medium, or high based on observer judgment. In addition, shade and canopy measurements can quantitatively be measured with a spherical densiometer in the field or (digital) extreme wide angle, fisheye pictures can be imported into imaging processing software for greater accuracy.

**Channel Erosion and Bank Stability**

Scholz and Booth suggest that for most bank erosion measurements, using a verbal ranking, with or without photos, is useful and appropriate because, "the information requires minimal effort, generally describes the current conditions, is useful for some level of trend analysis, and can locate areas for habitat restoration" (Scholz and Booth, 2001,151).

The verbal ranking system for stream bank stability, developed by Patricia Henshaw (1999), which was modeled after Galli's (1996) rapid stream assessment technique (RSAT), and adopted by Scholz and Booth (2001) is a descriptive assessment based on four categories: stable, slightly unstable, moderately unstable, and completely unstable (Appendix B). Variables such as the presence or absence of erosion, bank undercutting, exposed roots, and bank vegetation are used to describe stream bank stability. The classes are then ranked on a four-point scale (four being the most stable) to provide a means of quantifying qualitative information.

The aforementioned methods have proved useful in determining the health and integrity of riparian ecosystems in previous studies and provide a solid foundation in
creating a system for assessing erosion and the overall health of the Gun River (Appendix A, last column). The methods used in this study, to determine if there are measurable differences between land management practices and stream bank vegetative and erosional conditions along the Gun River, drew upon a combination of the techniques used in the previous studies mentioned above. The methodology chapter that follows will explain the procedure for collecting data from the Gun River.

**Literature Summary**

The literature reveals that alterations to stream channels and riparian corridors often negatively affect streams' natural and physical conditions. Furthermore, the removal of vegetation from riverbanks and floodplains increase soil erosion and increased sedimentation contributes to the degradation of the stream's ecosystem. It was expected that variations in land use and land management as well as the presence of vegetation along the Gun River influenced erosion and water quality. It was predicted that forested areas and vegetation along a bank provides slope stability, whereas residential and agricultural land uses with little natural stream bank vegetation experience erosion and bank instability.
CHAPTER III

STUDY AREA

Gun River Watershed

The Gun River Watershed is located in Allegan and Barry Counties, in Southwestern Michigan and is a sub-watershed of the Kalamazoo watershed (see Figure 1). The watershed encompasses approximately 227 square kilometers (107 mi²) of agricultural, urban, and forested land (ACD, 2003). The water source for the Gun River begins as a chain of springs, wetlands, and lakes north of Gun Lake that includes portions of Yankee Springs State Recreational Area (Michigan Department of Natural Resources [MDNR], 2002). The Gun River is a low-order stream that flows out of Gun Lake, in Barry County and flows south-southwest through much of Allegan County, where it eventually flows into the Kalamazoo River. The length of the Gun River is approximately 22.5 km (14 mi) from source to mouth. Figure 2 illustrates the length of the Gun River and its conjunction with the Kalamazoo River in the south.

The Gun River is unique in that a downstream portion of the River is recognized as a coldwater fishery and supports trout habitat (ACD, n.d.). As a result, it is one of the few rivers in southwestern Michigan that is a state designated trout stream (ACD, 2000). However, trout populations are not self-sustaining as a consequence of habitat degradation due to past dredging projects and current
Figure 1. Gun River Watershed, a Sub-Watershed of the Kalamazoo, Southwestern Michigan.
Figure 2. The Gun River, Allegan County.
sedimentation problems. Instead, the MDNR annually stocks trout to the Gun River (ACD, 2003). In addition, a twelve-mile section of the upstream portion of the Gun River is designated as an inter-county drain (ACD, 2000), in which Lynn Fleming, Allegan County’s drain commissioner exercises complete autonomy and control. As drain commissioner, one of his responsibilities is in the maintenance of “…a comprehensive storm water management system” (Allegan County, 2000, 20). Therefore, it is Fleming’s job to assure that the Gun River acts effectively as a drain to remove storm water from the surrounding land.

The fact that the Gun River is considered a drain has significant consequences for the biological and chemical components of the River. Sedimentation that enters the stream from surrounding land use activities in the watershed is a serious problem, and is considered the primary pollutant in the Gun River (ACD, n.d.). Additionally, since the stream functions as a drainage system for the surrounding agricultural, commercial, and residential land, other pollutants such as “pathogens, phosphorus, PCBs, mercury, and nutrients” have been found in the Gun River (ACD, n.d., 1). Unfortunately, inorganic fertilizers and farm runoff (mostly phosphorus) from upstream areas contribute much of the non-point source pollution downstream, threatening the health of the trout, macro-invertebrates, and other aquatic organisms, as well as their habitat (ACD, 2000).

Studies and tests conducted by the MDEQ indicate “that habitat and biological communities in the Gun River are significantly degraded due to non-point source pollution” (ACD, 2000). Results of the MDEQ’s sampling of Total Maximum Daily
Load reveal, “the Gun River ranks as the third highest contributor of phosphorus loads to the Kalamazoo River/Lake Allegan system...” (ACD, 2000). The excess of nutrients and sediments in the Gun River, and Kalamazoo River, create anaerobic conditions, lowering water quality, degrading aquatic habitats, limiting species diversity, and reducing fish populations.

Historical Changes to the Gun River

The past uses of the Gun River and the land along its banks has a direct effect on current conditions. The Gun River has been straightened and dredged in the past to speed up the process of removing excess water from farmlands and other developed areas. This procedure has changed the physical characteristics of the Gun River and its floodplain. For instance, the upstream portion of the Gun River is relatively straight and has few meander bends. The downstream portion does have meandering bends and associated pools, but riffles are rare.

Documents regarding the Gun River are maintained at the Allegan County Drain Commissioner’s Office where they are available to the public. The oldest documents concerning the Gun River date back to 1903. These documents are the first legal records in which property owners signed over legal control of their property adjacent to the River to Allegan County. These documents entitled, Release of Right of Way, gave the County the authority to channelize and dredge the river to establish an inter-county drain. The Release of Right of Way stated “For and in consideration of prospective benefits to be derived by reason of the locating, establishing, and
construction of a certain drain under the supervision of the County Drain Commissioner...” (Allegan County, n.d.a).

In 1903, 21 property owners had signed over their right of way of property to the County, including the Grand Rapids and Indiana Railway Company, a Michigan Corporation. In 1914, 35 more signatures indicated that property owners had signed over the right of way to their property along the River (Allegan County, n.d.b). In 1915, the project was only partially complete. Unfortunately, no records were found that indicate how much of the drain had been completed or which portion of the River had been channelized and established up to that period.

In 1935, the County established a 23-meter (75 ft) easement for the Gun River. This meant that the county drain commissioner now had the right of way to a distance of 23 m from the center of the drain. This easement continues to be part of the drain policy today. In fact, property owners need the permission of the drain commissioner to build permanent structures within the 23-meter easement.

There were no documents found that reveal the exact dates for the completion of the Gun channelization project. Instead, it is suggested by documentation that the channelization project had been completed by 1946. In 1946, The Release of Right Way documents had changed the declaration from the establishment of the drain (in 1903 and 1914) to the maintaining of the drain. Release of Right of Way documents signed by property owners between the dates of 1946 to 1949 read, “For and in consideration of prospective benefits to be derived by reason of the cleaning out,
deepening, widening, extending, and placing control structures…” (Allegan County, n.d.c, 1).

The mid-twentieth century was the last time the Gun River experienced any extensive dredging project. Since then, small-scale projects on the River have mainly involved the cleaning and removal of organic and inorganic material, such as large woody debris and trash. In 1985, Allegan County took on a massive clean-up and restoration project to remove much of the obstructive material in the Gun River.

Today, Fleming, assists in yearly inspections to assess the condition of the Gun River, in which he reports and makes assessments as to the current state of the River. For example, on a canoe inspection on May 15, 2001, Fleming, accompanied by Tom Doyle (drain commissioner for Barry County), Andy Raymond, and Abby Eaton, both of the Michigan Department of Agriculture, assessed that “large woody debris is a major concern [impairing agriculture, recreation, and diverting stream flow], but that, generally, the Gun River needs minor maintenance” (Fleming, 2001).

The past projects on the Gun River have had a direct impact on the current channel and bank conditions. Straightening of the River has increased flow velocity, which in turn increases the amount and rate of scouring and erosion along the banks. Erosion is a problem along the Gun River banks, as the river “naturally” recovers by reaching a state of dynamic equilibrium through channel widening. The erosion has gained the attention and interest of many of the residents and stakeholders within the watershed, especially riparian property owners who are concerned about the encroachment of the River and the loss of property. This is an issue that property
owners direct to Fleming. Ironically, "They [owners] want great capacity but don't want to yield width on the property" (Fleming, n.d.).

As evident by community involvement in designing a watershed management plan, residents and stakeholders are concerned about the condition of the watershed. Best management practices in the watershed will help to protect and conserve the Gun River for its resources and recreational uses for current and future residents.

**Watershed Geology**

The Gun River watershed is a landscape that is mostly comprised of flat poorly drained soils formed of unsorted sands and gravels of postglacial alluvium (Michigan Geologic Survey Division, 1982). The watershed is situated in the "Michigan/Indiana Till Plains Ecoregion, which is characterized by irregular plains, oak-hickory and beech-maple forests, cropland and pastures, and gray-brown podzolic soils" (ACD, 2003, 1). The glacial outwash plain that the Gun River flows through is referred to as the Gun Plain. The soil types found in the Gun Plain are primarily of the Glendora-Adrian-Granby association (Knapp, 1987). These soils are comprised of sandy loam and loamy sands that are poorly drained (Duffy, 1991). Therefore, surface runoff is slow or ponded (Knapp, 1987).

Wetness and flooding are major concerns for land use activities where these soil types are present. Unless tile drains or other measures are taken to remove excess water, these soils are unsuitable for agricultural production. When steps are taken to drain the soil, crops such as corn, soybean, small grains, hay, as well as specialty crops such as celery, potatoes, and asparagus can be grown (Knapp, 1987).
Hydrology

Gun Lake is a primary source of the Gun River and contributes a great deal to the stream flow. A dam just above Patterson Road controls the amount of water allowed to flow into the River. The dam helps to control lake levels, but also prevents overflow during dry periods. Ground water, natural tributaries, and man-made drains also contribute to the stream flow throughout the length of the River.
CHAPTER IV

MATERIALS AND METHODS

Land Use Data

Two questions were explored which helped to address bank erosion and current conditions of the Gun River:

1) Are there measurable differences between land management practices and stream bank vegetative and erosional conditions along the Gun River?

2) Are there differences in the stream bank vegetative and erosional conditions between the upper half of the river, which is designated as an inter-county drain and flows through primarily agricultural land use, with the lower half of the river that has more characteristics of a natural river, such as vegetative riparian cover, meanders, and the presence of large woody debris?

To answer these questions, channel stability along the Gun River was evaluated using qualitative observational methods and quantitative measurements of stream bank conditions and physical features as indicators of slope stability based on the Habitat Quality Rating (Simonson, et al., 1994), Index of Biological Integrity (Wang et al., 1997; Mensing et al., 1998), and an Erosion Index adopted by Henshaw (1999). Several recent stream bank and watershed conditions were examined to evaluate river conditions and were used as indicators of stream bank stability (Appendix A, last column). The following variables were used to assess river
Stream Selection

The fact that the Gun River is experiencing profound erosion along the channel banks creates concern for property owners about the encroachment of the river and the loss of property. Additionally, as evident by community involvement in the development of a watershed management plan, there is an immediate interest in protecting the River from increased sedimentation and chemical contamination due to bank erosion and surface runoff.

A twenty kilometer (twelve and a half mile) segment of the Gun River, beginning at the stream crossing at Patterson Road and ending at the bridge crossing of 107th Avenue, was chosen based on locations of erosion sites previously identified by Fishbeck, Thompson, Carr, and Huber (FTCH, n.d.). The stream crossing at Patterson Road marks the first sampling site and the last bank observation is located approximately 20 m (66 ft) upstream of 107th Avenue (Figure 2).

Site Selection

Sixty-seven sites at locations varying from approximately 50 to 723 meters apart were sampled along a twelve and a half mile stretch of the Gun River. The average distance between the 67 sites was approximately 300 meters. Sixteen of the
67 sites included the sampling of both banks as a result of logistics and the specific geography of sites. For instance, residential land use along the Gun River was often located at road crossings on both sides of the River. In order to acquire an adequate number of samples for the residential land use category, data collected from both banks were required. Thus, the sampling of both banks at sixteen of the 67 sites resulted in a total of 83 bank observations.

Sample sites were chosen on the basis of land use management and reconnaissance trips, in addition to fifteen bank locations identified as severely eroded by FTCH in the spring of 2002. It was originally intended that the sampling of 20 sites within each land use (residential, agricultural, and forested), in addition to the fifteen identified sites, would be sufficient to provide an adequate sampling distribution. However, the sampling of both banks at sixteen locations, the distribution of the fifteen erosion sites identified by FTCH, and the fact that there are few residential areas along the upstream portion of the river, constrained and influenced the site distribution. Additionally, it was realized after reconnaissance that approximately two miles of the river flows adjacent to 2nd Street and that bank conditions on the east side of the Gun River would be influenced by this land use (Figure 2). Based on this information a fourth land use category was added, considered as agriculture/road (the west bank bordered agricultural land use activity). Sites located adjacent to 2nd Street involved the sampling of both banks, to combine the two land uses into one. The final result was 27 agricultural, 27 forested, 19
residential, and 10 agricultural/road sites sampled. At least one of the fifteen FTCH identified erosion sites were found in each land use category.

Specific site location and the distances between sites were based on several factors, determined prior to field data collection. First, maps provided by FTCH revealed the locations of the identified erosion sites. Second, stratified sampling techniques established the minimum distances between sites for agricultural, agriculture/road, and forested land uses. However, neither stratified sampling techniques nor predetermined coordinates influenced the site section for residential land use. Instead, every occurrence of residential property along the banks of most of the Gun River (up-stream portion) warranted site selection since very few residential areas straddle the river. On the other hand, residential property makes up almost all of the land use along the Gun River downstream of 7th Avenue (Figure 2). Site criterion along this portion was chosen by selecting and sampling every third property parcel, based on stratified sampling techniques (22 houses, 7 sites).

The coordinates for all sites were established using USGS 7.5 minute Topographic Quadrangle maps, prior to field data collection. Locations were then found in the field using a Magellan 315 coarse-acquisition GPS handheld navigation unit. However, errors and restrictions on locating predefined coordinates did arise in the field due to canopy obstructions (which can impede GPS satellite signals) and the fact that the GPS unit can be off by as much as 15 m (50 ft) (Magellan, 2003). This combination of site distribution and GPS accuracy levels resulted in an unbalanced
sampling design among land covers. Figure 3 shows the GPS positions for each of
the sampled locations along the length of the river.

**Land Use**

Land use data were downloaded from the State of Michigan’s Center for
Geographic Information website (State of Michigan, 2003). This site provided 1992
National Land Cover Datasets, based on 30-meter Landsat thematic mapper (TM)
data (USGS, 1999). Revealing land use management from land-cover imagery at a
30-meter pixel resolution may be problematic for micro-scale, local assessments. For
instance, residential property may perhaps be classified as “deciduous forest” (other
land cover types are possible) instead of residential if the parcel and land surrounding
the property is forested. Therefore, caution of data accuracy must be considered when
interpreting this information. However, it should not be assumed that these data are
of no value. The information was useful in revealing land cover on a much larger
scale, for example the entire watershed. Consequently, the National Land Cover
Dataset, in conjunction with the 1998 digital orthophotos, provided a means to
classify land use activity adjacent to the Gun River and the entire watershed.

**Upstream and Downstream Land Use Characteristics**

Land use activity and channel characteristics were the two primary factors
used to separate the Gun River into upstream and downstream sections. The upper
portion of the Gun River flows mostly through agricultural land and the River’s main
Figure 3. GPS Site Locations Between Patterson Road and 107th Avenue.
function along this section is to help drain the surrounding fields. This stretch of the river is basically straight and has very few sites where buffer strips are present. The downstream section the Gun River has more characteristics of a natural river, such as meanders, pools and riffles, and large woody debris. This expanse of the river is mostly surrounded by forested land use, except in the one-mile section past 10th Avenue where residential land use is prominent. Additionally, the downstream segment near the mouth of the Gun River provides the habitat necessary to support trout, such as gravel and cool temperatures. Therefore, based on these factors, 110th Avenue was decided upon as the boundary to split these two sections.

The partition of the River into upstream and downstream portions at 110th Avenue can also be justified based on natural, scenic, and recreational functions and perceptions. At a Steering Committee meeting for the Gun Water watershed management plan in the spring of 2002, a community member proposed that the riparian zone downstream of 110th Avenue be maintained and that future development in the riparian buffer zone be restricted to low impact development. The objective of this proposal is to maintain the river’s natural and aesthetics values for naturalists, sportsmen, and canoe enthusiasts.

Field Data Collection

Field data were collected over a period of seven trips beginning on July 24, 2002 and concluding on August 13, 2002. Field data collected for each variable at all sites were compiled using uniform techniques and equipment for repeatable and reliable measurements between sites, as discussed below.
Surface current velocities were estimated by floating a fishing bobber attached to a measured amount of fishing line down the center of the stream. This technique is sufficient when surface current velocities are desired (Wetzel and Likens, 1979). Five floats were timed to generate an average velocity measured in feet per second. Possibly, a more accurate technique for determining velocity would have been the use of a velocity meter, a more sophisticated tool than the bobber and line. However, after employing both methods at several of the same sampling sites and yielding extremely similar results, it was decided and justified that the bobber float technique was a sufficient way to generate surface current velocities, especially in shallower reaches.

Mean depth and stream width were also measured. Mean depth was calculated by averaging the vertical distance from the water surface to the channel bottom, measured at four equally spaced points across the river. Stream width was measured horizontally across the river, perpendicular to stream flow from bank to bank at the water surface. Current velocity, mean depth and stream width were used to calculate stream discharge (Discharge = Flow Area (depth*width)* Velocity). Additionally, the bank full width was measured horizontally across the river from the top of each bank where the slope appeared to level off into the floodplain. The different lengths between the stream widths and the bank full widths can be used to expose relative slope angles (gradual versus steep).

Slope cover was used to describe the vegetation on the bank from the water line to the top where the slope seemed to level off into the floodplain (bank full level).
Five categories were used for slope cover based on canopy complexity, heterogeneity, and structure of the slope: (1) exposed or no vegetative cover; (2) lawn, both maintained and manicured; (3) grasses, including forbs, weeds, and unattended lawns; (4) mixed grasses and shrubs, which includes forbs, weeds, and shrubs; and (5) naturalistic forest, which includes grasses, shrubs, and trees.

Additionally, vegetation type was documented in the field at each site and used to help categorize landscape types. The landscaping categories are similar to the slope cover categories in that they both review vegetation types, except that landscaping deals with the floodplain and the adjacent land use parcel, not the bank slope. Four categories were used for landscaping: (1) fields, both agricultural and open space; (2) lawns; (3) naturalistic; and (4) roads, specifically 2nd Ave. The landscaping variable is useful for indicating relative root structure and vegetation density, which aids in supporting stream banks. Also, landscaping can influence slope cover, vegetation type, and erosion. For instance, residential mowed lawns (that are maintained up to the water’s edge) are less effective in supporting slope stability than native, riparian vegetation with well-established root structures (Schuppener, 2001). Depending on shoreline and lawn management, residents may accelerate erosion and bank instability problems by removing riparian vegetation.

To measure canopy density quantitatively, digital wide-angle pictures of the canopy were taken in the field and later analyzed in ERDAS IMAGINE 8.5 (ERDAS, 2001), a remote sensing image processing software. In order to capture the complete canopy over the bank and river, a fish-eye lens was used to take a spherical picture of
the sky, from the waters edge of the sampled bank. The fish-eye lens produced an image of most of the sky in all directions above the horizon, providing a 170-degree angle above the ground. Figure 4 illustrates the spherical picture of the sky and canopy taken at site thirteen on July 24, 2002.

Figure 4. Spherical Picture of Canopy and Sky at Site 13.

The spherical picture was then converted into a raster format recognizable to ERDAS to permit imaging processing. The ERDAS software allows the user to create a Supervised Classification of pixels based on homogenous colors. Thus, green pixels, that represent vegetation and canopy, were categorized and classified
differently than all other pixel colors and statistics generated in the program help to log all like pixels into the same group. The Supervised Classification of homogenous pixels are saved as the picture’s signature and can then be used to determine the percent difference between the pixels that represent vegetation and the pixels that represent the sky. The signatures created and used to determine canopy density in this study include all vegetation in the spherical picture, including grasses and brush. Grasses and brush were considered as part of the canopy because the literature reveals that vegetation on the slope does in fact provide some protection from wind and precipitation, in addition to the upper canopy (Pierce et al., 1997; Siepel et al., 2002). Figure 5 shows the supervised pixel classification of site 13 used to calculate canopy density.

For the purpose of this study, it was decided that a riparian buffer zone of 10-meters would be a sufficient width for supporting slope stability based on Dosskey et al. (1996) and Smith’s (1992) findings that a corridor of this size was effective in filtering sediment. To help ascertain the riparian buffer zone along the Gun River, Western Michigan University’s Geographical Information Science (GIS) department provided 1998 digital orthophotos. The aerial photographs were imported into ERDAS imaging software to resolve whether or not there were 10-meter riparian buffers strips at each site. In instances where the 10-meter distance was questionable, a measuring tool function in ERDAS was used to solve the matter.
Data Analysis

Erosion Index

A verbal ranking system, based on the erosion index (Appendix B), was used to describe and categorize slope stability and bank conditions based on visual observations and indicators used by Henshaw (1999). Bank stability was assessed in the field and again in the lab, using oblique digital pictures taken at each site; the latter provided the convenience of analyzing and confirming slope conditions on the
computer. Figures 6, 7, 8, and 9 illustrate four different types of banks and reveal the conditions used to categorize, or rank, slope stability.

![Figure 6. Completely Unstable, Category I on the Erosion Index.](image)

The bank on the right (east) side of Figure 6 was assessed as a completely unstable slope. Aside from the tree, which acts a hard point, the slope is exposed and no perennial vegetation is present on the slope. The east bank is adjacent to residential land use and the picture reveals a maintained and manicured lawn as the landscaping type.

The bank in Figure 7 was classified as a moderately unstable bank. Extensive erosion and undercutting is present. Perennial vegetation is present, but sparse at the water line and fine root hairs are also common where undercutting is present. The
vehicle in the top right corner of the picture reveals that this site is adjacent to 2nd Street. This location was identified by FTCH as a problem site for bank erosion.

![Image of a site classified as Moderately Unstable, Category II on the Erosion Index.](image)

*Figure 7. Moderately Unstable, Category II on the Erosion Index.*

The bank in Figure 8 was classified as a slightly unstable bank. The picture reveals that perennial vegetation is present in most places, providing stability. However, some minor erosion and bank undercutting is present. Additionally, exposed roots are rare but present. This site is adjacent residential land use. Although trees are present, it was determined that this site was absent of a riparian buffer strip based on the criteria explained above. The picture also reveals that the dominant landscaping type is a manicured mowed lawn.
Figure 8. Slightly Unstable, Category III on the Erosion Index.

Figure 9. Completely Stable, Category IV on the Erosion Index.
Figure 9 reveals a completely stable bank. Perennial vegetation, shrubs and grasses are present at the water line and cover the entire slope. The adjacent land use is agricultural. Although weeds reveal that crops are not bordering the riverbank, this site was determined to be absent of a riparian buffer strip. Open field was considered the landscaping type.

Summary Statistics

Data were organized and entered into the statistical software program SPSS Release 10.0 (SPSS, 2001). Summary statistics were first calculated to reveal frequency information about data for each variable. Eight primary variables measured and observed in the field and in the computer lab were used in statistical analysis tests. The variables that were considered most important are: (1) land use management; (2) slope stability, based on the erosion index; (3) slope cover conditions, based on vegetation type and canopy complexity; (4) the presence or absence of a riparian buffer zone; (5) landscaping characteristics; (6) physical channel and stream characteristics, which include velocity, depth, width, and discharge; (7) canopy density; and (8) upstream and downstream site comparison of vegetative and erosive conditions between the two portions of the stream.

Chi-squared

The problem statement that the chi-squared ($X^2$) test is used to answer can be summarized as: Are there associations between land management and vegetative
cover, as determined by the variables measured and observed at each site, against slope stability, as determined by the erosion index? The null hypothesis states that erosion is not influenced by land use activity and vegetation characteristics, whereas the alternative hypothesis states that land management and vegetative covering influence erosion.

Additionally, $X^2$ was used to assess if there were differences in the vegetative and erosional conditions between the upstream and downstream portions of the river since these two portions were physically different. The null hypothesis states there are no differences in the stream bank vegetative and erosional conditions between the two portions of the river, the alternative states that there is an association.

ANOVA

One-way analysis of variance (ANOVA) was used to determine if there are significant variations among the means of velocity, average depth, stream width, discharge, and canopy density. Variations among the means would indicate that slope stability is dependent on one of the five hydrological variables.

K-Means Clustering

K-means clustering was used to organize physical stream channel measurements into separate groups or classes, supplementing information from ANOVA. The algorithm helps to divide large data sets by minimizing variability within groups and maximizing variability between groups (StatSoft, 2003). Therefore, K-means clustering was used to combine site measurements into
homogeneous subgroups of cases, or sites, based on the following five variables: (1) bank-full measurements; (2) stream width; (3) average depth; (4) velocity; and (5) discharge.

Four cluster centers were generated and then used in chi-squared statistical analysis against the erosion index. Similar to the preceding $X^2$ test, used to determine if there were associations between slope stability and surrounding land use activity and land cover characteristics, $X^2$ can be used to determine if there are any associations between the cluster groups and slope stability.

Principal Component Analysis

To better understand the environmental factors that control or influence erosional patterns, principal component analysis (PCA) was used to generate “factors” or principal components (PCs) that could help explain arrangements in the distribution between variables. PCA is a type of factor analysis and data exploration that defines PCs that convey important patterns in the original variables to help make clear a few major gradients that may explain the variability in the total data set (McGarigal et al., 2000). Each component is a linear combination of the original variables grouped along an axis, or dimension, that describes the maximum variation between the variables as a gradient. In other words, PCA assumes that the variables change along linear gradients for each component, so that components with high loading scores explain much of the variance between variables.
The first component is determined along a linear axis and always explains the maximum amount of variance between the variables (Robinson, 1998). The second component explains the next greatest amount of variation between the variables and each successive component explains less of the variance than the prior component. Additionally, each succeeding component is orthogonal to the prior component. This means that each axis is at a 90-degree angle from one another, so that each factor is not overlapping and is independent of each other. An in-depth discussion of the PCA procedure and interpretation for this study is provided in Appendix C.

Although PCA does not directly test the research hypothesis of this study it is useful for data exploration and will help to better understand the environmental and vegetative factors along the Gun River that influence erosion patterns. The PCA was conducted using seven environmental and physical variables of the river channel and adjacent riparian zone in which variation between the samples could be identified and examined. The seven variables include: (1) slope cover; (2) buffer strips; (3) canopy density; (4) bank-full width; (5) stream width; (6) average depth; and (7) velocity. In order to include slope cover as one of the variables in the PCA, nominal data had to be converted to ordinal data. Five classes were used to rank slope cover types (naturalistic, mixed grasses and shrubs, grass, lawn, and exposed). Consequently, slope cover is ranked according to canopy complexity, with 5 representing the most complex canopy structure (naturalistic or forested slopes) and 1 representing the least complexity (exposed slopes).
PCA was also applied to include the buffer strips variable, which is categorical *dichotomous* data, or binary data (absent or present). Usually, PCA is only applied to categorical *polymorphic* data (more than two possibilities) because it will cause more redundancy in the later (higher) principal components (McGarigal *et al.*, 2000). However, binary data were used in this study because generalizations and exploration of real world data can still be drawn by the components and should be accessed for usefulness to the interpretation.
CHAPTER V

RESULTS

Statistical Tests

Summary Statistics

Land Use

Of the 83 total banks sampled, both forested and agricultural land uses involved the sampling of 27 banks (Table 1). Nineteen of the observed sites bordered residential property and the remaining ten sites were grouped into the agricultural/road category based on these site’s proximity to 2nd Street.

Table 1

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forested</td>
<td>27</td>
<td>32.5</td>
</tr>
<tr>
<td>Agricultural</td>
<td>27</td>
<td>32.5</td>
</tr>
<tr>
<td>Residential</td>
<td>19</td>
<td>22.9</td>
</tr>
<tr>
<td>Agricultural/Road</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Erosion Index

The summary statistics for the erosion index revealed that there is a fairly even distribution of slope types (categories I through IV) for all 83 sites (Table 2).
Completely unstable banks (category I) made up nearly 22 percent of the total sites sampled. Categories II and III, moderately unstable and slightly unstable respectively, together comprised 53 percent of the sampled sites. Finally, 21 banks were considered completely stable (category IV) and made up the remaining 25 percent of the sampled sites.

Table 2
Erosion Index Summary Statistics

<table>
<thead>
<tr>
<th>Class</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>18</td>
<td>21.7</td>
</tr>
<tr>
<td>II</td>
<td>22</td>
<td>26.5</td>
</tr>
<tr>
<td>III</td>
<td>22</td>
<td>26.5</td>
</tr>
<tr>
<td>IV</td>
<td>21</td>
<td>25.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Canopy Density

In order to simplify canopy density data for statistical analysis, ratio data for each of the 83 observations were aggregated into ordinal data. Four categories, based on percentages, were used to rank density from absent to high: (a) all sites with zero percent canopy were grouped as absent (none of the sites had a canopy density between one percent and 39 percent); (b) 40 to 70 percent as low; (c) 71 to 80 percent as moderate; and (d) all sites with 81 to 100 percent canopy density were aggregated as high. Employing these categories, fifteen sites were absent of a canopy, four sites
were considered to have a low canopy density, thirteen were grouped as moderate, and fifty-one sites had high canopy density measurements.

**Riparian Buffer Strips**

Riparian buffer data were treated as nominal, binary data for statistical analysis and were recorded as “present” or “absent”. Thirty-eight sites were absent of a riparian buffer strip whereas a buffer zone was present at forty-five sites.

**Landscaping**

Forty-one sites were considered naturalistic. This category, by far, contained the largest number of sites with nearly 50 percent belonging to this landscaping class. Fields, both agricultural and open, occurred at twenty-one sites. Eighteen sites had manicured lawns (recall nineteen residential sites) and only three sites had banks directly bordering 2nd Street.

**Slope Cover**

Summary statistics for slope cover, categorizing the vegetative structure of the slope (based on canopy complexity), revealed a fairly uneven distribution of sites between slope cover classes. Table 3 displays the number and distribution of slope types for all 83 observed slopes.
Table 3

Slope Cover Summary Statistics

<table>
<thead>
<tr>
<th>Slope Cover</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forested</td>
<td>29</td>
<td>34.9</td>
</tr>
<tr>
<td>Mixed Grass and Shrubs</td>
<td>8</td>
<td>9.6</td>
</tr>
<tr>
<td>Grass</td>
<td>17</td>
<td>19.3</td>
</tr>
<tr>
<td>Manicured Lawns</td>
<td>11</td>
<td>13.3</td>
</tr>
<tr>
<td>Exposed</td>
<td>18</td>
<td>22.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Upstream and Downstream Differences

Fifty-four sites were treated as upstream sites and twenty-nine sampled banks were regarded as downstream locations. Recall that the uneven distribution between the two portions of the river was due to the physical characteristics of the river and the surrounding land management practices (including meanders and naturalistic vegetation). Sites were not simply split in half based on distance (upper 6 miles versus lower 6 miles) or the division of all 83 sites into two halves.

Results of Chi-Square

Chi-Square was used to determine if there were associations between slope stability and the surrounding land use activity and land cover characteristics. Table 4 reveals the output of the chi-squared test results.
Table 4

Chi-Squared Results

<table>
<thead>
<tr>
<th>Variables</th>
<th>X²CV</th>
<th>Value</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>16.919</td>
<td>25.315</td>
<td>9</td>
<td>0.003*</td>
</tr>
<tr>
<td>Slope Cover</td>
<td>21.026</td>
<td>94.957</td>
<td>12</td>
<td>0*</td>
</tr>
<tr>
<td>Buffer Strip</td>
<td>7.815</td>
<td>8.845</td>
<td>3</td>
<td>0.031*</td>
</tr>
<tr>
<td>Landscaping</td>
<td>16.919</td>
<td>28.314</td>
<td>9</td>
<td>0.001*</td>
</tr>
<tr>
<td>Canopy</td>
<td>16.919</td>
<td>6.683</td>
<td>9</td>
<td>0.67</td>
</tr>
<tr>
<td>Up versus Down</td>
<td>7.815</td>
<td>7.853</td>
<td>3</td>
<td>0.049*</td>
</tr>
</tbody>
</table>

*Significant at the 0.05 level.

Where $X^2$ CV is the chi-squared critical value, which determines the rejection region based on degrees of freedom (at the $\alpha = 0.05$ level). Value indicates the calculated $X^2$, df represents the degrees of freedom, and Sig. is the significance of Pearson’s $X^2$ value used to determine whether to accept or fail to reject the null hypothesis. Significance also indicates the strength of the association.

The results indicate that there are significant associations between erosion and land use, slope cover, buffer strips, landscaping, and, to a lesser extent, up versus downstream sites. However, there is no association between erosion and canopy density. The results (where $X^2$ tests of significance reveals associations) warrant further investigation of the contingency tables for each of these variables (Stockburger, 1996). These investigations are in the following subsections.
Land Use

Investigation of the contingency table for land use and erosion attracts attention to a couple of interesting relationships. First, the expected count for residential land use and category II of the erosion index (moderately unstable) is 5.0. This is comparatively lower than an observed count of twelve sites that were categorized as moderately unstable. Over 60 percent of the sampled residential properties have moderately unstable banks and experience more erosion. Moreover, combining categories I and II (moderately and completely unstable), almost 70 percent of residential banks are considered unstable. Secondly, it is interesting to note that residential land use is the only land use category that had zero observations of completely stable slopes (erosion index category IV), indicating that the natural vegetative cover has been removed.

Slope Cover and Landscaping

Chi-square results for the slope cover and landscaping variables against the erosion index were characteristic of what one would expect, considering the fact that slope cover is the basis for determining slope stability and landscaping is similarly based on vegetation composition. Therefore, exposed slopes had lower scores on the erosion index (completely unstable and moderately unstable), where as naturalistic forested slopes typically were ranked higher on the erosion index (slightly unstable and completely stable). However, five observed counts of forested slopes were assessed as moderately unstable and one was determined completely unstable. Finally, nine of the eleven observed banks that were classified as having manicured
lawns for slope cover type (meaning lawns were maintained up to waters edge) were assessed as moderately unstable.

For landscaping (vegetation in the adjacent land use parcel), twelve sites that were classified as lawns were also considered moderately unstable according to the erosion index. This was considerably higher than an expected count of 4.8. Another interesting relationship that the contingency table revealed between landscaping and erosion is that nearly half (10 of the 21) of the observed sites considered fields (both open and agricultural) were also ranked as completely stable.

**Buffer Strips**

Only one comparison of the expected and observed counts in the contingency table for buffer strips and erosion draws attention to a possible relationship. Sixteen observed sites had no riparian buffer strips and were ranked as moderately unstable, where as ten was the expected count. Additionally, twelve residential properties, without buffer strips, are also ranked as moderately unstable. It is quite probable that no buffer zone exists because native riparian vegetation has been removed and replaced with ornamental grass and open lawns. Still, most of the sites with no buffer strips are considered relatively unstable, where twenty-two of the thirty-eight sites (57 percent) without buffer strips are ranked as categories II and I. Conversely, twenty-seven of the forty-five sites (60 percent) with riparian buffer strips were ranked as moderately unstable and completely stable (categories III and IV).
Upstream Versus Downstream

The significance of Pearson’s $X^2$ value for this variable (0.049) indicates that there is not a strong association for upstream and downstream differences. Still, one cell in the contingency table deserves notice. Twelve of the twenty-nine observed sites on the downstream portion of the river are ranked as moderately unstable, whereas the $X^2$ expected count is 7.7. Recall, however, that much of the residential property along the Gun River is located in the last mile section of the study area. Many of the residential banks in this downstream portion are considered unstable.

ANOVA

ANOVA was used to determine if there are significant variations among the means of velocity, average depth, stream width, discharge, and canopy density. Table 5 reveals the output of the ANOVA results generated in SPSS. All five of the calculated F-values in Table 5 are less than the critical value, where the critical F-value for $\text{df}_{3,79}$ at the $\alpha = 0.05$ level is 2.72. Therefore, the null hypothesis, which stated that there is no difference among the means of velocity, average depth, stream width, discharge, and canopy density, is not rejected and instead the means are explained by random variability. In other words, bank stability is not dependent on velocity, average depth, stream width, and canopy density.
Table 5

ANOVA Results

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>1.385</td>
<td>3</td>
<td>0.462</td>
<td>1.738</td>
<td>0.166</td>
</tr>
<tr>
<td>Within Groups</td>
<td>20.99</td>
<td>79</td>
<td>0.266</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22.375</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>317.788</td>
<td>3</td>
<td>105.929</td>
<td>1.961</td>
<td>0.127</td>
</tr>
<tr>
<td>Within Groups</td>
<td>4267.916</td>
<td>79</td>
<td>54.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4585.704</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>3606.406</td>
<td>3</td>
<td>1202.135</td>
<td>1.138</td>
<td>0.339</td>
</tr>
<tr>
<td>Within Groups</td>
<td>83434.597</td>
<td>79</td>
<td>1056.134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>87041.002</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>43.106</td>
<td>3</td>
<td>14.369</td>
<td>0.348</td>
<td>0.791</td>
</tr>
<tr>
<td>Within Groups</td>
<td>3259.705</td>
<td>79</td>
<td>41.262</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3302.811</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>1511236.6</td>
<td>3</td>
<td>503745.535</td>
<td>1.499</td>
<td>0.221</td>
</tr>
<tr>
<td>Within Groups</td>
<td>26552901</td>
<td>79</td>
<td>336112.669</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28064137</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

K-Means Clustering

K-means clustering was used to combine site measurements into homogeneous subgroups of cases (Table 6). Cluster one consists of sites that have the lowest mean values for all five variables. This cluster, which consists of sites, contains the slowest current velocities, the narrowest stream and bank-full widths, and a significantly lower average depth and discharge than the other three cluster centers. Coincidently, these sites are also spatially clustered in the field, making up the first
twenty-two consecutive sampling sites along the Gun River. However, land cover did not define the site grouping of cluster one. Although the land use in this section is primarily agricultural with grasses, shrubs, and low-lying vegetation along the banks, forested land use is also sporadically found in this section.

Table 6

<table>
<thead>
<tr>
<th>Clusters</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank-Full Width</td>
<td>41.76</td>
<td>44.66</td>
<td>46.35</td>
<td>43.63</td>
</tr>
<tr>
<td>Stream Width</td>
<td>24.26</td>
<td>37.57</td>
<td>36.06</td>
<td>37.52</td>
</tr>
<tr>
<td>Average Depth</td>
<td>10.29</td>
<td>20.88</td>
<td>19.45</td>
<td>25.48</td>
</tr>
<tr>
<td>Velocity</td>
<td>0.74</td>
<td>1.73</td>
<td>1.48</td>
<td>1.97</td>
</tr>
<tr>
<td>Discharge</td>
<td>153.45</td>
<td>1328.75</td>
<td>1015.62</td>
<td>1838.36</td>
</tr>
<tr>
<td>Number of Cases per Cluster</td>
<td>22</td>
<td>36</td>
<td>14</td>
<td>11</td>
</tr>
</tbody>
</table>

Cluster two consists of thirty-six cases and cluster three consists of fourteen occurrences. Clusters two and three are similar in the fact that they contain moderate cluster centers for each of the five variables. These sites have moderate discharge rates as well as intermediate bank-full and average depth measurements. An exception is that cluster two has the largest stream width measurements (just barely when compared to cluster four) and cluster three has the largest bank-full widths. Unlike cluster one, the occurrences of sites for cluster two are not grouped together continuously along the length of the Gun River. These sites are sporadically located,
but are primarily found adjacent to agricultural land use and in the downstream residential area. Cluster three, on the other hand, consists of sites that are generally located in the agricultural section adjacent to 2\textsuperscript{nd} Street. Therefore, cluster three hydraulic characteristics are defined by agricultural land use on one bank and 2\textsuperscript{nd} Street on the opposite bank.

Group membership for cluster four includes locations with the fastest flow velocities, the deepest average depths, and the highest discharge rates. This cluster also includes sites where the stream width is fairly wide. Eleven cases belong to cluster four and, essentially, are located along the banks of the downstream portion (where meanders, pools, and large woody debris are more prominent). It is not surprising that downstream sites should experience greater discharge rates due to tributary inputs upstream. However, it is not expected that these same sites would experience the deepest depths and the fastest currents. Usually, shallower waters experience the fastest stream flow and deeper waters slower velocities.

The four cluster centers were then used in chi-squared statistical analysis against the erosion index. The $X^2$ calculated value is 10.570, whereas the $X^2$ critical value is 16.919. Since the calculated value is less than the critical value, one would fail to reject the null hypothesis and trust that there are no associations between slope stability and the cluster groups. In other words, there are no significant differences between the observed and expected values.
Principal Component Analysis

Eigenvalues generated in PCA are used to determine which components are significant for analysis, and thus which to retain and interpret. Table 7 shows the eigenvalues extracted from the sums of the squared loadings and also reveals the percent of variance explained by the components in this study.

Table 7

<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>2.731</td>
<td>1.302</td>
<td>1.075</td>
<td>0.681</td>
<td>0.553</td>
<td>0.377</td>
<td>0.281</td>
</tr>
<tr>
<td>Percent of Variance</td>
<td>39.007</td>
<td>18.594</td>
<td>15.354</td>
<td>9.734</td>
<td>7.905</td>
<td>5.389</td>
<td>4.017</td>
</tr>
<tr>
<td>Cumulative Percent</td>
<td>39.007</td>
<td>57.602</td>
<td>72.955</td>
<td>82.689</td>
<td>90.594</td>
<td>95.983</td>
<td>100</td>
</tr>
</tbody>
</table>

The first three components in Table 7 have eigenvalues greater than one. Eigenvalues greater than one are considered significant, based on the latent root criteria, and are retained for interpretation. Eigenvalues are also used to calculate the percent of variance explained by each component. The formula for calculating the percent of variance for a component is to divide the eigenvalue by the total number of components and multiply the value by 100 to yield the percentage. For example, the percentage of variance for component one is \( \frac{2.731}{7} \times 100 = 39.007 \% \). Table 7 reveals that the percent variance of the first three components explains 73 percent of the total variance.
In addition to the latent root criteria, the scree plot criterion was also used to assess the importance of the principal components. Figure 10 illustrates the scree plot generated in SPSS and shows the line flatten or level off from component four to component seven.

![Scree Plot](image)

**Figure 10. Scree Plot.**

Investigation of the scree plot graph reveals that the line “breaks” or flattens out after component four. According to the scree plot criterion, components one, two and three are retained for interpretation. Therefore, both the latent root and scree plot criteria agree that the first three components are maintained for investigation.

The component loadings, generate from the correlation matrix (Table 10 in Appendix C), indicate how closely a variable and a component are related (McGarigal *et al.*, 2000). When the loading is large, then the component and the variables contain roughly the same information. Therefore, the larger loadings (weights) are of greater
importance for interpretation and help to define the component. Table 8 shows the factor loadings for each variable on the three extracted principal components.

Table 8

<table>
<thead>
<tr>
<th>Component Matrix</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Component 1</th>
<th>Component 2</th>
<th>Component 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope Cover</td>
<td>0.346</td>
<td>0.735*</td>
<td>-0.13</td>
</tr>
<tr>
<td>Buffer Strip</td>
<td>0.522*</td>
<td>0.469</td>
<td>0.463</td>
</tr>
<tr>
<td>Canopy Density</td>
<td>0.726*</td>
<td>0.326</td>
<td>-0.0574</td>
</tr>
<tr>
<td>Bank-full Width</td>
<td>0.326</td>
<td>-0.413</td>
<td>0.758*</td>
</tr>
<tr>
<td>Stream Width</td>
<td>0.82*</td>
<td>-0.227</td>
<td>0.0963</td>
</tr>
<tr>
<td>Average Depth</td>
<td>0.595*</td>
<td>-0.413</td>
<td>-0.425</td>
</tr>
<tr>
<td>Velocity</td>
<td>0.823*</td>
<td>-0.205</td>
<td>-0.277</td>
</tr>
</tbody>
</table>

*Indicates the highest absolute loading for a variable on each component.

A common way to interpret the meaning is to examine the component matrix and identify the highest factor loadings for each variable across components. Table 8 reveals the highest loadings for buffer strip, canopy density, stream width, average depth, and velocity all occur on PC 1. In other words, these variables, especially velocity, stream width, and canopy density with loadings approaching one, define component 1. Therefore, high canopy densities, wider stream widths, faster stream velocities, deeper depths, and the presence of buffer strips characterize PC1. Employing this standard, PC 2 is
represented by higher values of slope cover (forested and mixed grasses and shrubs) and PC 3 is defined by wider bank-full widths.

According to McGarigal et al. (2000), other significant loadings should be examined since component structure is difficult to interpret. A common rule in deciding other significant loadings is to interpret loadings greater than 0.4 or less than −0.4, but to place greater emphasis on loadings greater than 0.7 or less than −0.7 since they explain at least 50 percent of the variation (Tabachnik and Fidell, 1989). Additionally, both negative and positive loadings are important to note because they indicate direct or inverse relationships between components and variables (McGarigal, et al., 2000).

Examining all positive and negative significant loadings, PC 2 represents a gradient where slope cover and buffer strips contrast bank-full width and average depth. Thus, shallow depths and narrow stream widths, with significant negative loadings, also define PC 2. Accordingly, PC 3 is defined by bank-full widths and buffer strip on the positive side of the gradient. On the other side of the gradient, PC 3 is inversely related to average depth.

**Mapping the Principal Components**

PCA generates factor scores for each observation (site) that can be used as additional data for further analysis (McGarigal et al., 2000). The scores can serve as input data for other multivariate statistics because they are standardized values and are normally distributed. For this study, the factor scores were clustered and then mapped for analysis.
All 83 factor scores for the three components were clustered using the K-means clustering procedure employed in a previous analysis. Four cluster centers were generated and the means of the final cluster centers were used for analysis. Table 9 illustrates the four cluster centers for each component.

Table 9

<table>
<thead>
<tr>
<th></th>
<th>Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Component 1</td>
<td>-1.78044</td>
</tr>
<tr>
<td>Component 2</td>
<td>-.44541</td>
</tr>
<tr>
<td>Component 3</td>
<td>.21844</td>
</tr>
<tr>
<td>Number of Cases Per Cluster</td>
<td>13</td>
</tr>
</tbody>
</table>

A common way to interpret the meaning of the cluster matrix is to determine which PCs define the cluster. For instance, cluster 1 has a very high negative value for component 1. Recall that component 1 is defined by higher canopy, stream width, and velocity measurements. Therefore, cluster 1 is not associated with sites that have higher canopy densities, wider stream widths, and faster velocities. Put differently, environmental and hydraulic conditions for cluster 1 sites are lower stream velocities and depths, narrower stream widths, and lower values for slope cover.

On the contrary, cluster 2 has a relatively high (positive) value for PC 1, as well as PC 3. Cluster 2, therefore, represents sites that have relatively
high canopy densities, wider stream widths, faster velocities, deeper depths, and is dominated by wider bank-full widths. Continuing across clusters, cluster 3 has a strong positive relationship to PC 2 (densely vegetated sites), a negative connection with PC 1, and positive association to PC 3. Cluster 4 is positively connected with PC 1, and negatively associated with PC 2 and PC 3 (significantly with PC 3).

In summary, the environmental conditions of cluster 1 are lower stream velocities and depths, narrower stream widths, and lower values for slope cover, meaning that these sites consist of slopes with low lying vegetation (grasses and weeds). Cluster 3 is similar to cluster 1 except there is a higher and more complex canopy structure (forested and mixed grasses and shrubs). The environmental conditions for cluster 2 sites consists of greater canopy densities, wider, deeper, and faster stream conditions, as well as a presence of buffer strips. Cluster 2 also represents wider bank-full measurements. Cluster 4 sites are similar to cluster 2 except that bank-full measurements are not as wide and cluster 4 locations have lower values for slope cover (exposed, lawns, or grasses). Additionally, these sites tend not to possess buffer strips.

Next, the clusters were mapped to reveal geographically the locations of cluster membership. Two maps were created for analysis. Figure 11 shows the location of cluster membership for unstable slopes only (erosion index I and II, completely unstable and moderately unstable, respectively).
Figure 11. Unstable Slopes and the Corresponding Clusters.

Figure 12 displays the land use found at these sites. Both maps reveal a distinct geographic division between the upstream and downstream reaches.
Figure 12. Unstable Slopes and the Corresponding Land Use.

Figure 11 reveals that clusters 1 and 3 are located along the upper section of the river and clusters 2 and 4 are situated along the middle and downstream sections. Recall that clusters 1 and 3 both represent sites with
lower stream velocities, shallower depths, and narrower stream widths. However, cluster 1 has lower values for slope cover and cluster 3 experiences a higher and more complex canopy structure. Figure 11 reveals that in the upper stretches of the river, cluster 1 is associated with agricultural and residential land uses and in one unique case is adjacent to 2nd Street. Cluster 3 sites are associated with forested areas.

All residential land use and most of the agricultural land use at sites located along the downstream portion of the river are associated with cluster 4. These sites experience wider widths, faster velocities, and deeper depths, but also experience narrower bank-full widths. Additionally, these sites experience lower values for slope cover and have few buffer strips. Cluster 2 is mostly associated with forested sites, except for a few agricultural sites located about midway along the river. These sites also experience faster velocities, deeper depths, and wider stream widths, but additionally possess higher canopy densities, more complex vegetative structure, wider bank-full widths, and buffer strips.
CHAPTER VI

DISCUSSION

Statistical Tests

Chi-Squared

The hypothesis that there are associations between slope stability and the surrounding land use activity and land cover were mainly established by the chi-squared statistic test. A significance of 0.003 (at the $\alpha = 0.05$ level) for the chi-squared results for land use and erosion warranted investigation of the contingency table and evaluation of the observed and expected values exposed interesting associations. Two associations attracted further inquiry. First, nearly 70 percent (13 of 19) of the residential land use was considered unstable (categories I and II). Second, none of the sampled residential properties were considered completely stable. Therefore, based on chi-squared tests, one can conclude that residential property along the Gun River does correlate with bank instability and erosion. Stated differently, residential land management results in more erosion and increase sedimentation in the Gun River.

A probable explanation as to why most of the residential properties experience unstable slopes is because these areas possess little riparian vegetation that aids to protect the slope. Eighteen of the nineteen sampled residential sites maintain manicured ornamental lawns up to or within a foot of the stream bank (this was
observed and noted in the field). Mowed lawns provide little root structure for stability and are not as effective as riparian vegetation at slowing water velocities and trapping sediments during flooding.

One possible reason that residents maintain grass lawns is to assure a view of the River for aesthetic pleasures; a view of the stream provides a connection with nature. In a study conducted on five lakes in Kalamazoo County, MI, Lemberg et al. (2002a) found that residents' reasons for living on lakes was overwhelming because of the viewshed or views with nature (over 95 percent of the respondents surveyed considered viewshed as important). Although viewshed and nature were the overwhelming important features for lakeshore residents, the study found that more than 80 percent of the sample properties maintained manicured lawns, whereas less than five percent were determined natural (Lemberg et al., 2002b). Possibly, Gun River residents have similar perspectives as the lakeshore residents in the Kalamazoo study. In short, residents want a view of the River; a connection with nature.

In addition to maintaining grass lawns, almost all of the residential properties along the Gun River have no riparian buffer zone (which makes since if the landscaping is maintained lawns). Only two of the nineteen sampled residential banks possess buffer strips. The absence of a riparian buffer zone intuitively suggests that these sites also have relatively low canopy density measurements. However, this is not true in most situations, where thirteen of the nineteen property parcels experience high canopy densities. The reason canopy densities are high for most residential land uses is that mature trees, with large canopy crowns are present in many places along
the river bank and influence density measurements. Nonetheless, it was observed that most trees were sparsely scattered along the banks and riparian vegetation does not maintain the 10 m requirement of continuous vegetation used in this study. In accordance with the literature, the absence of a buffer strip may increase runoff and stimulate erosion along residential banks during rain events since little vegetation is present.

Based on the literature, it was also expected that the majority of unstable slopes would occur adjacent to agricultural land uses. However, the chi-squared contingency table did not reveal significant differences between the observed and expected values for agriculture and slope stability. In fact, of the 27 agricultural sites sampled, 17 (63 percent) were categorized as having stable banks (indexes III and IV). A credible explanation is that farmers are maintaining a narrow vegetative strip along the river and allowing grasses, weed, and trees to grow unattended. As Lynn Fleming documented about his May 15, 2001 canoe inspection of the Gun River, “From Patterson Road to 120 Avenue, it is good to see that the farmers are allowing trees to develop on the banks for strength with strong banks and shade” (Fleming, n.d.).

After investigation of the chi-squared contingency table, it is determined that agricultural land use along the Gun River does not influence erosion any differently than forested land use because there were no significant differences between the observed and expected values in the contingency table. Therefore unstable slopes along the banks of agricultural land use are explained by random variability. In other
words, land use activity does not explain the occurrence of unstable slopes adjacent to cropland.

The literature also suggests that forested and naturalistic areas will tend to have stable banks because vegetation and trees bordering the river will aid in slope stability. Although the contingency table for the chi-square results did not reveal significant differences between the observed and expected values for forested areas and slope stability, 13 of the 27 banks were unstable (indexes I and II). Contrary to the literature, forested areas had the most occurrences of completely unstable banks, with 10 (of the 27) banks categorize as completely unstable. Still, unstable banks within forested areas are accounted for by random variability.

Limitations of Chi-Squared Test Statistics

Chi-squared test of significance is only useful for determining associations between two variables. The test does not reveal causation between two variables and does not specify individual relationships. Instead, if $X^2$ tests are considered significance, investigation and interpretation of the contingency table is left to the researcher based on the differences between the observed and expected values and the researchers knowledge. Therefore, although associations do exist between slope stability and land use, slope cover, buffer strips, landscaping, and differences between the upstream and downstream portions of the river, the interpretation of those associations are subjective to some extent.
ANOVA and K-means Clustering

Results of ANOVA and the application of chi-squared tests conducted on the erosion index and the K-means cluster groups revealed no significant associations between erosion and Gun River channel hydraulics and physical conditions. However, characteristics of the River channel were exposed by the results of the K-means clustering procedure from which generalizations can be made.

Although Chi-square did not reveal associations between erosion and the agriculture/road land-use, the results of the K-means clustering procedure attracts attention to the geographic grouping of cluster 3. Cluster 3 represents sites along the straightened channel adjacent to 2\textsuperscript{nd} Street. These sites had the largest bank-full widths, but relatively narrow stream widths (compared with clusters 2 and 4). Additionally, slope cover along this section is mostly grasses and low-lying vegetation. A probable reason why the bank-full width is greater in this section is because channel widening is occurring from bank slumping. Figure 6 in Chapter IV and Figures 13 and 14 in Appendix D illustrate two sites where slumping is occurring along this portion of the River.

The wide bank full width measurements and the slumping along this portion of the river, adjacent to 2\textsuperscript{nd} Street, suggest that channel widening is resulting from bank instability. It is possible that chi-squared test did not reveal an association because of the extremely low number of sites within this land use categories compared to the other land uses (10 sites belong to agriculture/road category). Another possibility is bank instability and erosion along this section of the River is
not the result of land use/land cover and therefore, was not revealed by the chi-squared test. Instead, it is probable that increased erosion and bank slumping adjacent to 2nd Street is occurring because this portion of the river flows straight for nearly 3 km (2 mi), which effects hydraulic and channel conditions. The straighten reach increases flow velocities, which increases the rate and amount of scouring along the bank, further destabilizing the bank causing channel widening.

Other generalizations can be made from the clustering results that help to explain channel conditions. Cluster four includes eleven sites that are categorized as having the fastest surface current velocities, the deepest depths, and nearly the widest stream widths. These sites are located along the lower portion of the Gun River where meanders, pools, and large woody debris are more prominent. These physical and natural features (obstructions) may explain why these sites have the fastest velocities, the widest steam width, and the deepest depths. For instance, meanders and large woody debris may increase stream flow as water is directed towards the center of the stream or may increase erosion as water is deflected into the stream bank. Also, large woody debris and meanders can cause bed scouring, creating pools and deeper depths where they are located.

Another interesting cluster was exposed by the outcome of the K-means clustering procedure. Cluster one consisted of sites that had the narrowest stream widths, the lowest stream depths, and the slowest flow velocities. Additionally, cluster 1 represented the first 22 sites, located along the upper portion of the Gun River. However, land cover/land use and channel morphology did not define the site
grouping of cluster one. Unfortunately, the clustering of the first 22 sites was due to irregularities and inconsistencies in hydraulic and hydrologic conditions between sampling dates, which are discussed below, after the PCA discussion.

**Principal Components Analysis**

Although binary data were used in the PCA procedure (indicated as possibly useful in chi-square analysis), the buffer strip variable did not significantly alter the calculation and value of the analysis results. Data redundancy did occur on the buffer strip variable, across components, as revealed by the component loadings for PCs 1, 2, and 3 in Table 8, which have relatively the same weights (0.522, 0.469, and 0.463, respectively). However, comparing variable loadings on each individual component, the binary data did not weigh heavily on any of the three components, and therefore buffer strips did not define PC 1, 2, or 3. Additionally, the subsequent clustering analysis of the factor scores (generated from the component loadings) were mapped and are representative of real world values. In other words, when the clustered PCs were mapped, they were descriptive of actual site conditions, which is the goal of PCA interpretation.

The correlation matrix (Table 10 in Appendix C), from which the components were derived, revealed significant positive relationships between stream width, average depth, and velocity, indicating that as one variable increases the other variables increase as well. Intuitively, these relationships may not make sense. Usually, the characteristics of moving water are such
that wider stream reach widths with deeper depths will have slower stream velocities. Nonetheless, the correlation matrix reveals that increases in stream width and depth also correlate with higher stream velocities.

The correlation matrix (Table 10) reveals a direct positive relationship between slope cover, buffer strips, and canopy density. The positive relationships between the vegetative variables are easier to comprehend than the previous correlations between velocity, depth, and width. Naturally, canopy and buffer strips will be positively associated because the presence of a canopy will determine the presence of a buffer (i.e. buffer strips in this study were determined by the existence of a canopy). Likewise, slope cover is positively linked to canopy and buffer strips since cover is ordinal data, determined by canopy complexity in which more densely vegetative sites receive higher ranked values (4 and 5).

After the components were derived from the correlation matrix, the factor scores of the first three components were clustered and mapped to provide a visual assessment of cluster centers locations. The mapped PC clusters revealed the hydraulic and environmental conditions for unstable sites (Figure 11), but did not really aid in answering the main research hypothesis of whether or not land use activity influences slope stability.

The map, however, does reveal a distinct geographic break among the locations of clusters 1 and 3 and clusters 2 and 4 between the upstream and downstream areas of the Gun River. At first glance the map seems to answer the
second research question, are there differences in the stream bank vegetative and erosional conditions between the upper half of the river and the lower half of the river. Unfortunately, the clustering division is due to irregularities and inconsistencies in hydraulic and hydrologic conditions between sampling dates, which are discussed below.

Weather Conditions

Although field data were collected using consistent and uniform techniques, weather events during the three-week period of data collection affected physical and hydraulic measurements. A significant rain event had occurred between the first and second trip (July 24 and 29, 2002), in which the Grand Rapids, MI, National Weather Service Forecasting Office reported a total of 2.9 cm (1.14 in) of rain had fallen within a four day period beginning on July 26, 2002 and ending on July 29, 2002 (NOAA, 2002a). Prior to the four-day rain event, only 2.4 cm (.95 in) of rain had been recorded since the beginning of July, which was 3.73 cm (1.47 in) less than normal (NOAA, 2002a). Additionally, it rained on four separate occasions during the first two weeks in August. Together, the four rain events in the beginning of August contribute 5.1 cm (1.99 in) of total precipitation prior to the last trip on August 13, 2002 (NOAA, 2002b).

The irregularity of weather events had a direct impact on the field and hydraulic measurements and, thus, on the outcome of the statistical tests employed. The unseasonably dry period prior to the four-day rain event in July directly contributed to extremely shallow depths, narrow stream widths, and slow flow
velocities. In addition to lower than normal rainfall, the lake level of Gun Lake was so low that normal Lake overflow above the retaining wall was not contributing to the Gun River's stream flow (recall from chapter IV that Gun Lake is one of the main sources for the Gun River). During this period, the main contributing water source for the Gun River was either base flow from ground water or natural and man-made tributaries, which were not substantial due to low precipitation input and dry conditions.

The first 22 sites that were measured in the field were affected by the environmental and hydrologic conditions mentioned above. The Gun River was considerably low and in some places emergent sandbars were visible. This helps to explain the upstream geographic clustering of clusters 1 and 3 generated for the PCA factor scores in the data analysis section (Figure 11). These clusters represented sites with the lowest mean values for velocity, stream width, depth, and discharge. Only two sites that were sampled after the July precipitation event were grouped into cluster 1.

The field data that were collected on the remaining six trips, after the July rain event, better represent the normal hydraulic conditions of the Gun River. For instance, Gun Lake was again contributing to the River's stream flow. Moreover, measurements on the hydraulic and channel variables (such as average depth and velocity) from different sampling days and different sampled sites were comparable after the four-day rain in July. In other words, there were no drastic differences in measurements between sampling days, as had been the case between the first and
second trip. Overall, the sampled sites on the remaining six trips had a greater mean discharge, deeper depths, wider widths, and faster stream velocities than the first 22 sites. Again, this helps to explain the geographic separation between PCA clusters 1 and 3 upstream and the downstream clustering of clusters 2 and 4 (Figure 11).

In retrospect, the re-sampling of the first 22 sites after the July rain event would have been valuable for analysis. Obviously, the extreme variation of channel and hydraulic measurements during the low and normal flow periods will affect the statistical tests and could bias the results. Extreme differences in stream measurements may point to incorrect assumptions about the physical channel dimensions, when in fact the precipitation input is the primary factor.

Although weather was the fundamental factor controlling hydraulic conditions of the Gun River and was influential in the make up of the cluster centers for both the PCA and K-means clustering procedures, weather conditions did not affect the erosion index used to assess slope stability. The erosion index is repeatable and independent of weather conditions because it is based on perennial vegetation and the presence or absence of erosion and undercutting. Moreover, other vegetation and environmental variables, such as canopy density, landscaping, land use, slope cover, bank-full width, and buffer strips were not affected by weather patterns. Therefore, the applied chi-squared statistical test, and generalizations drawn from the K-means clustering analysis are not inadequate, biased, or incorrect. However, PCA, K-means clustering, and ANOVA analysis must consider and address the variations in hydrology for channel and flow measurements.
Erosion Sites

It was expected that all fifteen sites identified by Fishbeck, Thompson, Carr, and Huber (FTCH) as highly erosive banks would also be categorized as completely unstable (category I) in this study. However, based on the erosion index used in this research, only eleven of the fifteen erosion locations identified by FTCH were classified as completely unstable. Two of the sites recognized by FTCH as erosion areas were grouped into category II (moderately unstable) and two were grouped into category III (slightly unstable). Additionally, based on the standards of the erosion index applied in this study, three additional sites were classified as completely unstable that FTCH did not identify as unstable.

There are two reasons that explain the variations in the identification of stream bank erosion between FTCH and this study. First, there were different criteria used to determine bank erosion. Although both studies employed qualitative field observations, this study ranked bank type to provide quantitative measurements for analysis. The ranking system provided four categories in which slope type could be identified. FTCH, on the other hand, did not apply an erosion index or standard. It is possible that inconsistencies in identifying slope type and erosion could have occurred from not applying a standard. Second, field observations were conducted during different seasons. FTCH conducted field observations in the spring, when perennial vegetation was beginning to sprout and grow. It is possible that some slopes were not yet covered with vegetation explaining why a few of the erosion sites identified by FTCH were categorized in this study as moderately and slightly unstable. However,
this study was conducted during the mid-summer months when perennial vegetation had become well established. The seasonal difference does not explain why three additional sites were classified as completely unstable in this study and overlooked by FTCH.
CHAPTER VII

CONCLUSION

Summary

Soil erosion and subsequent sedimentation in the Gun River is a major problem that has captured public attention and concern. Remediation measures are currently underway through a Gun River Watershed Management Plan to reduce, and in some cases eliminate point and non-point sources of pollution and sedimentation by implementing best management practices. Past and current land use activities and management practices in the watershed, including channalization and the removal of vegetation for agricultural and residential property, continues to affect the biological and physical conditions of the Gun River and adjacent floodplains.

Vegetation along rivers is important because it provides bank stability, reduces sedimentation and pollution by absorbing nutrients and chemicals from surrounding land use activities, absorbs excess water, and provides aquatic and terrestrial habitat. In short, vegetation on the slope and in the adjacent floodplain operates as part of the overall stream ecosystem. Thus, the removal of stream bank vegetation increases soil erosion, sedimentation, and flooding events, exacerbating problems for downstream communities.

The purpose of this study was to determine if variations in land use and vegetative cover along the banks of the Gun River influence erosion. Additionally,
the study provided a unique opportunity to compare the upper and lower portions of the river to determine if there were measurable differences between the two sections.

Data collected from the Gun River channel and riparian corridor revealed that there are associations between land use/cover and slope stability. It was determined from examining chi-square contingency tables that overall, residential land property experience unstable banks, and thus increased erosion. In fact, none of the residential banks were categorized as completely stable. The characteristic of residential properties along the Gun River include little riparian vegetation, maintain manicured ornamental lawns, and overall, are absent a buffer zone.

It was also decided that agricultural and forested land use activities do not influence bank instability along the Gun River. Although both land uses possess unstable banks, there is no association between bank erosion and these two land use activities. Instead, bank erosion and instability are explained by random variability and not the management practices of these land uses.

Although chi-squared test results did not indicate an association between erosion and the agricultural/road land use, K-means clustering revealed a cluster of sites adjacent this land use that had the largest bank-full widths. It was reasoned that bank instability was resulting in bank slumping, erosion, and channel widening, although the cause of bank instability was undetermined. Therefore, it is inconclusive whether land use/land cover along this section causes erosion.

Finally, it was concluded that there are differences between the upstream and downstream portions of the Gun River. It was originally expected that any difference
in stream bank vegetation and erosion between the upstream and downstream portions of the Gun River were the results of agricultural and forested land use management. It was anticipated that the upstream reach, that flows primarily through agricultural fields, is designated as an inter-county drain, and had been dredged and straightened in the past, would experience more erosion along the banks. However, the main reason that this study found differences between the two portions of the Gun River is that most of the residential property along the Gun River is located in the downstream reach. All of the residential banks in the downstream portion are considered unstable, and thus, experience more erosion.

The results of this study are especially useful for residential landowners who live on the Gun River. The results indicate that residential land use experience more erosion because a lack of riparian vegetative cover exists along the banks. To stop erosion and the loss of property, residents should considered a landscaping design that will offer slope stability and erosion protection, which can still allow visibility and physical access of the River. Low ground vegetation such as sedges, grasses, and forbs that are shade tolerant can be planted among other vegetation to provide added protection as well as offer a natural and aesthetically pleasing view.
Data Collection

Sample Sites

It was originally expected that sampling sites would be representative of a balanced and systematically stratified technique. However, due to the geographic distribution of different land use activities and the sporadic locations of the eroded banks (determined FTCH), an unbalanced number of samples were taken from each land use, in addition to the sampling of both banks at sixteen sites.

In retrospect, sampling should have involved measurements and observations of both banks at all sites. This would have insured consistency among sites and revealed if bank stability and erosion were the same on both banks at the same reach along the Gun River.

Variables

After field data were collected it became apparent that a couple of important variables had been overlooked. To aid in assessing slope stability, slope angle and soil texture should have been determined and recorded since slopes experience instability based on steepness, as well as the size and texture of the grains. These data could have been useful in determining if bank instability and erosion on the Gun River were the results of the soil structure or slope angle.
Additionally, measuring the height of the slope would have been beneficial. In some instances the bank-full height was only a foot or two from the stream flow and in other cases the bank was more than 10 feet high. It would have been useful to study if and how bank height effects slope stability. Also, if the height of the bank was calculated, slope angle could have been determined from algebra by using the stream width and bank-full measurements.

Although the study focused on land use/cover influences on erosion and slope stability, water quality variables also could have been helpful for analysis. For example, turbidity measurements provide information about the amount and type of suspended material present in the water. The amount of suspended particles may point to different factors that influence turbidity, such as soil type, geology, or different land use activities. For example, clay soils may increase turbidity because the fine clay particles tend to stay suspended in the water longer. In contrast, streams in basins with sandy soils will tend to have less turbidity because the coarse sand particles will likely deposit faster. Additionally, land that is disturbed by construction, removal of vegetation, or production (usually associated with residential, agricultural, and urban land uses) can expose more soil, increase runoff, and contribute more sediment into streams. Turbidity measurements could have alluded to possible land use impacts. However, it is difficult and somewhat problematic to identify land use impact effects on erosion from water quality information, since data collected at one site is usually characteristic of upstream conditions.
Erosion Index

The erosion index used in this study is recommended to aid in assessing erosion and slope stability in future research projects on low order streams in forested Midwestern settings. The erosion index proved universally well designed and easily adapted to the riparian vegetative conditions of the Gun River banks. The bank types along the Gun River were generally easy to identify based on the classification criteria developed by Henshaw (1999). However, there were a few instances where bank stability and erosion were not easy to categorize because Gun River bank conditions included vegetation and erosion characteristics that included criteria found in two or more classes of the index. For example, a few banks had minor erosion and bank undercutting (Class III), but also had tree roots and fine root hairs common (Class II). In those cases, other criteria in the class (or classes) that best described the erosion and vegetative conditions on the bank were used to determine the classification. This was done in a consistent manner, whenever identification was not straightforward.

Hydrology

It is important that hydrological conditions are similar between sites and field collection trips. The different weather events that occurred during this study did in fact influence measurements. One may consider weather forecasts or return to previous sites if conditions change considerably by rain events.
In future studies a three-dimensional profile of the river channel is also recommended. Data in this study revealed that the faster currents tend to occur in the wider and deeper reaches of the river, which are not the normal characteristics of rivers. Although this may be the result of past dredging and modification projects, a three-dimensional cross section of measurements, where depths are taken at regular intervals, would provide a more accurate profile of the channel than the average depth measurements used in this study. A more accurate profile may reveal an explanation.

Finally, the data collected in this study could also have been used to assess the quality of the water and the integrity of the river ecosystem in addition to assessing bank conditions and slope stability. However, due to time and cost constraints, water quality and riparian habitat was not assessed. Instead, it was determined that erosion and slope stability be the focus of the study, since sedimentation is the primary source of point and non-point pollution in the Gun River, degrading both water quality and riparian habitat.
Appendix A

Models for Measuring River Ecosystem Health and Integrity
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Appendix B

Erosion Index
Stream bank stability classification criteria (from Henshaw, 1999).

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<thead>
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<th>Class</th>
<th>Description</th>
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<td>IV</td>
<td>Stable</td>
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<tr>
<td></td>
<td>Perennial vegetation to waterline</td>
</tr>
<tr>
<td></td>
<td>Now raw or undercut banks (some erosion on outside of meander bends OK)</td>
</tr>
<tr>
<td></td>
<td>No recently exposed roots</td>
</tr>
<tr>
<td></td>
<td>No recent tree falls</td>
</tr>
<tr>
<td>III</td>
<td>Slightly Unstable</td>
</tr>
<tr>
<td></td>
<td>Perennial vegetation to waterline in most places</td>
</tr>
<tr>
<td></td>
<td>Some scalloping of banks</td>
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<tr>
<td></td>
<td>Minor erosion and/or bank undercutting</td>
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<tr>
<td></td>
<td>Recently exposed tree roots rare but present</td>
</tr>
<tr>
<td>II</td>
<td>Moderately Unstable</td>
</tr>
<tr>
<td></td>
<td>Perennial vegetation to waterline sparse (mainly scoured or stripped by lateral erosion)</td>
</tr>
<tr>
<td></td>
<td>Bank held only by hard points (trees, boulders) and eroded bank elsewhere</td>
</tr>
<tr>
<td></td>
<td>Extensive erosion and bank undercutting</td>
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<tr>
<td></td>
<td>Recently exposed tree roots and fine root hairs common</td>
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<tr>
<td>I</td>
<td>Completely Unstable</td>
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<tr>
<td></td>
<td>No perennial vegetation at waterline</td>
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<tr>
<td></td>
<td>Banks held only by hard points</td>
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<tr>
<td></td>
<td>Severe erosion of both banks</td>
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<td></td>
<td>Recently exposed tree roots common</td>
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<td></td>
<td>Tree falls and/or severely undercut trees common</td>
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Appendix C.

Principal Components Analysis Procedure and Interpretation
Principal Component Analysis

Robinson (1998) suggests that a standard analytical model can be applied to most factor analysis techniques, including PCA. The investigative model can be thought of as a four-step process that helps in the identification, analysis, and explanation of the PCA. Figure 13 illustrates the steps commonly followed for PCA design.

Figure 13. The Basic Stages of Factor Analysis (Adopted from Robinson, 1998).

Stage one considers the geographic sampling location from which measurements were conducted on each variable. The matrix consists of \( p \) variables (columns) and \( n \) observations (rows) (Robinson, 1998). In this study \( p \) variables represent the seven environmental and physical variables and \( n \) observations are all 83 sites.

The second step is to form the correlation matrix from which the components can be derived. McGarigal et al., (2000) propose a variance-covariance matrix could also be used to derive PCs, but a correlation matrix is desired if the measurement scale differs between the variables (ratio and
ordinal data was used). The correlation matrix is useful in revealing positive and negative relationships between variables and can aid in preliminary analysis of the PCA. As with Pearson’s correlation coefficient ($R$), higher correlations indicate stronger relationships between variables. More importantly for PCA, the higher correlations indicate redundancy in the data, which results in more variation extracted in fewer components (McGarigal et al., 2000). Using Pearson’s $R$, $2\sqrt{n}$, all correlations greater than $2/\sqrt{83} = .219$ are considered significant (Rogerson, 2001). Table 10 illustrates the correlation matrix and highlights the significant relationships.

**Table 10**

**Correlation Matrix**

<table>
<thead>
<tr>
<th></th>
<th>Slope Cover</th>
<th>Buffer Strip</th>
<th>Canopy Density</th>
<th>Bank-full Width</th>
<th>Stream Width</th>
<th>Average Depth</th>
<th>Velocity</th>
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<td>Buffer Strip</td>
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<tr>
<td>Canopy Density</td>
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<td>0.371</td>
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<tr>
<td>Bank-full Width</td>
<td>-0.117</td>
<td>0.198</td>
<td>0.06</td>
<td>1</td>
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<tr>
<td>Stream Width</td>
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<td>0.295</td>
<td>0.469</td>
<td>0.354</td>
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<tr>
<td>Stream Width</td>
<td>0.078</td>
<td>0.038</td>
<td>0.182</td>
<td>0.112</td>
<td>0.431</td>
<td>1</td>
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<tr>
<td>Velocity</td>
<td>0.103</td>
<td>0.237</td>
<td>0.531</td>
<td>0.121</td>
<td>0.619</td>
<td>0.559</td>
<td>1</td>
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</table>
The correlation matrix reveals significant positive relationships between stream width, average depth, and velocity. The positive relationship indicates that as one variable increases the other variables increase as well. The correlation matrix (Table 10) also reveals a direct positive relationship between slope cover, buffer strips, and canopy density.

Once the correlation matrix is examined and significant relationships are identified, the third step is to examine the component loadings, otherwise known as factor loadings (Figure 13). However, before discussing and interpreting the outcome of the factor loadings, it is important to explain how the components are generated.

PCA generates eigenvectors and eigenvalues from the correlation matrix. The eigenvectors define the PC and are referred to as the PC weights, which “...are directly proportional to the correlations between the corresponding variables and the PC” (McGarigal et al., 2000, 39). In other words, the eigenvectors are vectors that define the axis (the component) that maximizes the variance between components. Eigenvectors always maintain orthogonality (i.e. are statistically independent).

The eigenvalues are the sums of the squared loadings for each component, which measure the degree of variation between sites along the axis determined by the PC (McGarigal et al., 2000). They are the relative lengths of the axis and are used in determining the importance of the
component. Hence, the eigenvalues with the longest lengths determine which components are retained and examined.

Eigenvalues are also used to calculate the percent of variance explained by each component. The formula for calculating the percent of variance for a component is to divide the eigenvalue by the total number of components and multiply the value by 100 to yield the percentage. For example, the percentage of variance for component one is \( \frac{2.731}{7} = .39007 \times 100 = 39.007\% \). Table 7 (Chapter V) illustrates the eigenvalues extracted from the sums of the squared loadings and also reveals the percentage of variance explained by the components for this study.

Assessing the Components

Once the eigenvalues and eigenvectors are generated the factor loadings can be examined (Stage 3 in Figure 13). The first step in examining the loadings is to eliminate those components that represent little variability in the data set since these components can portray error variance (McGarigal et al., 2000). Several methods can be used to determine which components are retained for exploration (McGarigal et al., 2000, Robinson, 1998). A few of the more common methods were used in this study and are described below.

Both the latent root and scree plot criterion were used to assess the importance of the principal components, which helped to determine how many components to keep and analyze. The latent root criterion retains components with eigenvalues greater than one. Components with eigenvalues less than
one are not retained because they "represent less variance than is accounted for by a single original variable" (McGarigal et al., 2000, 41). Therefore, using the latent root criterion, components one, two and three are maintained for interpretation.

The scree plot works by graphing the eigenvalues on a vertical axis against the components on a horizontal axis. Since the first components represent the greatest amount of variance between the variables, the values on the vertical axis will plot high for the first few components and successive components will have low eigenvalues that will tend to flatten or level out on the scree plot. The point at which the plotted line flattens out indicates which components to keep and which to discard. As with the latent root criterion, the scree plot criterion determined that components one, two, and three be retained for interpretation. Figure 9 (Chapter V) illustrates the scree plot generated in SPSS and shows the line level off from component four to component seven.

Additionally, the relative percent variance criterion is another method commonly used to determine which components are important and therefore, which to keep (McGarigal et al., 2000). This method compares the relative percent of variance explained by each component. According to McGarigal et al., (2000, 44) a cumulative percent variance of 70 percent or higher for the first three components indicates that "...the data structure was effectively summarized in few dimensions". Table 7 (Chapter V) reveals that the first
three components explained 73 percent of the total variance. In other words, 73 percent of the total sample variation in the data set is accounted for by the first three components.

**Interpreting Principal Components**

The next step of the analytic model is to examine the factor loadings of the remaining components. The component loadings indicate how closely a variable and a component are related (McGarigal *et al.*, 2000). When the loading is large, then the component and the variables contain roughly the same information. In other words, the loadings are weighted averages that indicate which variables dominate a component. Therefore, the larger loadings (weights) are of greater importance for interpretation and help define the component. Table 8 (Chapter V) illustrates the factor loadings for each variable on the three extracted principal components.

A common way to interpret the meaning is to examine the component matrix and identify the highest factor loadings for each variable across components. The component matrix (Table 8) reveals the highest loadings for buffer strip, canopy density, stream width, average depth, and velocity all occur on PC 1. In other words, these variables, especially velocity, stream width, and canopy density with loadings approaching one, define component 1. Therefore, high canopy densities, wider stream widths, faster stream velocities, deeper depths, and the presence of buffer strips characterize PC1. Employing this standard, PC 2 is represented by higher values of slope cover
(forested and mixed grasses and shrubs) and PC 3 is defined by wider bank-full widths.

According to McGarigal, et al. (2000), other significant loadings should be examined since component structure is difficult to interpret. A common rule in deciding other significant loadings is to interpret loadings greater than 0.4 or less than -0.4, but to place greater emphasis on loadings greater than 0.7 or less than -0.7 since they explain at least 50 percent of the variation (Tabachnik and Fidell, 1989). Additionally, both negative and positive loadings are important to note because they indicate direct or inverse relationships between components and variables (McGarigal, et al., 2000). Positive loadings represent a direct relationship and negative loadings signify an inverse relationship. In this way, components can be thought of as linear gradients, from the highest positive loading to the greatest negative loading. Therefore, interpretation of the PC should acknowledge “bi-polar loadings” because they could correspond to opposite extremes or “…contrast variables in which there is no obvious causal link” (Robinson, 1998, 125).

Examining all positive and negative significant loadings (Table 2), PC 2 represents a gradient where slope cover and buffer strips contrast bank-full width and average depth. Thus, shallow depths and narrow stream widths, with significant negative loadings, also define PC 2. Accordingly, PC 3 is defined by bank-full widths and buffer strip on the positive side of the gradient. On the other side of the gradient, PC 3 is inversely related to average depth.
The final stage of the analytic model (Figure 13) is to analyze the factor scores. PCA generates factor scores for each observation (site) that can be used as additional data for further analysis (McGarigal et al., 2000). The scores can serve as input data for other multivariate statistics because they are standardized values and are normally distributed. For this study, the factor scores were clustered and then mapped for analysis. The cluster results and the mapped PCs are presented in Chapter V under “Mapping the Principal Components” section.
Appendix D.

Bank Slumping at Site 23.
Figure 14. Site 23 Bank Slumping (View From 2\textsuperscript{nd} Street).

Figure 15. Site 23 Bank Slumping (View From Top of Bank).
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