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Assessment of Threshold Values for Ephemeral Gully Initiation:
GIS Applications in Allegan County, Michigan

presented by

Diane Lorraine Hornbrook

has been accepted towards fulfillment
of the requirements for

Master of Science degree in Resource Development

Major Professor

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ASSESSMENT OF THRESHOLD VALUES FOR EPHEMERAL GULLY INITIATION: GIS APPLICATIONS IN ALLEGAN COUNTY, MICHIGAN

By

Diane Lorraine Hornbrook

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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ABSTRACT

ASSESSMENT OF THRESHOLD VALUES FOR EPHEMERAL GULLY INITIATION: GIS APPLICATIONS IN ALLEGAN COUNTY, MICHIGAN

By

Diane Lorraine Hornbrook

The slope and contributing area relationship for ephemeral gully formation in Allegan County, Michigan can be expressed as slope = 0.08 * contributing area$^{-0.37}$. Ephemeral gullies form in Allegan County most often in soils that are loamy and are in the hydrologic soil group C. The threshold for ephemeral gully formation is slightly higher for soils that are more permeable. A model can be created using GIS that will use the above equation to predict vulnerability to gully formation in Allegan County, Michigan.

ACKNOWLEDGEMENTS

I would like to thank Dr. Jeroen Wagendorp of the Allegan County GIS Department for supplying me with data layers vital to my research. I would like to thank Anne Marie Chavez and my co-workers at the Allegan Conservation District and NRCS for their input and advice. Not least of all, I thank my husband, David, and my family for their words of encouragement and support.

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CHAPTER 1 - INTRODUCTION

Watersheds across the world have been distressed by soil erosion and those of Michigan are no exception. Government programs are being created on federal, state, and even some local levels to combat this problem. Most of these programs focus on agricultural areas and practices. We are now facing a time where environmental concerns are high and feelings are mixed about what the responsibilities of farmers should be. The American Midwest is steeped in Agrarian Romanticism and a love-hate relationship often exists between farmers and neighbors who have fled the cities for "country living." (Chavez, 2002)

Financial, social, political, and behavioral causes of pollution from agriculture have been the subject of much research. Current popular opinion is that financial incentive and voluntary participation offers the best approach. As a result, programs were developed that give cost share for installation of certain practices, such as Environmental Quality Incentive Program (EQIP) and incentive payments to compensate for lands taken out of production, such as the Conservation Reserve Program (CRP). The Continuous Conservation Reserve Program (CCRP) was created to compensate landowners for land taken out of production for the purpose of environmental benefits. Practices covered by CCRP include grassed waterways and filter strips, which are designed to reduce erosion and prevent sediment from reaching surface waters.

The Soil Erosion Problem

Water quality pollutants are varied; some pose immediate threats while others are slow in their degradation effects. Though it is not generally perceived by the public to be the most harmful, sediment is the largest pollutant of surface waters in the state of Michigan. (MDEQ, 2002) Soil erosion and the resultant sedimentation have destroyed habitat and stream morphology, as well as adding excess nutrients. When sediment enters the river, it increases turbidity, suffocates macroinvertebrates, and clogs fish gills. As it settles, the sediment alters the course of the stream, creating sandbars, which may cause even greater erosion at the banks. (Brooks et al., 1991) As agricultural drains become filled with sediment, the water conveyance is reduced and the financial burden of clearing the drain is borne by all landowners in the drainage district. (Fleming, 2002)

Streambank erosion contributes much of the sediment and may result in trees falling into the stream. Fallen trees further divert the flow, exacerbating the problem. Rill erosion, caused by turbulence and eddies in surface runoff, creates the greatest soil loss worldwide. (Brooks, et al., 1997) Sheet erosion, movement of the surface layers of soil, and gully erosion, caused by surface flow on sloping land, are commonly seen in agricultural watersheds in Michigan. (Semeyn, 2002) Gullies are formed when topography forces water to flow together into a temporary waterway during rainfall events. Gullies account for up to 44% of sediment production in Belgium and 80-83% in Portugal and Spain. (Poesen, 1998) Allegan County also has a large amount of number, as evidenced by the fact that it had the second highest number of practices installed to combat gullies in Michigan in 2002. (NRCS, 2003)

Gullies not only channel and contribute sediment in the stream, but also contribute to the loss of valuable topsoil. Woodward (1999) studied 12 gullies in Michigan and found that an average of 7.2 metric tons of soil was removed per year. Characteristics that affect rate of soil erosion include slope, soil type, vegetative cover, and tillage practices. (Boardman and Favis-Mortlock, 1998) Erosion can be reduced greatly with the implementation of systems of Best Management Practices (BMPs). Exposed soil is washed away with the rushing water in a field, but it can be reduced by turning a gully into a grassed waterway, for example. Establishing permanent vegetation, as in hayfields, or using winter cover crops can slow sheet flow by increasing surface roughness and promote infiltration. Riparian buffers filter sediment out of sheet flow and reduce rill formation on the banks.

Various studies have been conducted, yielding different results, but the same message rings through – there is a high price to be paid for agricultural practices that allow erosion to continue. Pimentel, et al.(1998) estimate that more than 50% of pastureland and 80% of all agricultural lands across the world have significant soil erosion problems. In the US, the loss of land productivity is about $27 billion per year and downstream impacts add $17 billion per year to that figure. (Pimentel, et al., 1998) According to Glanz (1998) soil erosion by wind and water costs up to $400 billion per year in agricultural land across the world. The United States government has recognized that investment in BMPs could dramatically reduce this loss and created programs to promote them. (Kalahar, 2000)

The Evolution of Soil Erosion Programs in the U.S.

The evolution of government programs relating to agricultural practices has been a tumultuous one. The infamous Dust Bowl disasters in the 1930's devastated America's Heartland, and provided a wake up call about soil conservation. As a result, the federal government created new programs, such as the Soil Conservation Service and the Civilian Conservation Corps.

Crops began to grow again, but lessons had been learned and in 1956, the Soil Bank Program was created though the USDA. Similar long-term contract programs were created, the Cropland Conservation Program in 1962 and the Cropland Adjustment Program in 1965. (USDA, 1999)

The world outside the United States was changing and in the 1970's and 1980's, the message given to producers that the American farmers must boost production to "feed a hungry world." (Kalahar, 2000) The message was heard and farmers spread their fields to the edge of the banks and agricultural technologies proliferated domestically and abroad.

The United States had been going through a state of Cultural Revolution and cries of injustice and humanity rang out. Many people wanted to save the Earth. Some wanted to feed the hungry, some wanted to save the environment, and some wanted to do both. The first wave to hit the United States Department of Agriculture was the humanist one. The way to save the Earth was to increase production and the American farmers would be the ones to do it. Indeed, acreage under production and exports did increase, efforts encouraged even more by decreased farm commodity prices. (USDA, 1999)

The results of these policies have been often criticized and a paradigm shift occurred in the mid-1980s. By this time, overproduction and a strong dollar had driven farm incomes to fall to their lowest levels since the Dust Bowl days. (USDA, 1999) Saving the Earth didn't mean just sending aid overseas; there were problems at home.

Not only were ecosystems suffering, but also precious resources that were needed to keep the American Dream alive.

The 2002 Farm Bill expanded assistance programs with technical assistance and engineering administered by the Natural Resources Conservation Service (NRCS). Many offices are juggling multiple large projects with only a handful of staff. (Semeyn, 2002) Agreements with private Technical Service Providers are being created, but rule makers are having difficulty with the details of potential contracts. It is not certain that this will prove to be a viable and cost-effective solution to the need for qualified technical assistance suppliers. (Semeyn, 2002)

Soil and Water Conservation Districts (CDs) and the NRCS often act as partners in conservation. Conservation Districts (CDs) are non-profit associations associated with government and generally work at the county level. Minimal budgets are heavily supplemented with grants; therefore much of the funding and staffing is sporadic. The missions of the CDs are to work with local landowners to help conserve the soil and water resources. (Chavez, 2002) They provide technical and financial resources through grants to voluntary participants. In Michigan, they tend to have good working relationships with local agricultural producers. (Chavez, 2002)

Watershed management planning with the help of section 319 grants has become a common undertaking of many CDs. Watersheds often cross district and county lines, so partnerships become large and CDs must be able to coordinate many agencies, landowners, and other partners who may have conflicting ideas. At the same time, they must maintain working relationships with landowners and keep up to date with the latest resources and technical procedures. They are the crews that not only coordinate the planning, but also put the put the plan in place and ensure it is maintained. In order to do this, they need the best information obtainable with limited or sporadic funding and staff.

Problem Statement

Popular opinion is that the best way to gain committed participants is to offer incentives to attract landowners. Keeping in mind that the desire is for the most cost-effective implementation, a system to quickly and efficiently locate and prioritize potential sources is needed.

One of the first steps in creating a watershed management strategy is to perform an inventory. Topographic, soil, and wetland maps are often used when prioritizing inventory plans. (Chavez, 2002) Nothing can replace local knowledge and field inventories, but what about areas that are unknown or inaccessible? How do technicians focus their field inventory if there is limited time relative to the area that must be covered? How will areas that are not eroding presently, but as farming practices change may become more susceptible be identified and treated? Will the results of conservation efforts be to merely correct current problems, or will it be as forward thinking as to prevent future problems from occurring? The best way to address these issues is to create an efficient system to locate and prioritize potential sources. With this list, local workers may ground truth the points to discover whether there is active erosion at that site.

There are many tools to assist with estimating runoff, soil loss, and erosion. Logistically, choosing the right one for a particular situation depends largely on the type and amount of data available, desired output, climate, and expertise. In this situation, the need is to have an understanding long-term average conditions and tendencies. Staff time and resources are limited and not all areas are accessible. A model that quickly and efficiently takes advantage of readily available data to determine areas that are most prone to non-point source pollution is needed.

What if a landowner wanted to consider expanding operations or changing a field that has had constant cover to a tilled field? Knowledge of the risk of gully erosion at that site would be valuable to making decisions about how to manage those fields. Let us even think beyond the current programs for a moment and consider possible alternatives. If a consistent method of prioritization were to be used, then incentive programs could be centered on the resultant rank given. The higher the susceptibility to erosion, the higher the incentive that would be given to motivate producers to enroll. Many rules would need to be created to form the program around its intent, reducing pollution and soil erosion efficiently, but it may yet lie in the future.

Though soil erosion programs offer incentives, not everyone volunteers for such programs for a variety of personal and political reasons or simply that they do not understand what the programs can do for them. Indeed, the landowners with the most highly eroding areas will not necessarily be lining up to enroll. NRCS and Conservation District employees tasked with facilitating Farm Bill programs and administering watershed management programs are strapped for resources and time to conduct field inventory and landowner recruitment. Under the current budget situation, efficiency and cost-effectiveness are imperative for the success. ***What must be determined is how to predict areas that are most susceptible to gully formation so that proper management can occur.***

Goals of the Study

The purpose of this study is to create a tool that can be used for decision-making by farmland managers, including landowners, NRCS, and Conservation Districts. It is a study of ephemeral gullies in the agricultural fields of Allegan County, Michigan. This study will center only on the critical factors associated with the initiation point of gullies. For the purposes of this paper, the initiation point of the gully is defined as the ordinary head of the gully or the typical highest point of a recurring gully. The process will take advantage of available data and scientific processes to objectively determine potential soil erosion locations based on geology not individual land management practices. The objectives of the study are to:

1. Find existing gullies and locate their initiation point
2. Calculate the area contributing runoff to that point
3. Determine the slope at the initiation point
4. Gather information about the soil, including texture and hydrologic soil group, at the initiation point and the predominant soils texture and hydrologic soil group of the contributing area

This study is not intended to give information about length and severity of gullies, though this would give information essential to the start of such a study. An analysis of gullies currently existing in Allegan County will be used to give a prediction tool that will be another layer of information for managing soil erosion and watershed management. It will show the likelihood of ephemeral gully formation under agricultural soil management conditions. Results of the models and analysis of the data will be provided to the Allegan County NRCS and Conservation District Field Office.

CHAPTER 2 - BACKGROUND

Soil Erosion Modeling and Model Verification

As humans make their mark on the Earth and land use changes, the Earth responds in turn. Soil erosion by water and air have not only reduced the productive capacity of soils and changed the landscape, but also degraded waterbodies and filled the air with particulate matter. Soil erosion is the major type of human-induced land degradation based on a global scale. (Oldman et al., 1991) Modeling soil erosion is globally relevant. International consortiums such as the one sponsored by NATO in 1995, 'Global Change: Modeling Soil Erosion by Water, have brought scholars together to address the problem. The Global Change and Terrestrial Ecosystems Core Project of the International Geosphere-Biosphere Programme created the Soil Erosion Network to address soil erosion prediction capability. (Boardman and Favis-Mortlock, 1998)

Modeling soil erosion has been proven cost-effective in estimating how changes of various agricultural practices affect soil productivity. (Ramanarayanan, et al., 1988) However, models should be validated to verify their level of accuracy before they are implemented. Soil erosion models are best used for long-term trend prediction, not singular events. They are also good for relative prediction, not absolute numbers. (Boardman and Favis-Mortlock, 1998)

Many tools to assist with estimating runoff, soil loss, and erosion have been developed. Logistically, choosing the right one for a particular situation depends largely on the type and amount of data available, desired output, climate, and expertise. Testing of the chosen model against known data can show its strengths and weaknesses. Soil erosion modeling in Michigan has occurred, but not on a large scale with the intent of serving the needs of agencies with limited resources such as the Conservation Districts.

Because of the dynamic nature of gullies, it is very difficult to measure the exact location where a gully has started. One rain event may have dramatic headcut effects, moving the initiation point of the gully upslope. Land managers often obliterate small gullies, smoothing them by disking or other mechanical means. These effects introduce a lot of error in the modeling and model verification of gullies. Studies can examine a gully on a small scale to determine the effects of formation and movement or on a larger scale to determine what influences formation of persistent or recurring gullies.

Gully Formation

Gullies are classified as areas where soil has eroded in a small channel, and is distinguished from rill erosion in that gullies are greater than one foot in cross section (Hague, 1997). Gullies are found throughout the world, because they form due to surface runoff patterns: slope, soil type, tillage, residue management, and drainage area. Topography and vegetation cover plays a large role in their anatomy. The critical amount of energy from overland flow must overcome the holding power of the soil it passes over. Root masses, soil type, and slope angle (gravitational pull and resistance) determine the "holding power." Drainage area, soil conditions and infiltration capacity will determine the amount of water that reaches the gully site for each storm event. Slope and surface roughness, including condition of vegetation and tillage practices will determine the speed of the water that reaches the gully point.

Gullies are formed in areas where precipitation has exceeded soil infiltration capacity. When conditions are that the energy of the overland flow exceeds sheer stress capabilities, the soil begins to wear away and a gully forms. (Govers, 1985; Rauws and Govers, 1988; Moore and Foster, 1990) This overland flow is called Hortonian Flow and forms small rivulets as the runoff slopes together. Hortonian flow may occur during heavy precipitation events or during frozen soil conditions. (Porter, et al. 1977)

The hydrologic soil group shows how quickly the soil allows water to infiltrate. Group A soils allow water to infiltrate quickly, while group D soils are almost impervious. Based on this principle, hydrologic soil group would play a role in gully formation. Drainage areas that have proportionately larger amounts of hydrologic group D and C soils, because of their lower infiltration capacity, should have smaller contributing areas compared to the group A contributing areas for gully formation. Regions that have hydrologic group A soils would only be expected to form gullies during severe rain events, such times where precipitation falls at such a rate to exceed the ability of this porous soil to percolate.

There are two major types of gullies, bank gullies and ephemeral gullies. Bank gullies exist on streambanks and ridges, and are closely related to rills. Ephemeral gullies generally form due to local topography, and though they may be erased with agricultural equipment, they will reappear in the same place when precipitation and vegetation conditions are met. (Poesen et al., 1998 and Woodward, 1999)

There is an initiation point of the gully and a toe. As overland flow persists, it may cut deeply at the head, pushing the head of the gully further upslope. The toe may extend to the bank, or it may end in the field. As the topography levels and water slows, it begins to deposit the sediment it has picked up, creating the toe of the gully. (Poesen et al., 1998) Changing precipitation conditions, antecedent soil moisture conditions, vegetation condition, and tillage practices play a large roll in the formation and behavior of gullies. Land management, such as direction and extent of tillage, can play a large roll in soil loss on fields that are on borderline conditions. (Desmet and Govers, 1997)

There are small differences between permanent gullies and ephemeral gullies. Permanent gullies are larger and cannot be removed by tillage, whereas ephemeral gullies may be. Permanent gullies are in well-defined drainageways, and soil is transported by flowing water, slumping, and headcut retreat. Ephemeral gullies are upstream from incised channels or gullies and soil loss is only during periods of flowing water. Cross sections of permanent gullies are deep and narrow with steep sidewalls. Ephemeral gullies are wide relative to depth and sidewalls are not well defined. (Laflen et al., 1985)

Slope-Contributing Area Relationship

Slope and contributing drainage area are the two most important factors to gully formation. Once the combination of critical slope and critical drainage area are met, then the sheer stress is exceeded and a gully forms. (Begin and Schumm, 1979) Studies conducted in Europe, Australia, and the American West have shown that an inverse relationship exists between slope and contributing area. Because both slope and contributing area are measured and can contain errors, orthogonal regression is used to establish the relationship. (Vandekerckove et al. 1998) This relationship can be expressed in many ways, all of which have an exponential variable on the contributing area. Begin and Schumm (1979) and Poesen et al. (1998) expressed this relationship as

$S=a*A^b$, where *S* is critical slope for ephemeral gully head development (m/m), *A* is the corresponding drainage area (ha), and *a* and *b* are coefficients. Desmet and Govers (1997) showed it as a threshold relationship, as $SA^b > t$, where *S* is the slope gradient (m/m) at the initiation point of the gully, *A* is the contributing drainage area (hectares), *b* is the exponent variable, and *t* is the threshold value. Many studies show that *b* is approximately –0.4 in level or slightly undulating topography. (Poesen et al., 1998 and Vandaele et al., 1996)

Vandekerckove et al. (1998) found that the correlation was strengthened when tillage direction was included. The less permeable the soil and the greater the soil stoniness, the greater the threshold will be for gully formation.

Whereas when estimating rill erosion, slope length can be substituted for drainage area, this is not applicable to gullies. Depending on topography, drainage area may be oblong, round, or even more convoluted. The shape of the drainage area may play a role in gully formation because of momentum that flow may build up. However, this factor is highly variable based on surface roughness and slope plays a much larger role in the speed of flow than watershed shape. (Desmet and Govers, 1997)

Related Gully Research

Betts and DeRose (1999) conducted a study on gully degradation rates using digital elevation models (DEMs) created from sequential aerial photographs. They found that gully degradation rates, or the growth rate of a gully, are directly proportional to the square root of the gully area. Using orthophotos with a minimum resolution of 2 m, they were able to precisely define gully boundaries. This study was done in a forested area of

New Zealand with sandstone, mudstone, argillites, and bentonitic clays. Slumping and mass earth changes are prevalent, and were the most common areas for gullying in their study area.

The Ephemeral Gully Erosion Model (EGEM) was developed by the NRCS to model the rate at which gullies erode. It is designed to be used on a field level, and can predict the erosion rate based on varying storm types. It uses the NRCS curve number, drainage area, flow length, slope, and 24-hour rainfall to calculate hydrology. It combines this with information about the width and depth of the gully to derive the rate of erosion. This is a very useful tool for calculating sediment transport or reduction after BMP installation, but it needs very specific input about watershed size, soils, and slope. (Woodward, 1999) It only designed to predict erosion rates, not predict location.

Study Area

Allegan County is located in southwest Michigan, approximately halfway between Kalamazoo and Grand Rapids (Figure 1). As of 1981, approximately 50% of the land is in agriculture, 28% is forested, and 22% is urban/built-up or park recreation. Approximately 48% of the county has well drained soils, 35% is somewhat poorly drained soils, 12% are poorly or very poorly drained soils, the remaining 5% is water, urban, or miscellaneous. (USDA, 1981)

Figure 1

The winter average temperature is 25.7°F with an average minimum daily temperature of 17.8°F, and the summer average is 69.6°F with an average daily maximum temperature of 81.6°F. Total annual precipitation 35.7 inches, 56% of which falls in April through September. (USDA, 1981)

The bedrock of Allegan County is Mississippian Sandstone and shale. The upper bedrock is Marshall Formation and Coldwater Formation, overlain by 50 to 400 feet of glacial drift. Two north-south moraines are in Allegan County. The Lake Border moraine is located on the shore of Lake Michigan, and the Valparaiso moraine is in the center of the county. There is a sandy lakebed deposit between the moraines and till plains to the east of the Valparaiso moraine. The easternmost section of the county is outwash plain. (USDA, 1981)

The largest river in the county is the Kalamazoo River, which outlets at Saugatuck. Its major tributaries are the Rabbit River, the Gun River, Swan Creek, Dumont Creek, and Pine Creek. There are also 97 inland lakes and reservoirs. The largest of these are Lake Allegan – an impoundment of the Kalamazoo River, Hutchins Lake, Green Lake, and Miner Lake. (USDA, 1981)

Allegan County was intensively logged until 1880, when agriculture became the dominant land use. The area was originally a mix of coniferous and deciduous forest. It is now predominantly row crops, but also commonly grown are cherries, grapes, blueberries, apples, pickles, asparagus, celery, and radishes. Perennials, such as day lilies, and hostas are also grown. Livestock operations include dairies, beef cattle, hogs, and poultry enterprises. (USDA, 1981)

Though the county is predominantly agricultural, it serves as a bedroom community for many who commute to Grand Rapids and Kalamazoo. Allegan County also had the highest rate of Right to Farm complaints in the state in 2001 and 2002. (NRCS, 2003) It has not been determined whether poor soils and environmental conditions, poor farming practices, tensions between farmers and their neighbors, or a combination of all of these are to blame for the larger than average number of complaints. It is certain that many farmers find themselves without Right to Farm protection. Many farmers participate in federal Farm Bill programs, and in 2002 Allegan County had the second highest rate of grassed waterway installation through the Continuous Conservation Reserve Program in the State of Michigan. (NRCS, 2003)

There are many watershed management projects occurring in Allegan County. The study area includes the Lake Macatawa Watershed and the Rabbit River Watershed. Lake Macatawa is a hypereutrophic lake that drains into Lake Michigan and steps are being taken to manage both nutrients and sediments. Best Management Practices (BMPs) are being encouraged and funded in agricultural, residential, and urban settings. The Macatawa Watershed was one of only three watersheds in the State of Michigan to be selected to participate in the Conservation Reserve Enhancement Program.

The Rabbit River Watershed is immediately to the east of the Macatawa Watershed. Though it is mostly in Allegan County, it also reaches into Ottawa, Kent, and Barry Counties. It is a heavily agricultural area with small pockets of urbanizing areas in Wayland, Dorr, and Hopkins. Macroinvertebrate communities are rated poor and sediment is a serious problem in the Rabbit River and its tributaries. The current watershed project offers technical and financial assistance to landowners to address erosion and nutrient management issues as well as habitat development. It also sponsors a stream monitoring program with local students and a land use initiative with municipalities in the watershed.

CHAPTER 3 - METHODS

Research Directions

The goal of this study is to determine the threshold values at which a gully will form in agricultural fields in Allegan County, Michigan. While there are many factors that affect the precise point where a gully will form, the intent of this study is to provide a planning tool. A land manager should know which fields are the most likely to erode and the approximate locations. The exact point of incision, which is highly variable based on storm events, is not necessary to make overall field decisions. Therefore, precision in this planning tool is sacrificed for simplicity and takes advantage of existing information sources.

Field data

Information about existing gullies was obtained by identifying where grassed waterways were installed through the Continuous Conservation Reserve Program. These sites had caused landowners enough problems as to warrant an investment in a grassed waterway. It is not only an expense and inconvenience to install it, but also often cuts the field so as to disrupt tillage patterns and removes land from production. While soil rental payments are made, these payments are not large. NRCS staff also inspected the sites to verify gully erosion was a problem and could be mitigated with a grassed waterway. After obtaining the permission of the landowners, Global Positioning System (GPS) points were taken at each site at a point along the grassed waterway. Since these sites had already been disturbed by installing the grassed waterway, it was not possible to see the head of the gully. Other gullies were observed during the field surveys. The GPS locations of these gullies were recorded if public access was available, most often along the roadside.

With GPS, exact locations of the gullies were found. However, the initiation point of the gully still needed to be found. The GPS locations were overlain on digital orthophotographs from 2000. The location of the gully initiation point was determined by following the gully upstream from the GPS point.

GIS Data Input

GIS data is readily available for many geographic features in Allegan County, including the National Elevation Datastet (NED) Digital Elevation Model (DEM) (see Figure 2), orthophotography, streams, roads, and political boundaries.

Flowlines, catchments, and soils were obtained for the northeast portion of the county, the Rabbit River and Macatawa Watersheds. Figure 3 shows the study area in Allegan County.

Overland flowlines and associated catchment areas were created by the Allegan County GIS Department. MapInfo was used to derive flowlines and catchments using a Digital Elevation Model (DEM) with two-foot contour elevation accuracy and five-meter pixel size. The flowpaths were created by running an application that assesses the surrounding elevations for each pixel and determines the direction and amount of cumulative flow for each pixel. It then compiles this data and performs calculations to determine the stream order based on the overland flow, and creates the drainage area boundaries.

Figure 2

Allegan County Topography

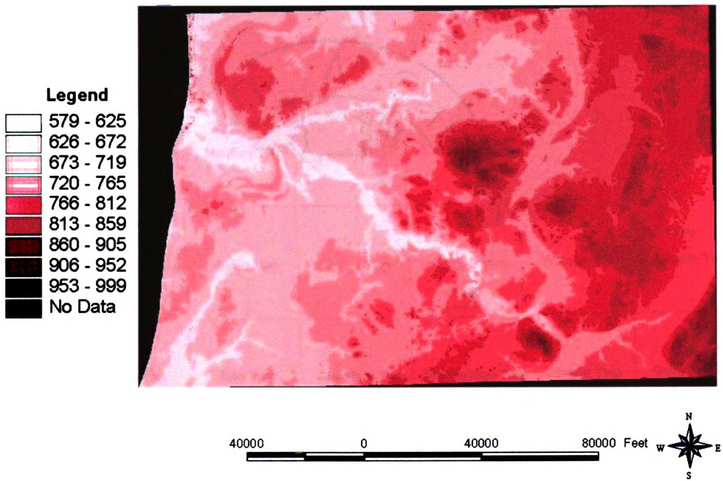
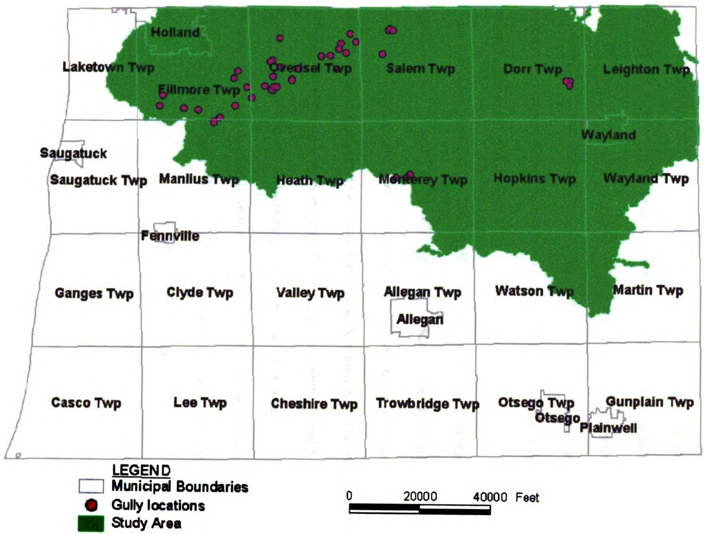


Figure 3

Study Area and Gully Locations



The contributing area was calculated by using the outer borders of the modeled drainage areas as the uppermost delineation, but it was interpolated to reflect the position of the gully initiation point. In other words, the drainage polygons were used as a guide, but they were revised to account for the fact that most gullies were toward the center of the modeled drainage area. Contributing area only includes the area that truly contributes runoff at the initiation point of the gully.

The soils were digitized by Western Michigan University, and additional information from the Allegan County Soil Survey was added to the .dbf table. This information included erosion hazard, k-factor, hydrologic soil group, permanent high water table, texture, hydric, prime farmland, septic, and development. The more accurate SSURGO soils have not yet been completed for this county. Figures 4 and 5 show the hydrologic soil groups and soil textures respectively for the study area.

Percent slope was derived from the USGS National Elevation Dataset (NED) using ArcView 3.2a and Model Builder extension. This DEM has an approximately 10-m resolution. To create the percent slope with Model Builder, pixel size was kept the same and one-percent intervals up to 50% were obtained. Percent slope was then converted to meters/meters. The slope at the initiation point was used rather than the average slope because it not only represents the most immediate velocity at the initiation point, but also reflects the sheer stress. (Desmet et al., 1999)

Figure 4

Hydrologic Soil Groups

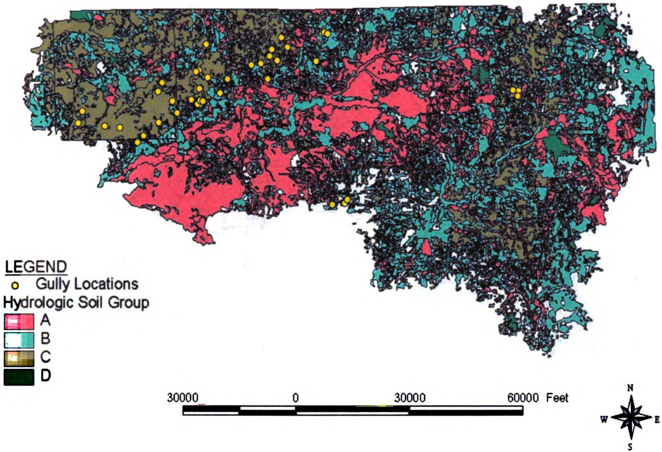
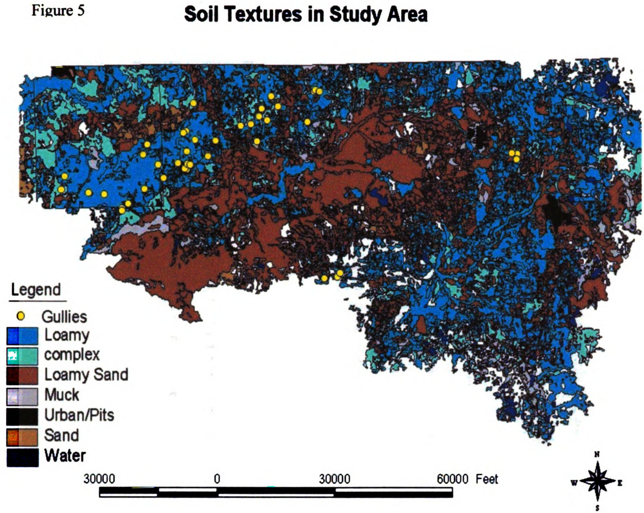
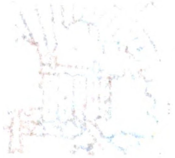


Figure 5


Soil Textures in Study Area
Legend
Gullies
Loamy
complex
Loamy Sand
Muck
Urban/Pits
Sand
Water
30000
0
30000
60000 Feet
N
W
E
S



GIS was used to obtain the slope, contributing area, soil texture, hydrologic soil group, and flow types at each observed initiation point. This information as well as the predominant soil texture and hydrologic soil group of the contributing area were recorded. Appendices 1-5 show examples of the GIS information obtained for one township section that contains a large density of gullies.

For the purposes of this study, which is intended to be used as a planning tool, tillage practices and vegetation were assumed to be approximately constant. Common tillage practices in Allegan County are conventional fall plow and mulch tillage with minimal mulch residue, as were observed during the field visit and confirmed from local NRCS and CD employees.

Software and Extensions

MapInfo was used to create the flowlines and catchments. ESRI ArcView 3.2a with Spatial Analyst, 3D Analyst, and Model Builder extensions were used to gather all empirical data associated with the gullies.

CHAPTER 4 – RESULTS AND DISCUSSION

Gully Locations

Forty-three gully initiation points were found in the study area. Overisel and Fillmore Townships have the largest concentration of gullies. These townships are in the lake moraine with Capac sandy loam and hills.

The overland flowpaths with associated catchment areas that were created by the Allegan County GIS Department were based on two-foot elevation intervals, a resolution not often available. The precision afforded from this two-foot DEM is excellent, and the modeled flowpaths can be observed to match with striking accuracy the flowpaths that are overlaid on the orthophotographs (Figure 6).

Table 1 gives the empirical data associated with the initiation points of the gullies used in this study. It gives the contributing area, slope at initiation point, flowline classifications, soil texture and hydrologic soil group at gully initiation point, and predominant soil texture and hydrologic soil group of the contributing area.

Figure 6

Example of Orthophoto with Flowline Overlay

Table 1: Empirical Data of Ephemeral Gullies in Allegan County

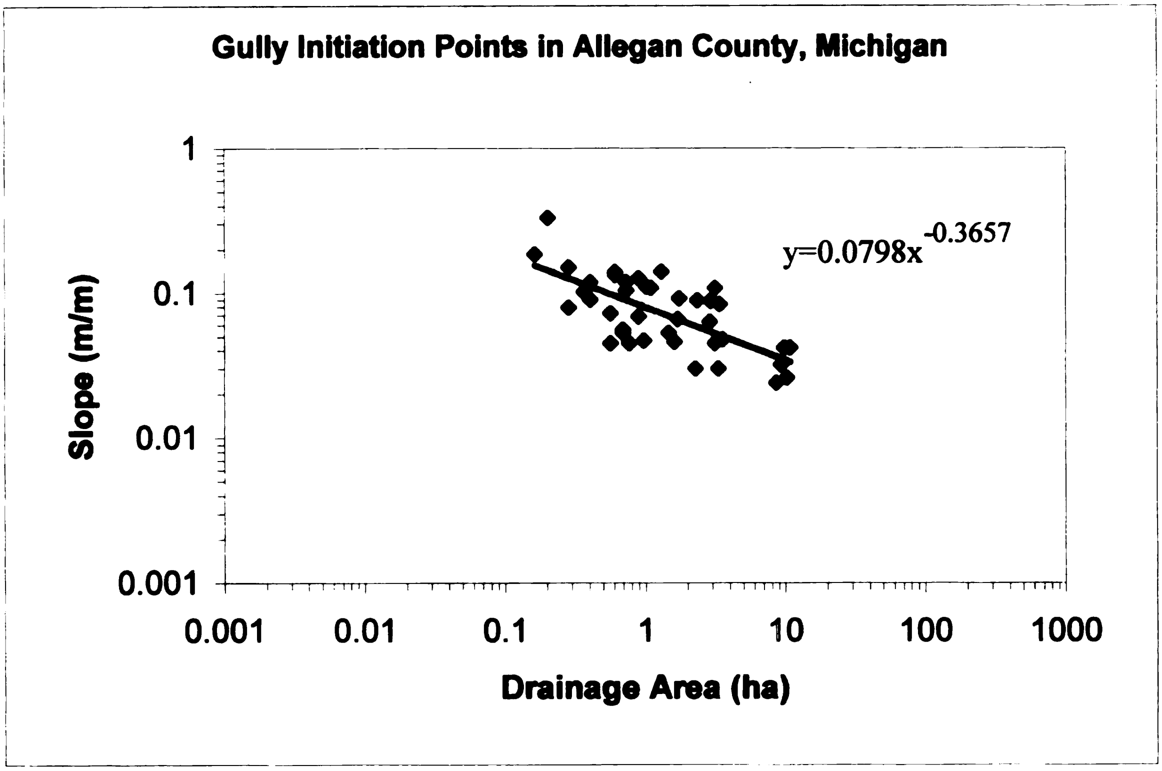
Site ID	Contributing Hectares	Average Slope (m/m)	Soil	Soil Texture	Predominant Soil Texture	Hydrologic Soil Group	Predominant Hydrologic Soil Group
1	0.1619	0.1860	8C	clay loam	clay loam	C	C
2	3.1162	0.0450	21B	loam complex	loam	C	C
3	0.8903	0.0690	41B	silt loam	silt loam	C	C
4	0.6880	0.0560	8B	clay loam	clay loam	C	C
5	9.2272	0.0320	48	loamy sand	clay loam	B	C
6	2.2663	0.0300	45	silt loam	loam	C	B
7	0.2833	0.0790	14C	loam	loam	B	B
8	0.6071	0.1330	33A	fine sandy loam	fine sandy loam	B	B
9	3.1162	0.1080	16B	loam	loam	C	C
10	0.7689	0.0450	16B	loam	loam	C	C
11	0.5666	0.0720	16B	loam	loam	C	C
12	2.9138	0.0880	36	sandy loam	loam	B	C
13	8.6201	0.0240	16B	loam	loam	C	C
14	1.0118	0.1100	41B	silt loam	silt loam	C	C
15	0.4047	0.1190	30	silt loam	sand	B	B
16	10.7650	0.0420	44B	loamy fine sand	sand	A	B
17	3.3590	0.0840	28A	loamy sand	loamy sand	C	C
18	1.6188	0.0460	22A	loam	loam	B	B
19	0.6880	0.0530	41B	silt loam	silt loam	C	C
20	0.9713	0.0470	21B	loam complex	loam	C	C
21	2.8734	0.0630	16B	loam	loam	C	C
22	2.3473	0.0890	16B	loam	loam	C	C
23	0.8903	0.1270	16B	loam	loam	C	C

Site ID	Contributing Hectares	Average Slope (m/m)	Soil	Soil Texture	Predominant Soil Texture	Hydrologic Soil Group	Predominant Hydrologic Soil Group
24	0.7285	0.1040	12C	loam	loam	B	B
25	9.7937	0.0420	41B	silt loam	silt loam	C	C
26	0.5666	0.0450	41B	silt loam	silt loam	C	C
27	0.2024	0.3310	16B	loam	loam	C	C
28	1.0927	0.1080	75B	loam	loam	B	B
29	3.3185	0.0300	16B	loam	loam	C	C
30	10.1984	0.0260	16B	loam	loam	C	C
31	3.5614	0.0480	16B	loam	loam	C	C
32	0.6071	0.1400	16B	loam	loam	C	C
33	0.4047	0.0900	8C	clay loam	clay loam	C	C
34	0.3642	0.1020	41B	silt loam	silt loam	C	C
35	1.4569	0.0530	8C	clay loam	silt loam	C	C
36	1.2950	0.1400	8C	clay loam	clay loam	C	C
37	0.2833	0.1510	14C	loam	loam	B	B
38	1.7402	0.0920	75B	loam	loam	B	B
39	1.6997	0.0660	75B	loam	loam	B	B
40	0.7285	0.1190	75B	loam	loamy fine sand	B	A
41	25.4152	0.0240	10B	fine sand	fine sand	A	A
42	0.8094	0.0870	44B	loamy fine sand	loamy fine sand	A	A
43	11.5744	0.0190	49A	fine sand	fine sand	B	B

Slope-Contributing Area

When slope (meters/meters) was plotted against the contributing area (hectares) on a log-log scale, a close scatter was found (Figure 7). An orthogonal regression was performed to determine the relationship between these factors. Orthogonal regression was used because it tests the errors of both x and y as independent variables. In Microsoft Excel, a power regression was plotted, giving an orthogonal relationship where Slope = 0.08 * Contributing Area$^{-0.37}$. This relationship closely matches the results of previous studies done around the world, in many different climates, soil types, and land uses, where Slope = a * Contributing Area^{b}. These results most closely matches the results from central Belgium by Poesen et al., 1994. Topography and climate in this region more closely match southwest Michigan than do the other US locations of the California, Sierra Nevada, and Oregon (Vandaele et al., 1996). Similar to the observations in central Belgium, in Michigan gullies form mostly during winter before crops are sown and during late spring heavy rains. (Personal observation) The first coefficient also closely matched the South Downs of the UK, though the exponent value was slightly lower. Climate is somewhat similar to the UK site, but the sandy loam soils of the Michigan site are closer to the silty loam soils of the UK than to the loess wind-blown clay of Belgium. The steeply sloped areas of Oregon and California had much higher *a* coefficients.

Figure 7

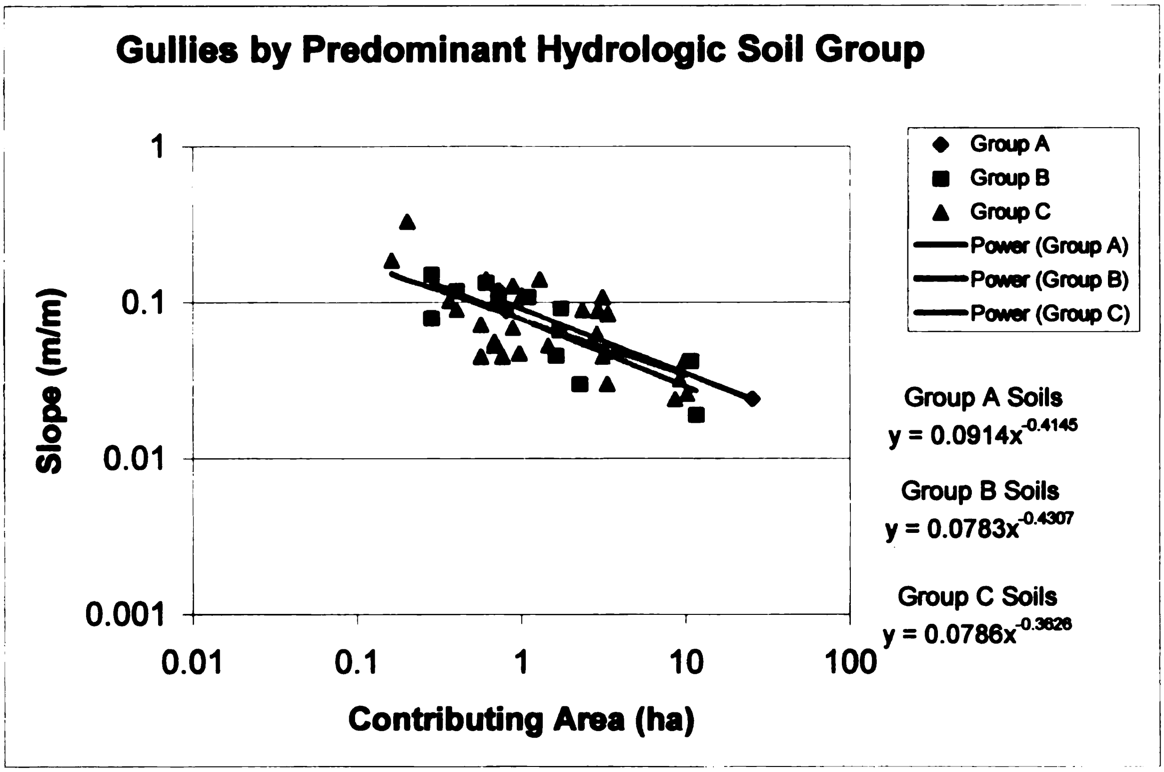


Hydrologic Soil Groups

Figure 8 shows the slope and contributing area of the gullies by hydrologic soil group. Twenty-eight of the 43 sites are in predominantly hydrologic group C soils, twelve are group B soils, while only three is a group A soil. This shows an interesting trend, since only 21% of the study area is hydrologic group C soils, 38% were group B, and 31% are group A soils.

Group A soils have a larger *a* coefficient value than Group B and C soils. However, Group A and B have similar *b* values, and the *b* value for Group C soils is less. In other words, for a Group A soil, as slope decreases, the amount of contributing area must increase more than with Group B and C soils. Group A are very permeable and overland flow does not accumulate as quickly as with B and C soils. Therefore, a much larger contributing area is needed to reach critical runoff levels in Group A soils than B or C. Group A soils need a much larger amount of contributing area to initiate soil erosion even on the steeper slopes. Group C and B soils tend to not need as much contributing area to form gullies.

Figure 8



Soil Textures

Of the soils that gullies formed in, there were twenty-two loam soils, eight silt loam, five clay loams, two loamy sand, two loamy fine sand, one sandy loam, one fine sandy loam, and two fine sand. These indicate that loams are more likely to form gullies than sand, which percolates water, or than clay, that forms a tough barrier. Figure 9 shows slope and contributing area of the gullies by texture at the initiation point.

Figure 10 differentiates gullies by the predominant soil type of the contributing area. Sandy areas tend to gully in areas where the acreage is higher, but the slope is less.

The finer particle soils of the study area, clay loam and silt loam, tend to gully where the slope is higher, but the acreage is less. Since sand tends to allow rainwater to infiltrate quickly, it may not be the acreage that is the determining factor for gullying. Sand does not have good "holding power" and moves more easily than loamy soils.

Figure 9

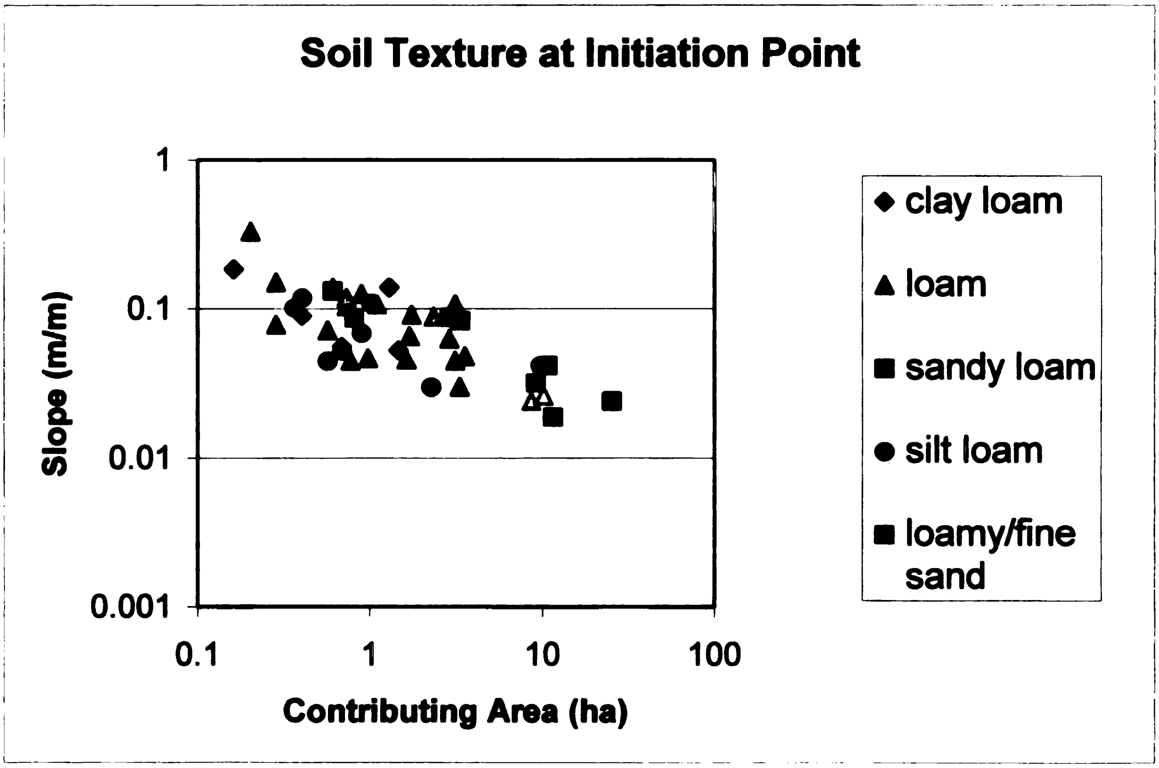
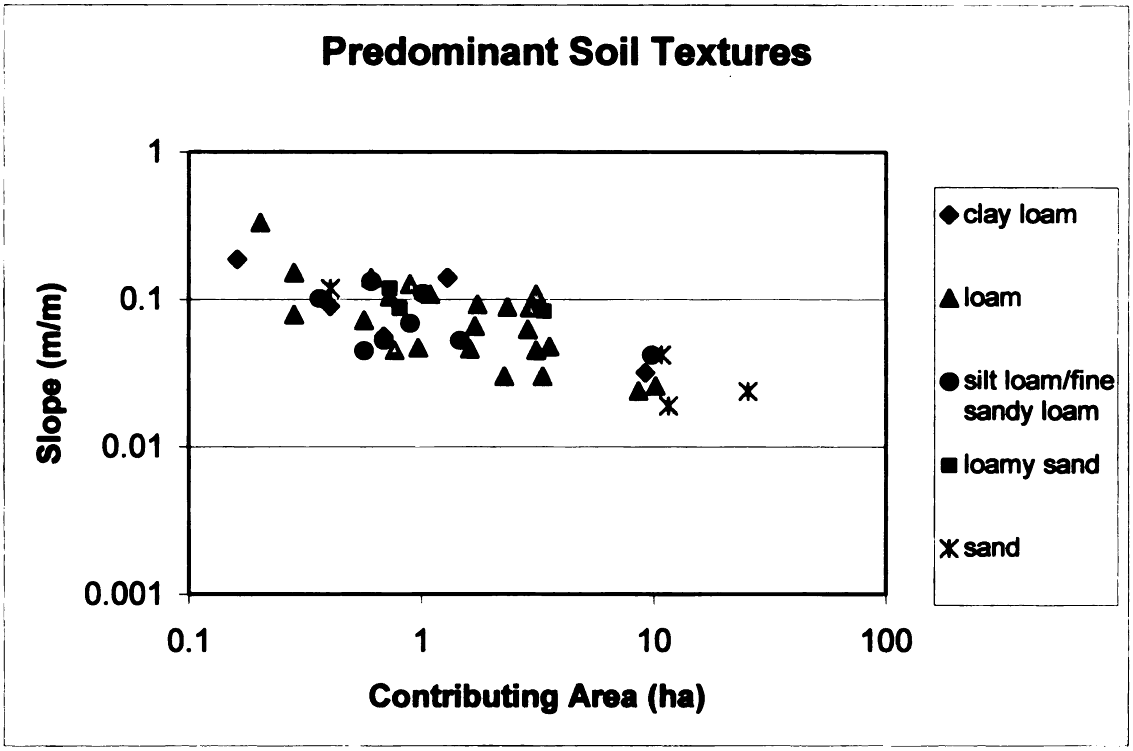


Figure 10



The slightly different behavior of the soil textures in the gullying situation can also be seen in their orthogonal regression. Figures 11-15 show how each soil type plots and their regression. In the relationship, Slope = a * Contributing Area^{-b}, most textures resulted in an *a* of 0.08 and *b* of –0.4. The notable exception is the loamy sand/sandy loam graph, where there are only three data points. The very low number of data points makes it highly likely that this is not a representative sample. The silt loam and fine sandy loam gives an *a* of approximately 0.07 and a *b* of –0.2, slightly lower than the other textures. The lower numbers are most likely due to the fine texture of the soil, which tends to be more slope dependent, regardless of the contributing area. With a b value of –0.45, the loam had the highest dependency on the slope-area relationship. In other words, as the contributing area lessens, there needs to be more increase in slope for a gully to for than in either a silt loam or a sand. The fine particles of the silt loam are more easily transported, yet the sand infiltrates water more rapidly. There is more of a "one-to-one" relationship in the well-sorted loam.

Figure 11

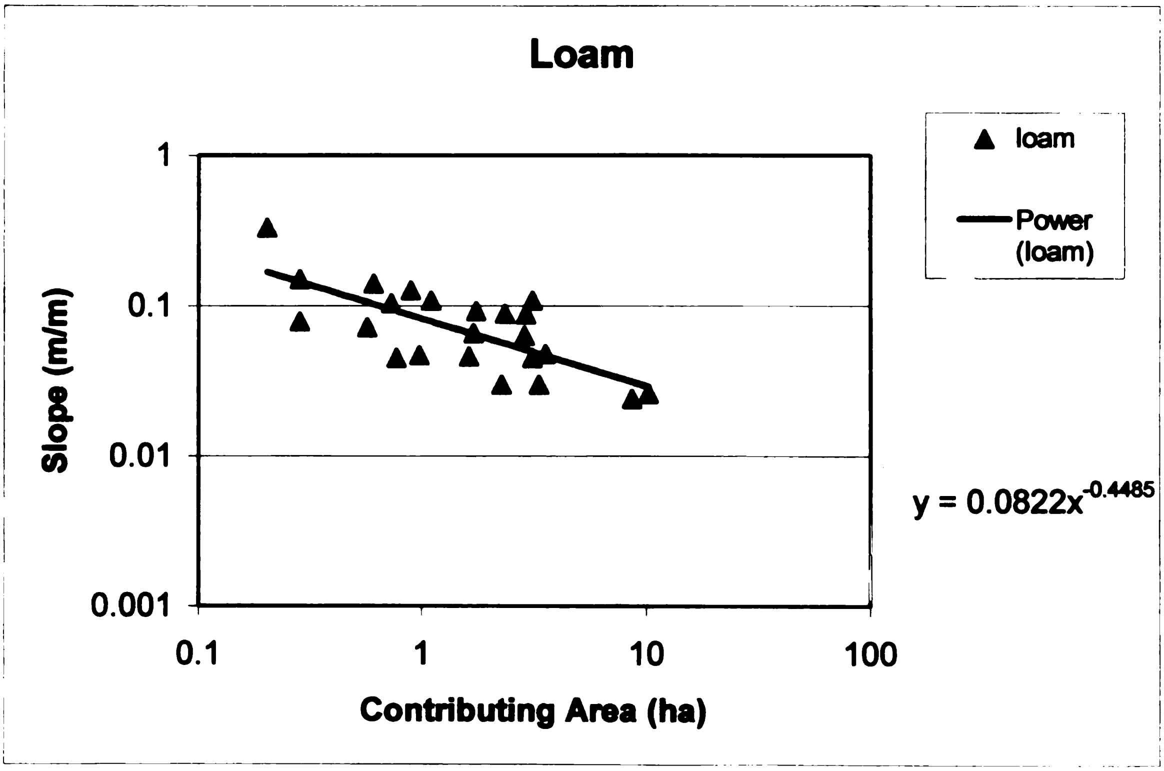


Figure 12

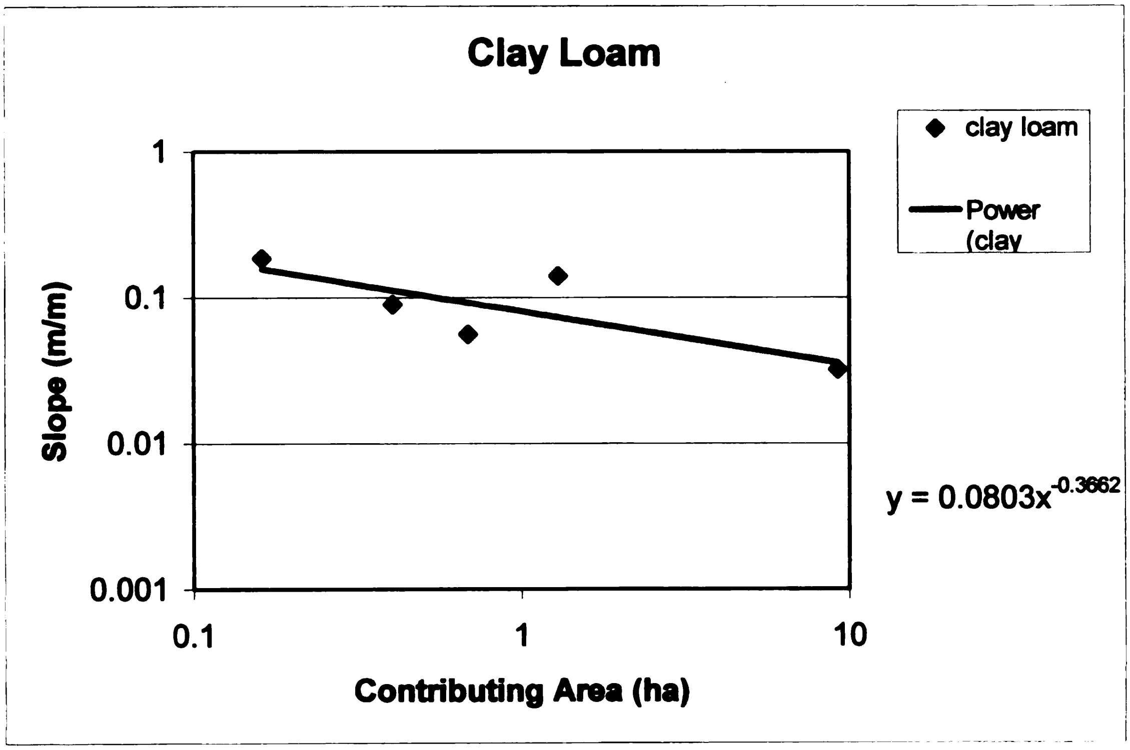


Figure 13

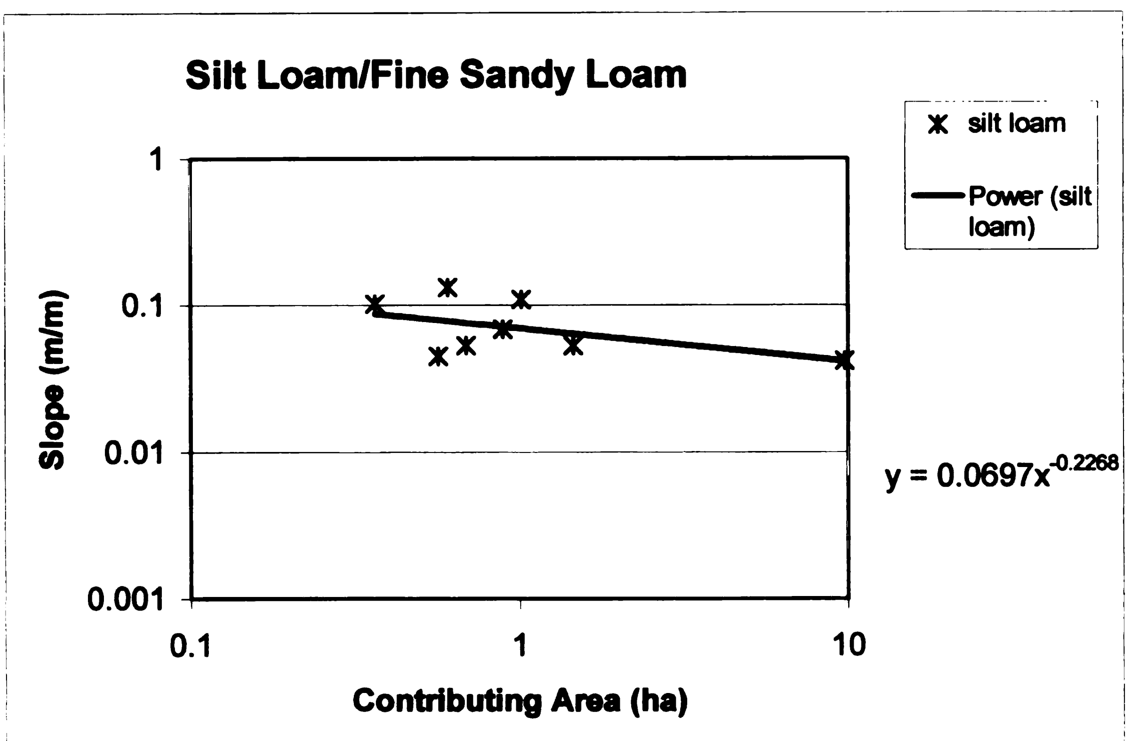


Figure 14

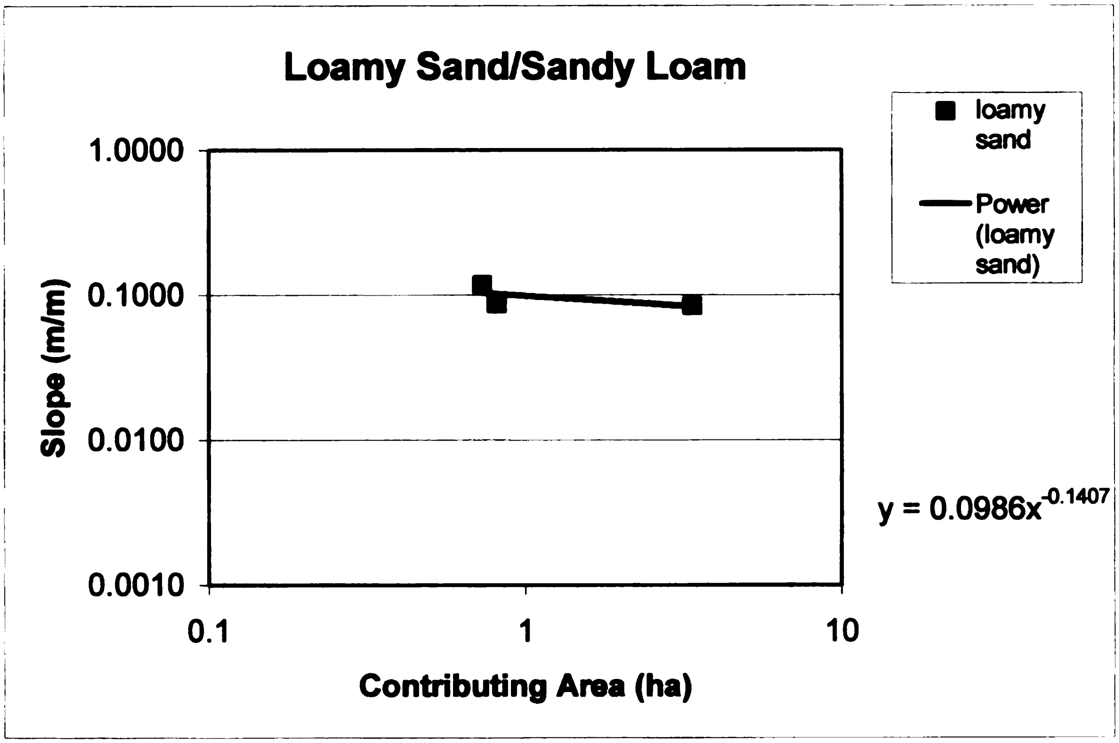
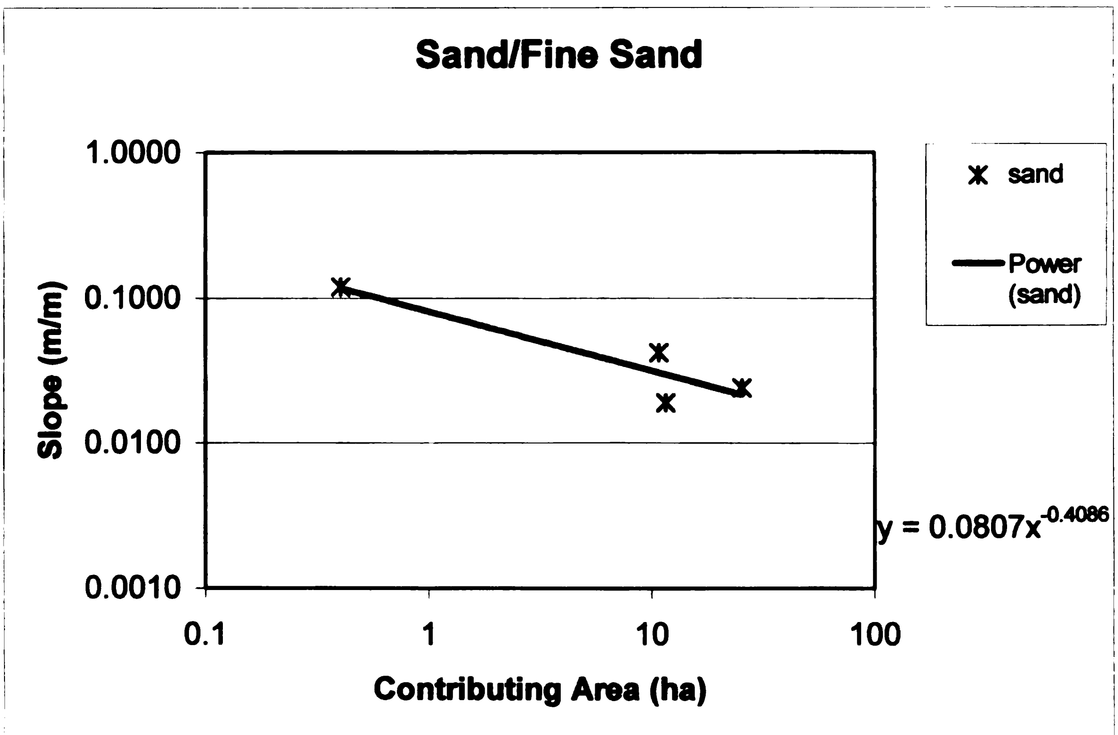


Figure 15



Sources of Error

There were two DEMs used in this study. The first, which was used to derive overland flowlines and associated drainage area were created using 2-foot elevation accuracy and five meter pixels. The second, used to derive slope was the United States Geological Survey (USGS) National Elevation Dataset (NED) with 7.5-second accuracy and 10 m pixels. Sources of error with DEMs include scale, image initial quality, image scanning quality, camera calibration and ground control, and vegetation (Betts and DeRose, 1999). The slopes derived from the NED do not give the precise slope at the point of gully initiation. The NED derived slopes give the modeled average for the surrounding 100 square meter area. Therefore, slopes may be slightly over or under estimated.

The orthophotographs that are generally preferred for soil conservation work are taken in the autumn. At this time of year, crops are not yet harvested yet and visible, but deciduous leaves have fallen, so the photographs have clearer visibility to ground features in forests. However, because of the sun's low azimuth as winter approaches, these photos can contain strong shadows that skew results when used for gully research (Betts and DeRose, 1999). Gully initiation point may have been located further upslope than they actually were because shadow effects may have made the gullies seem deeper or more sever than they actually were.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of this study closely matched those done in similar settings. For Allegan County, gully initiation points can be estimated by using the equation, Slope = 0.08 * Contributing Area$^{-0.37}$. Loamy soils and hydrologic group C soils showed the highest rates of gully formation. Slope has more of an influence on gully initiation location than catchment are because catchment area has a negative exponent. (Desmet et al., 1999) The results of the hydrologic soil group comparison for gullies in Allegan County parallels that of Vandekerckove et al. (1988). The less permeable the soil, the closer the hydrologic soil group to A, the greater the threshold for gully formation.

Limitations

This application analyzes elevation and waterway information to show where gullies may form. It must be emphasized that the results of this study are intended to be used for planning purposes only. The formula created from this study gives information to identify potential areas of gully erosion. Whether or not a gully actually form is dependent on a variety of variables, including land use, tillage, and precipitation patterns. However, it does raise a red flag and alters planners that there is potential for problems.

Sources of error include DEM resolution, true gully initiation point. Because headcutting of gullies occurs frequently, it is very difficult to determine where the gully originally started. This task becomes even more difficult when using aerial photography.

Applications

The results of this study can be used to build a model that will show where gullies are most likely to occur in Allegan County, Michigan and may be applied to surrounding areas. It can be combined with site visits and other information to prioritize sites for BMPs. The decisions of which BMPs to implement will ultimately be made by technicians and landowners. This study will be given to the Allegan Conservation District and NRCS Field Staff and can give them a head start toward action on soil erosion and sedimentation in the local watersheds.

These results can also be used to predict what will happen when land is put into or returned to row crop production. Comprehensive Nutrient Management Plan writers, Total Maximum Daily Load writers, landowners, and field staff can use it as a planning tool for agricultural areas to predict soil loss and sedimentation. It can also be useful in setting budgets and estimating amount of cost share that might be needed to solve gully erosion problems over large areas.

Recommendations for Further Study

This study showed a relationship between slope and contributing area in agricultural fields. Valuable information could be gained by studying where the slope and contributing area relationship is met, but gullies do not form. For a given slope, the requisite contributing are can be found with the relationship equation, $\text{Slope} = 0.08 * \text{Contributing Area}^{-0.37}$. Management practices, such as tillage type and direction, as well as vegetation condition should be recorded at these locations.

Many studies used the Soil Conservation Service Runoff Curve Number method or factors used within this method to determine discharge, which was than plotted with slope (Souchere et al., 2003). This requires much more intensive calculations and adds more steps to the process. For these reasons, it does not meet the criteria of being a simple method that was a goal of this study. However, it would likely yield results that are much closer to exact. It could also be used to determine what the annual probability of gully formation would be. If gullies were found after 2-year, 5-year, 10-year, etc. storms, then the relative frequency of such gullies could be determined.

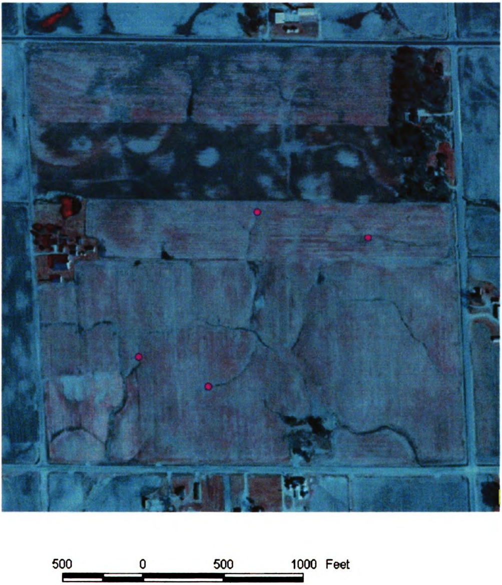
A recommended next step to this study would be to perform grid cell analysis of contributing area and slope. An analysis that calculates cumulative contributing area for each grid cell can be run. This could be combined with the slope of the grid cell. Using the results of this study, the grid cells that are above the threshold levels can be selected, yielding areas that would be expected to gully. This information would be useful for many management purposes, both for individual landowners, as well as agencies.

Not only the locations of gullies is important for land management, but also the severity of the potential gully. Cross sections and length of the gullies could be collected to determine severity. This could be further analyzed to find the threshold conditions around the formation of the most severe gullies. This would be a good preliminary indicator of where efforts might need to be focused.

This study gives provides background information that could be used in a variety of planning situations. It gives solid results, that reflect work done in other areas, but contributes information regarding soil types that was previously unstudied. There may be many other applications for the results of this study yet undiscovered.

APPENDIX 1

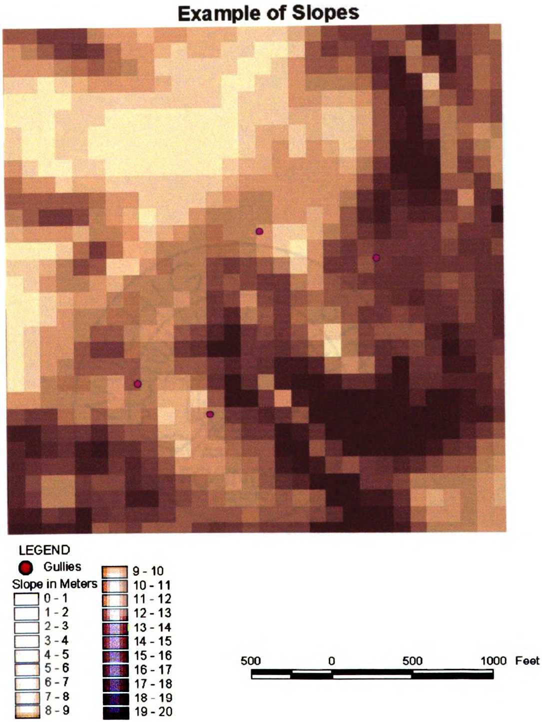
Examples of Gully Locations in Alllegan County



APPENDIX 2

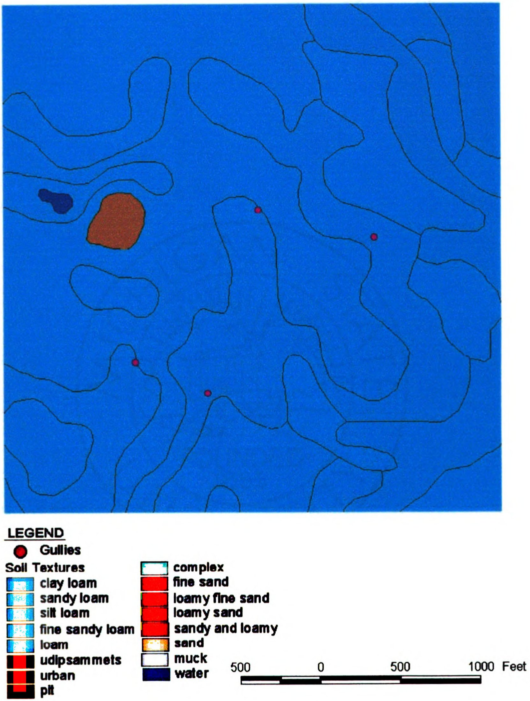
Example of Flowlines and Catchment Areas

APPENDIX 3


Example of Slopes
LEGEND
Gullies
Slope in Meters
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
500
0
500
1000 Feet

APPENDIX 4

Example of Soil Textures



APPENDIX 5

Example of Hydrologic Soil Groups

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