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REMOTE SENSING FOR THE IDENTIFICATION OF CRITICAL EDGE-OF-FIELD EROSION CONTROL SITES

By

Stephen D. Cunningham

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ABSTRACT

REMOTE SENSING FOR THE IDENTIFICATION OF CRITICAL EDGE-OF-FIELD EROSION CONTROL SITES

By

STEPHEN D. CUNNINGHAM

Locating and indexing the severity of critical edge-of-field erosion control sites is an essential step in the process of reducing non-point source water pollution. Changes in land use and remoteness of problem areas often make up-to-date and uniform watershed evaluation time-consuming and expensive. Remote sensing and Geographic Information System (GIS) analysis provide a quick, accurate, and relatively inexpensive method of identifying areas of highest priority for objectively allocating resources for corrective action. This investigation has resulted in the development of a watershed erosion survey technique that maps the ephemeral drainage pattern, identifies critical erosion areas, ranks drainage catchments within the watersheds (according to sediment yield) and identifies the critical control points associated with each catchment. The technique utilizes existing aerial photographs and USLE-sediment delivery ratio analyses on a personal computer based (GIS). This process offers simulation capabilities that enable managers to test management options. Data for usefull land use decision making has been produced by applying the survey technique to a 4800 acre watershed in Wheatland Township, Hillsdale County, Michigan.

ACKNOWLEDGMENTS

I began this investigation with the vague notion that there were new tools to be applied to an old problem. The direction and focus of the resulting study is largely attributed to the insights and guidance provided by my major professor Dr. Eckhart Dersch. I expressly thank Dr. Dersch as well as my other committee members Dr. Kyle Kittleson and Dr. Lawrence Libby for their contributions, comments and criticisms regarding this thesis. Special appreciation is also extended to this committee for their patience and sense of humor.

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Finally, I wish to thank my wife Ria and my two boys, Simon and Ethan for their never ending patience and encouragement. This thesis is dedicated to my father Arthur B. Cunningham in honor of his ability to work hard and laugh even harder.

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CHAPTER I

INTRODUCTION

The effort to control soil erosion and the subsequent sedimentation of our surface waters has been an on-going battle for many years. There has been a great deal of success with advancements in tillage practices, improved farm management plans and new regulations to control erosion. In spite of this progress, annual soil losses which exceed tolerable levels needed to maintain long-term soil productivity still continue (Duttweiler and Nicholson, 1983). These losses not only jeopardize productivity, they also represent the cause of most non-point source water pollution.

Surface waters are degraded by both the soil particles themselves and the chemical pollutants attached to them. Although the technical means for correcting these problems are quite well understood, procedures for identifying the most serious problem sites need refinement. The challenge is as Libby (1984) has stated, how to get these practices installed in places where they will make a difference. While this is in essence a policy questions of who will absorb the cost of erosion control and who will receive the benefits, these questions are hampered by a lack of information on which to base locational decisions. Recognizing this problem, a hypothesis central to this thesis is that the identification of critical erosion areas and their associated control points is a prerequisite to effective budget and program decision making.

The Problem

Cultural sources of nutrients have long been associated with the accelerated eutrophication of lakes and streams (Beaulac 1980). While natural sources seldom contribute to water quality deterioration, human activities often overload the assimilative capacities of surface waters causing adverse consequences. Nutrients and eutrophication represent only a portion of the water pollution problem. Of equal importance are the ecological impacts of toxic chemicals such as pesticides in our surface waters.

Water pollution sources can be divided into point and nonpoint sources. Point sources enter a watershed at discrete, identifiable locations (Chester and Schierow, 1985). They are easily quantified and would include sources such as industrial and municipal discharge points. Nonpoint water pollution sources enter a watershed from diffuse origins. They are by nature sources of pollution that depend on the mechanisms of the hydrologic cycle to transport them to surface waters (DeCoursey, 1985).

Nonpoint sources of water pollution account for more then 50% of the total water quality problem (Novotny and Chesters, 1981; Chester and Schierow, 1985). They are responsible for the delivery of such materials as sediments, nutrients, pathogenic bacteria, pesticides, acid rain and polychloroinated biphenyls (PCBs). Nonpoint sources contribute roughly 80% of the total nitrogen load and more than 50% of the phosphorus load into receiving waters. An estimated 4 billion tons of sediment are delivered annually into streams and rivers of the United States (Novotny and Chesters, 1981).

Much of the nonpoint pollution load is in the form of sediment. Most of the sediments, related nutrients and toxic chemicals originate on agricultural land. Water caused soil erosion, the detachment of soil particles from the soil mass and subsequent transport of these particles by flowing water, is the causal factor driving this process (Khanbilvardi et al., 1983). It is clear that much erosion is caused by what farmers and other land users deliberately chose to do on their land. Land use decisions that result in erosion are rarely irrational. They are caused by a complex set of incentives not the least of which is the pursuit of an economic livelihood (Libby, 1985).

The negative effects of soil erosion on agricultural productivity are difficult to quantify. This is due largely to the difficulty of isolating the effect of erosion from the many other variables influencing crop production. Farmers often substitute other inputs for their loss of natural productivity, increasing their yields while simultaneously experiencing excessive soil loss rates. This substitution of inputs is perhaps one of the most important explanations for continued high erosion rates in spite of years of control efforts. As has been pointed out, the cost of labor and land have skyrocketed compared to other agricultural inputs. Farmers have thus substituted the relatively cheap inputs of fertilizer, water, and gasoline for the relatively expensive ones of land and labor (Batie, 1983).

While difficult to quantify, the on-farm impacts of soil erosion must be viewed as a threat to long-term productivity of land, resulting in costs which are often delayed or transferred to others (Batie, 1983; Libby, 1984). Nationally, erosion has been estimated at 4.5-5.0 tons per acre each year on 416 million acres of cropland (Elfring, 1983; Duda and Johnson, 1985). Much of this soil loss exceeds soil formation rates or tolerance levels and constitutes soil mining. Some of the secondary effects of erosion on soil properties and productivity include reduced rooting depth, deteriorated soil tilth, increased susceptibility to compaction due to a loss of organic matter, increased draft on farm implements, soil fertility and textural changes (Foster et al., 1984).

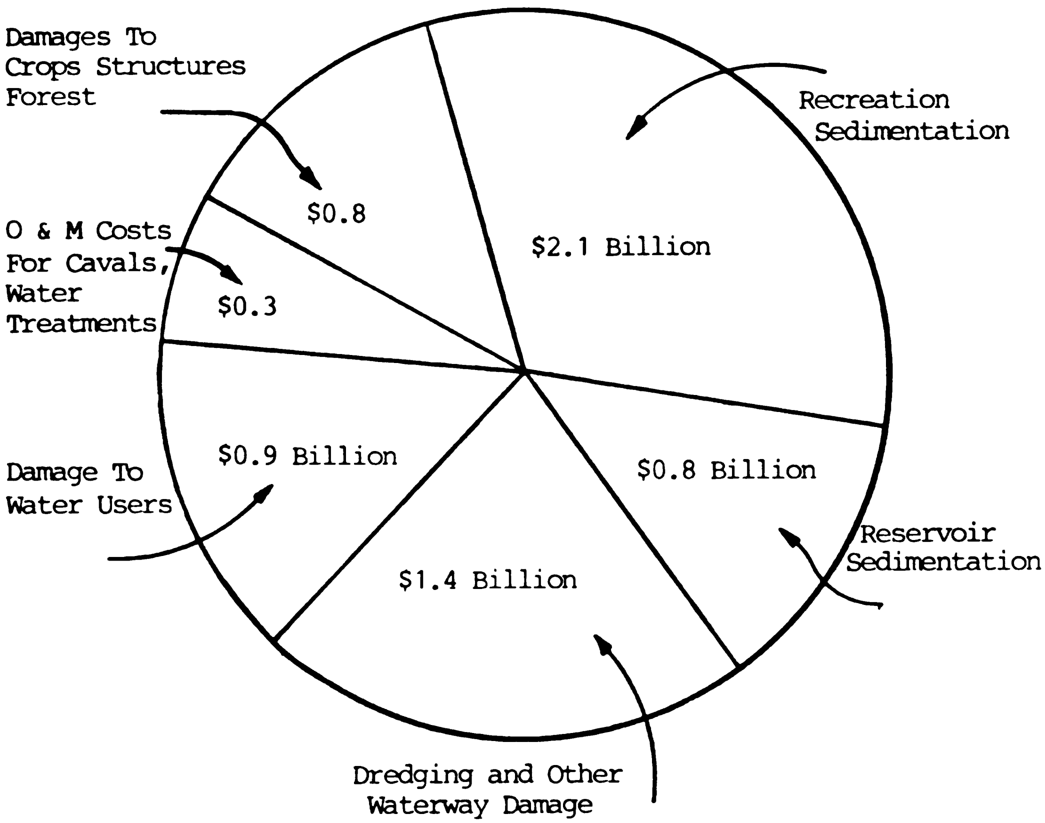
Economic costs of these on-site damages are related to both reduction in crop yields and the costs associated with substituting technology for soil. Willis and Evans (1977) estimated that the cost associated with replacing just the nitrogen, phosphorus and potassium averaged $4.00 for each ton of eroded soil. This could account for a national bill of $7 billion per year for nutrient replacement given estimated average soil losses (Duda and Johnson, 1985).

The public has an interest in the erosion debate not only because of the cost associated with maintaining soil fertility and the assurance of long-term food and fiber production but because many of the off-farm costs of erosion are passed on to others. The off-site erosional damages are not as apparent or obvious to most of us, yet account for economic costs of $6.2 billion per year. Much of this ($1.2 billion) is directly attributed to cropland erosion (Clark, 1985). These costs are related to the maintenance of waterways such as dredging, damages to reservoirs in the form of reduced storage capacity, impacts to recreation, as well damages to water users such as water-dependent industries. Figure 1 represents the estimated cost of off-site sediment damages in billions of dollars per year.

The economic impacts of non-point source pollution on recreation becomes apparent when we consider Florida's Lake Apopka. This lake, a national attraction in 1950 for its famed fishery and water-based recreation, has received massive loads of nutrients from agricultural activities. The resulting eutrophication has caused a collapse of the fisheries and other recreation. The estimated restoration costs have been placed at $25 million (Duda and Johnson, 1985).

The effect of sedimentation and the resulting eutrophication are not limited to inland lakes in the warmer region of the country. Lake Erie, one of the Great Lakes, with a volume of 109 cubic miles, was a major symbol of environmental degradation in the 1960s and 1970's. While its so called "death" was not entirely caused by non-point source pollution, much of the environmental degradation could be interpreted as erosion-caused off-farm damages. In 1971, the lake was described as the embodiment of all that can go wrong in an equatic system. The fifty million pounds of commercially valuable fish caught in 1920 had dropped to a mere one thousand pounds. Mats of filamentous algae covered entire square miles of lake surface and the once clear water was filled with excessive numbers of microorganisms (Wagner, 1971). The market and

Figure 1 Off-site Sediment Damages
$6.2 Billion/Year



From Duda and Johnson, 1985. (orginally from Clark, 1985).

non-market costs of these types of damages are difficult to quantify. The transfer of costs to the managerially independent user is a basic part of the nonpoint pollution problem and gives impetus to control strategies that emphasize not only the reduction of soil detachment but also the reduction of down-stream damages.

A diversity of interest groups benefit from or support the control of soil erosion. Farmers, adjacent property owners, those who use or care about our surface waters and the agencies mandated to control erosion, all have an interest in the policy that is aimed at reducing soil erosion. Incentives that encourage soil erosion or conservation are complex and imbedded in a wide range of factors. A few include: on-site costs of control which often exceed the income generated by that particular control; governmental policy which has encouraged erosion by rewarding high levels of production with price supports that in turn encourage farming erosive lands; tax structures and lending policies; and the basic concept of fee-simple property rights that encourage the belief that property owners have a right to erode (Batie, 1983; Libby, 1984).

Erosion Information: A Basic Part of the Solution

For those who care about erosion control, for whatever reasons, acquiring information concerning where erosion is occurring and at what rates is essential. Cooperative areawide water quality planning, including the identification of nonpoint pollution sources, has been outlined and mandated under Section 208 of the Federal Water Pollution

Control Act of 1972 (Public Law 92-500). Clearly, the existing voluntary and educational programs designed to meet the "fishable and swimmable" goals also required by the Act have not been achieved in spite of the good intentions of Section 208. While these objectives may have been doomed to failure because of their economic implications, many programs have failed, due to their lack of focusing or targeting on the technical solutions to the problem. As Duda and Johnson have recently (1985) emphasized, programs have shown little water quality improvement when cost-sharing and technical assistance were devoted to an entire watershed rather then to pollution hotspots. An estimated 50% of the soil loss due to erosion is produced on 10 percent of the nation's cropland (Batie and Healy 1980). At the same time, the cost of reducing excessive rates of erosion tend to increase as increased reductions in soil erosion are obtained (Batie, 1983). In other words, the cost of reducing erosion by 5 tons per acre on land eroding at 20 tons per acre per year is much cheaper than reducing erosion by 5 tons per acre on land eroding at 8 tons per acre per year.

Accountability has become a very important aspect of agency efforts to control erosion. The Soil and Water Resources Conservation Act of 1977 (RCA) has created increasing concern for program efficiency in a climate of budget austerity. The targeting of resources to priority problem areas has become a key element of erosion control program development since some of the early RCA drafts (Libby, 1982). As Batie (1983) has pointed out, U.S. Department of Agriculture (USDA) studies have shown that less than 19% of the soil conservation practices installed by 1981 had been placed on the most erosive land with a majority of the control resources being devoted to land eroding at less then 5 tons per acre per year. It is findings such as these that has increasingly led to a desire to implement some form of targeting into the erosion control effort.

Targeting control resources is a data dependent process. In order to target resources, the location and severity of erosion losses and discharge points must be determined. Procedures are required which would make these determinations in an inexpensive and accessible way which would produce results that could be understood and accepted by landowners. Even if program managers had attempted in the past to focus assistance on farms with the greatest erosion problems, the lack of data on the nature and extent of soil erosion would have limited their ability to do so (Batie, 1983).

There are many different types of targets chosen for many different reasons. For example, if maintaining soil productivity is the major concern, then fertile but shallow soils will be priority control targets regardless of erosion rates. On the other hand, if the managers interest is water quality, just the opposite will be true. Other problems inherent to targeting relate to the question of who will chose the targets, the equitable distribution of public resources, and the destabilization of existing programs (Batie, 1983). Whether or not targeting resources is the major theme of soil conservation programs, most control strategies will need to rely on accurate data on which to base decisions.

Present Efforts

The identification and assessment of soil detachment areas (on-site problems) is a process that is constantly taking place. Farmers continue to inspect their fields and soil conservationists work, as they have for many years, gathering and processing data on this problem on a field-by-field basis. We are quite proficient at identifying and predicting erosion problems on the field scale. Erosion can be observed because of its scars and can be predicted because its causal factors are known. What is not done on a regular basis is the identification and prioritizing of erosion and its control points at the watershed level. This is the level of data acquisition required for agency resource targeting.

The effort spent to identify and index downstream or off-site erosion control points is almost nonexistent. Storm events often occur with runoff forces that are not easily controlled. Structures such as detention ponds, settling basins, drop spillways and flow dispersion devises do not stop soil detachment, yet they do offer a means of reducing the amounts of sediment and nutrients that could enter downstream surface waters. The placement of such structures is crucial because they are expensive and should be located at the most critical edge-of-field locations to be the most effective.

Stephens and Chilar (1981) and Duda and Johnson (1985) have emphasized that interagency, cooperative programs must be targeted to pollution hotspots in watersheds if Clean Water Act goals are to be attained. In an effort to be more efficient in the use of their limited resources, the U.S. Department of Agriculture's Soil Conservation Service (SCS) has conducted watershed protection plan surveys. These surveys assess the total watershed and specify those areas to be included in protection plan goals. By targeting resources to those areas found to be critical, SCS can achieve the greatest benefit for any given amount of agency resources. Alternative targets have been chosen by comparing different mixes of management practices which maximize erosion reduction while addressing the problems of lost productivity and the loss of farm income. The definition of what land is critical therefore changes with each alternative and associated mix of management options (USDA, SCS, 1983). The information obtained during these surveys will determine to a large extent the implementation of their watershed protection plans. SCS survey procedures presently consist primarily of delineating on aerial photographs impressions gained from "windshield surveys." Agency personnel drive the section line roads throughout the watershed and record on aerial photographs any visible erosion activity (Ditson, 1984).

While windshield surveys offer detailed information that cannot be duplicated, they are often hampered by poor vehicle access. Section line roads provide a view at the perimeter of each square mile however, erosion problems in mid-sectin can go undetected. Topography and vegetation in close proximity to the road can also limit visibility. A further drawback to ground surveys is their high costs related to automobile, time and manpower usage.

Research Questions and Objectives

Studies have indicated that the tools of modeling, remote sensing and geographic information systems analyses offer a practical and improved alternative to "windshield surveys" for agencies like SCS who need to gather sizable quantities of data from the landscape (Smart et al., 1981; Stephens and Chilar, 1981; Adams et al., 1982; Morgan and Nalepa, 1982; Johannsen, 1983; Beaulac et al., 1984; Pelletier 1985; Johannsen, 1985).

While there have been studies that have utilized the above tools the often complex models, specialized remotely sensed data and GIS systems necessary to generate predictions are not always practical for most soil conservationist and land-use planners. The principal questions of this research effort were: 1) Could a watershed erosion survey method, utilizing the tools of modeling, remote sensing and GIS analysis, be designed that would be both practical and easily implemented? 2) Could the survey system be made economical from a land use manager's point of view?, and 3) Would this survey technique provide the information required to effectively target erosion control resources? The objective of this research was to answer these questions by applying those tools to an actual erosion problem area. While it was beyond the scope of this research to conduct *in situ* measurements and fully test the survey technique that has been designed, this thesis provides an affirmative answer to the research questions.

To acquaint the reader with the tools and the survey technique, a discussion of their design and nature is provided in Chapter II. Particular attention is given to the Universal Soil Loss Equation because of its historical role in erosion prediction and its central place in the survey design.

Chapters III and IV focus on the application of the erosion survey technique to a small watershed in Michigan. These chapters include descriptions of the data bases, data entry, computations and results of the survey application as well as sources of error.

Chapter V presents summaries, conclusions and recommendations for further refinement of this research. The need for building geographical data bases and roadblocks to that end are also discussed. The recommendations provided in Chapter V emphasizes research areas or topics which remain to be investigated by those interested in the erosion and nonpoint source pollution problem.

CHAPTER II

DESIGN OF THE WATERSHED EROSION SURVEY

Introduction

The two objectives of agricultural water pollution control should be to stop soil detachment protecting soil productivity and to reduce the impacts of pollutants that are not held in the field. A conceptual basis for efficiently attaining this objective views the watershed as the basic system in which any planning or control technology must function. Webster's Dictionary defines a watersheds as the geographical area drained by a water course. Regardless of size, it is comprised of an interconnected set of geographical components upon which agricultural and/or other activities occur. Watersheds function as interconnected hydrologic and ecologic systems where a change in one variable can impact seemingly independent variables. It is within this system that any erosion survey technique and its tools must operate.

The Tools

Models and the Universal Soil Loss Equation: The USLE

Models have been defined as abstractions of the real world. They permit the simplification of real world phenomena such that they can be handled in a finite and effective manner (Bailey and Swank, 1983). Modeling the erosion process and watershed pollutant delivery is a complex and formidable task. Baily and Swank (1983) have listed some of the many objectives of modeling this dynamic processes:

1. To organize knowledge of the system response in terms of its driving function in a concise, quantitative manner.
2. To frame concepts such as a systems representation of pesticide and nutrient attenuation and transformations and then piggyback these onto existing hydrologic models.
3. To test concept validity.
4. To predict system-agricultural chemical behavior under different sets of conditions (spatial and temporal).
5. To provide a tool for decision making.

There are many types of models being applied to the nonpoint source pollution problem but as Wischmeier and Smith (1978) pointed out, the adequacy of a model or equation must be judged on the basis of how well it meets its intended purpose. This statement is key in the selection of the USLE for the survey system used in this research. While many erosion and watershed models exist, the USLE offers a relatively simple equation that could be directly applied to GIS technology and yet model the interaction of watershed variables basin-wide.

For example, CREAMS, the Chemical Runoff and Erosion from Agricultural Management Systems model is designed to be applied to field-size areas (DeCoursey, 1985). The ANSWERS model (Aerial Nonpoint

Source Watershed Environment Response Simulation), is expensive and cannot be used economically for longterm simulation (KNISEL et al., 1983). Both of these models as well as SWRRB (Simulator for Water Resources in Rural Basins), SPUR (Simulation of Production and Utilization of Rangelands), and SWAM (Small Watershed Model) require extensive and detailed data sets that are rarely available for most watersheds (DeCoursey, 1985). Many Michigan counties, for example, do not have completed or up-to-date soil surveys, let alone data such as surface roughness, chemical application rates and daily or hourly rainfall data, which is the type of information necessary to apply models such as CREAMS.

The intended purpose of this research was to develop a survey or screening system that would provide land use decision makers with information which would enable them to target their resources. Bailey and Swank (1983) have described the criteria that such a screening system should possess. These criteria include:

1. It must include the ability to identify potential environmental problem areas within a larger geographical area.
2. It should be simple, quick and relatively inexpensive.
3. It should be supported by available databases.
4. The system needs to produce longterm, average, or steady-state predictions.
5. It should handle large geographic areas.
6. It should be set up for easy repetitive application.

The Universal Soil Loss Equation (USLE) is the only widely used model that can meet the screening system criteria and yet be applicable to geographical information system technology.

The USLE is an erosion model designed to predict the longtime average soil losses in the runoff from specific field areas for each feasible alternative combination of crop system and management practices in association with a specified soil type, rainfall pattern, and topography (Wischmeier and Smith, 1978). The equation groups the numerous interrelated physical and management parameters influencing erosion rates under six major factors whose site-specific values can be expressed numerically. The USLE was formulated by Wischmeier and Smith (1978) as:

$$A = (R)\ (K)\ (LS)\ (C)\ (P)$$

Where:

A = Computed soil loss per unit area; usually expressed in tons per acre per year

R = Rainfall and runoff factor; the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K = Soil erodibility factor; the soil loss rate for a specified soil as measured on a unit plot, which is defined as a 72.6 ft. length of uniform 9-percent slope continuously in clean-tilled fallow.

LS = Slope length/steepness factor; the ratio of soil loss from the field slope length and gradient to that from a 72.6 ft. length of uniform, 9-percent slope under otherwise identical conditions.

C = Cover and management factor; the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P = Support practice factor; the ratio of soil loss with a support practice such as contouring, stripcropping, or terracing, to that with straight-row farming up and down the slope.

Numerical values for each of the six factors can be found in numerous handbooks explaining the use of the USLE such as the U.S. Department of Agriculture's (USDA) Handbook Number 537 or state-specific handbooks such as the Soil Conservation Service's Michigan Water Erosion Control Technical Guide, Sec. I-C.

The numerical values in the USLE were derived from analyses of over 40 years of experimental field plot data gathered by the USDA's Agricultural Research Service (Norotny and Chesters, 1981). They represent long-term averages for erosion values that may vary greatly during any one storm event. As Wischmeier (1976) has pointed out, soil losses computed by the USLE must be recognized as the best available estimates rather than as absolute predictions. It should also be emphasized that the soil loss predicted by the USLE only represents soil detachment and transport caused by sheet and rill erosion and does not account for losses due to gully, streambank and channel erosion.

Sediment Delivery Ratios

The value of soil loss predictions can be enhanced if it leads to insights relating to sediment yield. Soil loss must be distinguished from field sediment yield. Soil loss, as predicted by the USLE, represents soil that is detached and transported from its original position in the field. A field's sediment yield, on the other hand, is the sum of the soil losses occurring in that field minus deposition in depressions within the field, at the toe of slopes, along field boundaries and in terrace channels (Wishmeier, 1976). The USLE does not account for deposition. To compute the sediment yield from eroding soil to a water body, gross soil loss estimated by the USLE must be reduced to account for deposition. This is done by applying a sediment delivery ratio to the sum of soil loss estimates. Sediment delivery ratios are factors that express the ratio between sediment yield and gross upstream erosion (Novotny and Chesters, 1981). This relationship in its simplist form can be expressed as:

$$DR = Y/A$$

Where: DR = Sediment delivery ratio

Y = Watershed sediment yield

A = Upland erosion potential (USLE results)

While this relationship is easily expressed, the factors controlling the dynamic process are difficult to quantity. Renfro (1975) has listed many factors influencing the ratio between sediment detachment and delivery, including: the magnitude and proximity of the sediment source, the relief-length ratio, the channel density of the drainage area, main-stem channel length, and alluvial soils area.

A number of empirical relationships have been developed between the factors influencing sediment delivery and actual yields. For example, by comparing sediment yield data from reservoir sedimentation records with calculated gross erosion rates, expected sediment delivery ratios can be determined for specific watersheds as was determined by Beaulac et al., (1984) for the State of Kentucky.

Developing reasonable estimates of pollutant transport efficiency or delivery, while especially difficult for individual storm events, can be developed if they are based on long-time averages. These ratios better represent the watershed morphological characteristics and are more reliable and easier to ascertain (Novotny and Chesters, 1981). Based on studies by Roehl (1962), Renfro (1975), Beaulac et al., (1984) and others, a single similarity has emerged from the data; sediment delivery ratios vary inversely as the 0.2 power of the drainage area. In other words, as the drainage area increases, the proportion of detached sediment delivered off-site decreases.

Recognizing this relationship, SCS has developed geographically specific sediment delivery ratios to accompany their USLE handbooks. The erosion survey or screening system developed during this research utilized the USLE and the sediment delivery ratios supplied by the SCS, as will be shown, to estimate where critical soil erosion areas and locations in the watershed where serious sediment loading is occurring.

Remote Sensing

Remote Sensing is the science and art of acquiring information about material objects from measurements made from a distance without coming into physical contact with the objects (Lillesand, 1979). Past research has shown remote sensing to be a beneficial tool in erosion studies. As early as 1966, Jones and Keech were using aerial photographs to measure the extent of gully erosion and to pinpoint erosion "black spots" in Rhodesia. Frazier et., al (1983) also found aerial photographs useful in documentating erosion under various management practices. Many others have found this technology to be beneficial not only in direct erosion assessment but also in providing information relating to the causal factors of erosion (Stephens and Chilar, 1981a; Blanchard and Chang, 1983; Johannsen, 1983; Spomer and Mahurin, 1984; and Wildman, 1984).

A relatively recent development has been the use of remote sensing in determining the factors needed to generate the USLE. Because the USLE factors must be assigned site-specifically, applying the equation over vast areas such as a watershed can be expensive and time consuming. Aerial photographs enable researchers to generate those factors not supplied by existing maps on a site-specific basis with considerable efficiency (Morgan et., al 1978; Stephens and Chilar, 1981b; Stephans et al., 1982; Stephens et., al 1985). One study found the generation of the USLE utilizing aerial photographs to be two to four times faster than conventional techniques while still maintaining a high degree of accuracy (Stephens et., al 1985). Remote sensing also allows the creation of a permanent record of land uses with in a watershed. Land uses which determine the 'C' and 'P' values in the USLE can be easily up-dated on a regular basis by obtaining the most current images.

A further rationale for utilizing this tool during this research effort was its usefulness in mapping ephemeral stormwater channels. These runoff concentration paths have been mapped during previous research (Ishaq and Huff, 1974; Williams and Morgan, 1976), with up to 75 percent accuracy using aerial photographs (Stephens et., al 1982). Ephemeral storm water drainage channels have been shown to be important morphological features in control structure placement. Omernik et al., (1981) cited these paths of concentrated runoff as one of the primary reasons for the failure of stream-side buffer strips. Ishaq and Huff (1974) have demonstrated that these ephemeral waterways are the source areas for sediment delivery from micro-watersheds. They found that the perennial stream channel system expands its original size during storm events into areas that become saturated thus providing a direct connection for eroded sediment to reach the receiving surface water. The identification and prioritization of these runoff features were essential to the erosion survey system developed during this investigation.

Geographic Information Systems (GIS)

A GIS is a computerized, data-grid based system that merges land information using variations of map overlay procedures. Because the objective of this research was to develop an erosion survey system with watershed applications, the ability to process vast quantities of spatial data was essential. A geographic information system (GIS) offers this capability in its ability to store, analyze and display land information with speed and accuracy (Morgan and Nalepa, 1982). GIS applications have been especially useful to USLE investigations especially useful (Smart et., al 1981; Adams et., al 1982; Beaulac et al., 1984; Pelletier, 1985). This is true because the individual factors in the equation can be easily represented in map form. These maps can then be digitized, converting them to coded map files in the GIS. These files or data layers can be recoded and multiplied, grid cell by grid cell, to compute the USLE. Spatial integrity is maintained by geographically referencing all of the digital data to a standard coordinate mapping system such as the Universal Transverse Mercator or the State Plane system.

Once a database has been established, a GIS has the ability to easily update existing files using a recode function thus allowing up-to-date landuse mapping, near real-time erosion calculations and the testing of future management scenarios.

In order to meet the Bailey and Swank (1983) screening system criteria previously mentioned, it must be simple, quick and relatively inexpensive to use. The GIS chosen for this survey technique was the personal computer (PC)-based Comprehensive Resource Inventory and Evaluation System (CRIES) which was designed at Michigan State University in The Department of Resource Development (Schultink et al., 1985). Using this software, the GIS can be used on any PC capable of word processing. The choice of this software or another PC-based GIS enables the survey system developed during this research effort to be implemented with what are now becoming common office or home computers.

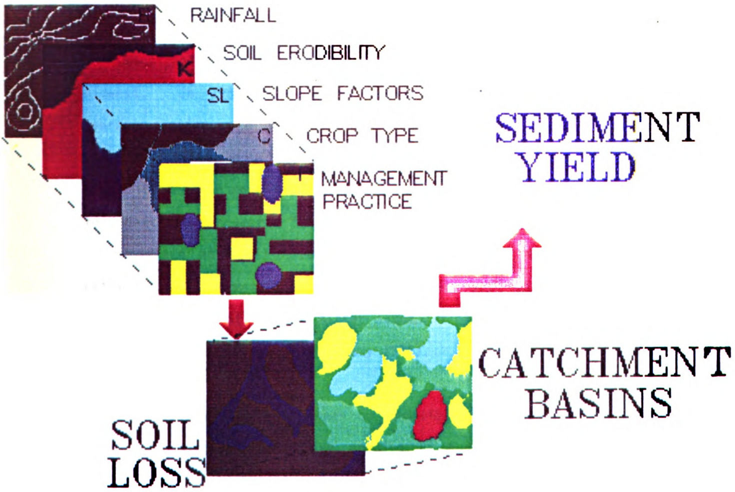
Overview of The Survey Design

The USLE, remote sensing, and the GIS have logically been merged together to create a very useful and practical targeting device. In order to produce both on-site and off-site information, the erosion survey was designed in two phases. First, the data on which to base the USLE factors was gathered for an entire watershed. This data, in map form, was then digitized and entered into a GIS. The USLE was then calculated for each grid cell within the data files. The output of this computation is a map illustrating (gross) soil loss estimates, in tons per acre per year, for the entire watershed.

The second phase of the survey consisted of mapping the ephemeral drainage pattern for the entire watershed and subdividing the area into mini-watersheds or catchment basins based on the ephemeral drainage network. Estimated soil loss for the sum of the catchment basins was then totaled and the sediment yield for each catchment was then estimated using sediment delivery ratios. This information was then used to produce a map illustrating the ranking of catchments according to their sediment yield. Because the ephemeral drainage patterns have been mapped and stored in the GIS, they can be overlaid onto this ranked catchment map revealing those channels needing stabilization and the point at which the surface water runoff of the catchment discharges into a receiving surface water. These points are considered the edge-of-field control points. The integration of data layers for both phases of the system are graphically illustrated in Figure 2.

The survey system has a two-fold purpose. It produces information on the location of severe soil loss in the field, thus allowing land-use decisions to be made that will have direct effects on erosion and crop productivity. It also is designed to delineate those micro-watersheds within a study area producing large sediment yields. This information allows the targeting of control resources by identifying the locations where grassed waterways, spillways, sediment traps and other best management practices might be located.

FIGURE 2 GIS LAYERS FOR USLE INPUT



CHAPTER III

APPLICATION OF THE EROSION SURVEY IN MICHIGAN (PHASE I)

Introduction

Michigan's erosion problem is typical of states throughout the midwest. In 1982 (the latest publicized data) SCS estimated the average erosion rate on Michigan's cropland at 4.5 tons per acre per year, an estimate very near the national average. The "T" or "tolerance" levels listed for most Michigan soils fall into the range of two to five tons per acre per year. "T" values represent the erosion rate that soil can tolerate and still remain productive. It is determined by the estimated soil formation rate of a particular soil which is related to that soil's rate of organic matter accumulation and the weathering rate of the soil's parent material (Brady 1974).

With average erosion rates near or exceding "T" values, it is obvious that some Michigan soils are eroding at a critical rate. Erosion control practices such as contour farming, conservation tillage, grassed waterways, and crop rotations are needed on an estimated 3,448,000 acres of the state's cropland to reduce soil erosion and sediment damage, and maintain crop production (USDA, SCS, 1985). The need to identify and prioritize the most critical areas of erosion and sediment yield is crucial in Michigan as it is elsewhere.

Geographical Setting of the Study Area

The Bean Creek watershed in Hillsdale and Lenawee Counties, Michigan is no exception to these statistics. Of the 97,400 acres of cropland present in the watershed, 80,000 acres are clean tilled. The estimated annual soil loss for the clean tilled acre is 833,000 tons. Erosion rates vary from 5 to 20 tons per acre per year. An estimated 34,000 acres in the watershed are critically eroding at a rate greater than 10 tons per acre per year (U.S. Dept. of Ag., SCS, 1983). SCS (1983) has estimated crop production in this area will decrease by 20 percent for every inch of topsoil lost. Losses in productivity on the 34,000 acres of cropland with a critical erosion problem result in an estimated income loss of $542,000 annually.

Many of the off-site erosion damages originating in the Bean Creek watershed are not easily quantified. SCS (1983) has reported that sediment deposition in the watershed is causing a problem with crop and soil burial, the filling of drainage and roadside ditches, the obstruction of water disposal systems and the degradation of wetlands. While many of these problems can be corrected with maintenance dredging, the accumulation of sediment in wetlands can have devastating effects due to the accelerated succession of wetlands to drier conditions and the subsequent species change (Wagner, 1971).

Another off-site damage of equal importance is the downstream effects of Bean Creek sediment. Bean Creek's ultimate discharge point (via the Maumee River) is the shallowest and most eutrophic basin of Lake Erie (U.S. Army Corps of Engineers, 1982). Bean Creek was one of five Lake Erie tributaries selected in 1980 for a detailed non point source pollution study by the U.S. Army Corps of Engineers. The purpose of that study was to determine the extent of diffuse source pollution within the watershed. Much of the watershed was determined to be eroding at critical rates (the average was 7.7 tons/acre/yr) and a main contributor to the annual sediment load discharged to Lake Erie.

The Bean Creek Watershed Management Study published as part of the Lake Erie Wastewater Management Study in 1982 by the Army Corps of Engineers emphasized the need to control soil erosion and left the identification of critical control locations to the county SCS offices. An effort has been made by SCS, using their windshield survey system, to determine those locations where control resources should be targeted. Based on the concentration of visible erosion scars on the landscape, a critical area eligible for cost-share assistance was identified within the watershed (Ditson, 1984). While both efforts were beneficial, the Corps of Engineers and SCS studies did not produce an adequate database from which particular erosion control targets could be identified and prioritized.

The Bean Creek watershed was selected by this investigator to illustrate the erosion survey system developed during this research because it offered the following conditions:

-serious erosion conditions affecting production

-serious off-site erosion damages

-environmental conditions including cropping systems, topography, rainfall, and soils typical of Midwest agriculture

-the opportunity to compare the GIS-based survey to the traditional windshield survey used by SCS.

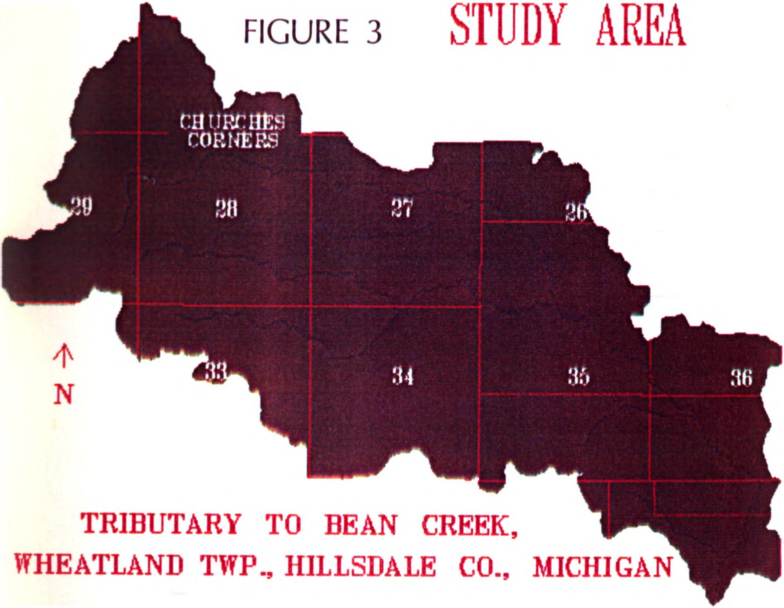
Time and budget constraints limited the application of this research to the 4800 acre watershed of an un-named tributary of Bean Creek (see Figure 3). Its environmental conditions were very representative of those in the entire Bean Creek watershed.

Methods

Obtaining Primary Data Layers

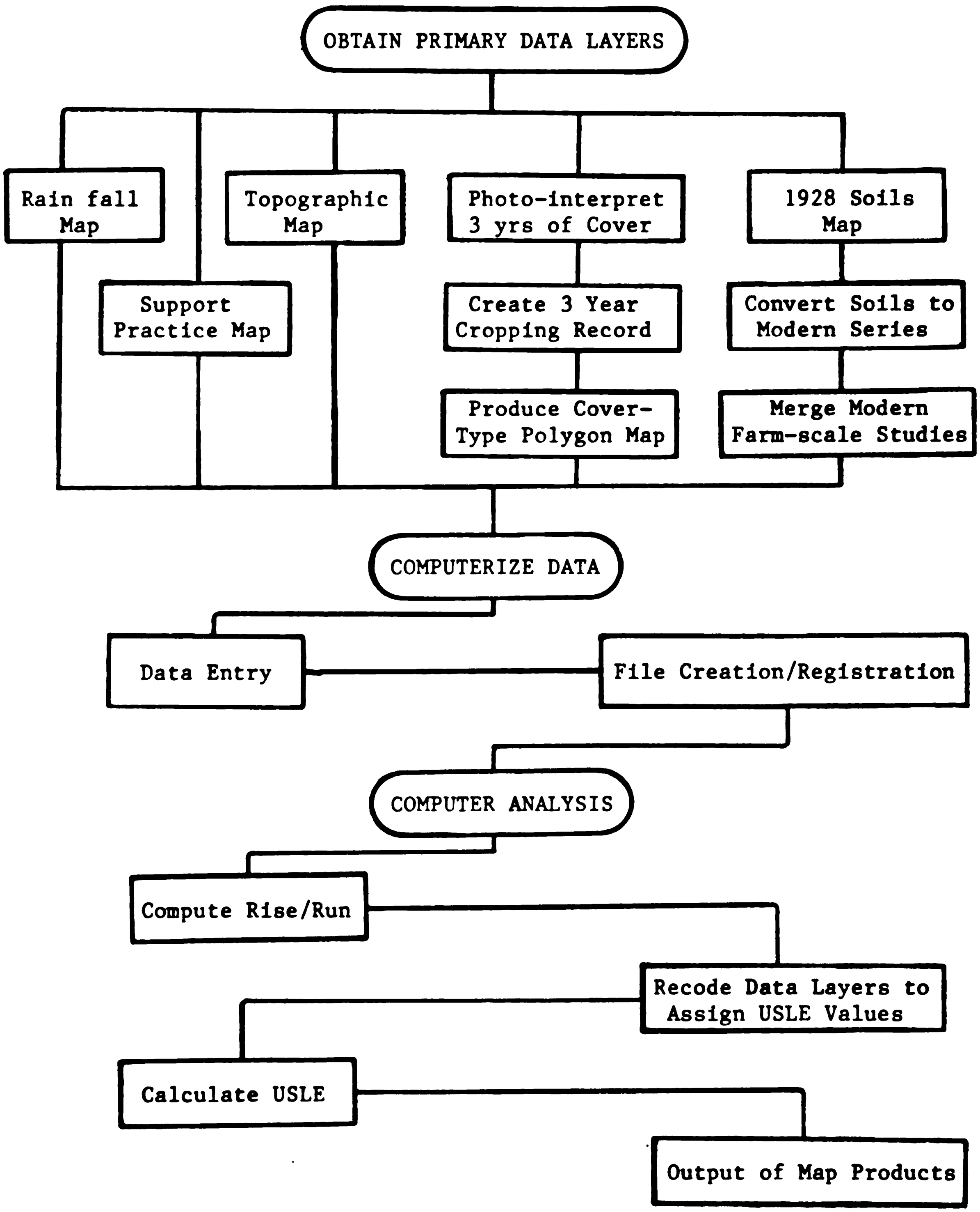
In order to calculate the USLE, a database was required which would supply the variables for each of the USLE factors. The data, once gathered, also needed to be entered into the GIS with a compatible geographic reference system in order to maintain spatial integrity. To facilitate this process the 7.5 minute U.S. Geologial Survey (USGS) topographic quadrangle map for the watershed was chosen as the base map to which all the data was referenced. The calculation of the USLE required the use of site-specific values for each of the USLE variables. Each of the values for these variables were obtained from primary data sources such as existing maps and photographs.

FIGURE 3 STUDY AREA



TRIBUTARY TO BEAN CREEK,
WHEATLAND TWP., HILLSDALE CO., MICHIGAN

Figure 4 Procedures for Determining Critical Erosion Control Points (PHASE I)



1. Rainfall (R)

Local values representing the rainfall erosion index may be taken directly from the isoerodent maps supplied in USLE handbooks. The plotted lines on these maps are called isoerodents because they connect points of equal rainfall erosivity (Wischmeier and Smith, 1978).

The USLE handbook prepared for Michigan by SCS (the Michigan Watershed Erosion Control Technical Guide Sec. I-C, hereafter called the Tech Guide), lists a rainfall erosion index of 125 for the entire study area. A map of the study area was therefore prepared with a single attribute value (125). The R factor is often held constant in USLE computations, becoming a constant in the multiplicative equation (Morgan and Nalepa, 1982).

2. Soils (K)

A modern soil survey has not been conducted in Hillsdale County where the study area is located. As a result high quality soils information was not available. It was therefore necessary to converge three sources of information to produce the best soils data for the USLE computation. Using the 1928 soil survey, a base soil map was created for the study area referenced to the USGS topographic map. The old mapping units were then converted to the new soil series names using the updated version of the survey developed by the Department of Crop and Soil Science, at Michigan

State University (Laurin and Whiteside, 1977). Portions of Hillsdale County have had modern farm-scale soil maps prepared by the local SCS office. Where possible, the maps from these studies were collected and transferred to the base map using a zoom transfer scope, a magnifying instrument used to visually merge maps or photographs of differing scales. The resulting composite map represented the best available soils data for the study area.

3. Slope Length and Degree (LS)

USGS 7.5 minute topographic maps are available for most areas in Michigan including the Bean Creek watershed. The Wheatland Quadrangle map, besides serving as the base map, also supplied topographic data at 10 foot contour intervals.

4. Cover (C)

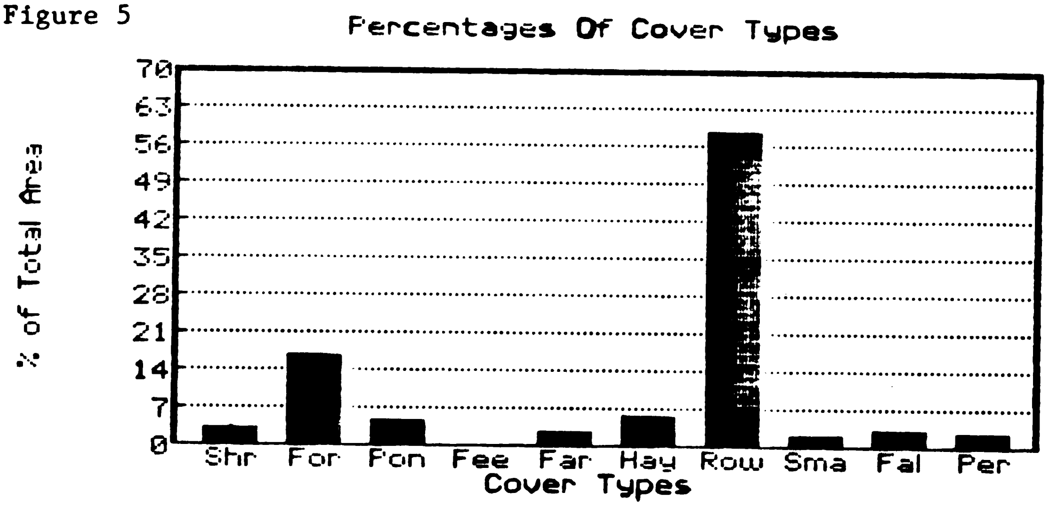
The C factor is the most variable factor in the USLE because it is easily altered by human activity. Average rainfall amounts can be predicted, and soil types and topography are only changed by massive measures. Cover type and land use, however, often change annually with some changes actually taking place during the growing season. It is this variability that makes the need for the use of remote sensing and GIS so apparent. Aerial photos capture large areas of the landscape, creating permanent records of human activities on the ground. These records are easily stored and updated on a GIS, making real-time land use maps and accurate erosion predictions possible (Morgan et at., 1978; Morgan et al., 1980; Stephens et al., 1982; Stephens et al., 1985).

The value of C on a particular field is determined by many variables that are influenced by management decisions. These variables include: crop rotations, crop canopy, residue mulch, incorporated residues, tillage, land-use residual, and other interactions (Wischmeier and Smith, 1978). Special imagery is needed to remotely capture data representing all of these variables. For example, spring photographs using color infrared film have been used to decipher spring-plowed/residue-left conditions from spring-plowed/residue-removed operations (Morgan et al., 1980). Spring-plowed/fall-plowed distinctions can be made by comparing sets of time-sequenced photographs taken at opportune intervals.

These types of image resources rarely exist for conservationists on a regular basis. What is available through agencies like the Michigan Department of Natural Resources (MDNR), the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service (ASCS) and SCS are mid-season, aerial photographs taken specifically to inventory land cover/use types. While these photographs cannot be used to precisely determine C values, they can be used to approximate C values, producing meaningful USLE results. These photographs are also inexpensive and easily attainable.

ASCS mid-season color 35mm slides were used to determine crop types and land use for the study area. These slides, taken to inventory crop acreages, at a scale of 1:24,000, are available on an annual basis. Using a zoom transfer scope, the photographs provided the data needed to create a landcover base map drawn on a mylar overlay referenced to the USGS topographic map. Each land use unit (a total of 668) including individual farm fields, was given a unique numerical identifier. Three different years (1982, 1983, 1984) of imagery were then used to create a cropping sequence record for each land/use/cover type polygon. The crop rotation pattern for any particular polygon was then determined by comparing the three years of cover types in the crop record. Percentages of the dominant cover-types for the study area found during this procedure are shown in Figure 5.

Figure 5



Shr - Shrubland	3.4%		Hay - Hay	5.7%
For - Forest	16.8%		Row - Rowcrops	58.6%
Pon - Ponds	4.7%		Sma - Small Grains	2.3%
Fee - Feedlots	.1%		Fal - Fallow Fields	3.2%
Far - Farmstead	2.7%		Per - Permanent Pasture	2.5%

5. Erosion Support Practices (P)

Aerial photographs can also be used to identify areas where farmers are using erosion support practices such as contour plowing, contour strip croping and terracing. If these practices are not observed, the P factor may be held constant, equal to one (Pelletier, 1985). Contouring and terracing in the Bean Creek watershed are very difficult to apply due to the undulating mottled topography left during the last glaciation. Consequently, the use of erosion support practices were not observed in the study area and the P factor was held constant by creating a map with one as the single attribute value.

Table 1 summarizes how each of the USLE factor values were determined. It should be noted that all of the factor values were determined without field studies using data sources which already exist in most SCS offices.

TABLE 1 USLE FACTOR VALUE DETERMINATION

Factor	Information	Data Sources
R	Rainfall Erosivity Index	SCS Isoerodent Map
K	Soil Erodibility	1928 Soil Survey
		1977 Soil Survey Update
		Farm Management Studies
L	Estimated Slope Length	SCS, County Soil Conservationist
S	Slope Gradient	USGS Topographic Map
C	Crop Management/Cover	
	Crop/Cover type	ASCS Crop Inventory Slides
	Rotation	Comparison of Three Years of Slides
P	Support Pracitce	ASCS Crop Inventory Slides

Procedures To Computerize Data Layers

1. Data Entry

Each of the maps produced or obtained thus far was digitized for entry into the computer. The maps therefore became data layers and were digitized into separate attribute files. They included the following:

- A rainfall map, with the 'R' value taken from the SCS Tech Guide entered as the data value for the total area.

- A support practice map, with a data value of one entered for the entire study area.

- A map of the land cover type, with each cover type polygon and agricultural field given a unique numerical identifier as its data value.

- The soils map, with each soil series given a numerical code as the inputed data value.

- The topographic map, with each elevation between contour lines given a separate data value.

2. File Creation And Registration

The primary data, once gathered and entered into the GIS, became attribute files by assigning a set of State Plane coordinates to each gridcell within the study area. This registration brought all of the data layers into cartographic agreement. The gridcell size was determined by the number of rows and columns chosen to divide the study area. A 50 foot by 50 foot gridcell was chosen because it offered the level of detail needed to both utilize the equation and to produce results that would be practical in the field. The resulting map grid contained 202,000 cells (400 rows and 505 columns). Each of the following sets of data were entered into the GIS using this standard geographically referenced grid pattern.

Computer Analysis

1. Computing Rise/Run

After the contour lines of the topographic map were digitized and entered into the GIS, it was possible to generate the degree of slope for each gridcell by running a program on the GIS called SEARCH. This program calculated the degree of slope by searching in every direction from each gridcell until a contour line was encountered. The machine, knowing the width of the gridcell (50 feet) and the change in elevation between the encountered contour lines (10 feet), was able to compute rise/run and assign a slope degree to each gridcell.

Slope length is not as easily derived from topographic maps. Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel (Wischmeier and Smith, 1978). Because ephemeral stormwater channels and deposition areas are not mapped on USGS topographic maps, this source alone cannot be used to produce slope length values. Ephemeral channels and deposition areas were mapped as part of this study but slope lengths based on this data set proved out-of-step with known slope length values supplied by local SCS personnel. For the purposes of this study, a typical slope length supplied by SCS was assigned to each gridcell as has been done in other studies (Adams et al., 1982; Pelletier, 1985).

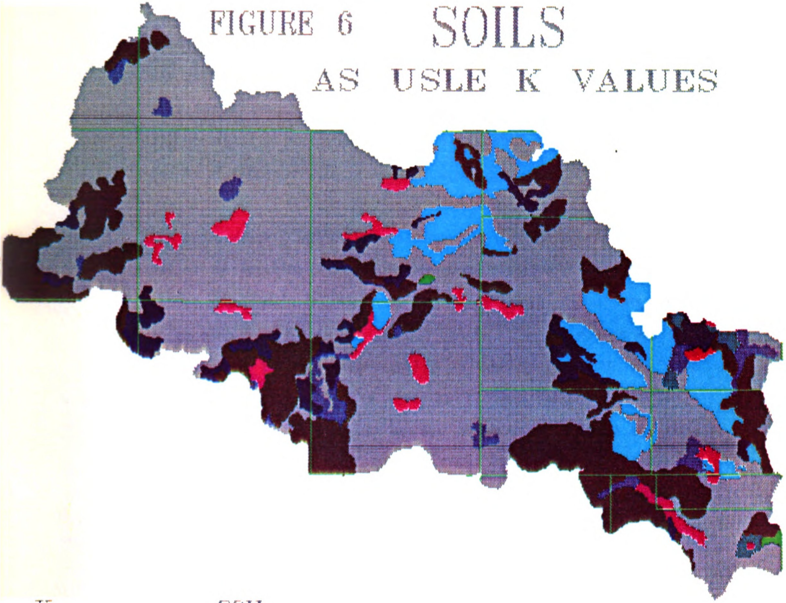
2. Assigning USLE Values

The layers of data that were directly used in the USLE computation were derived from the attribute files using a recode or re-numbering function.

Once the soils map was digitized and entered into the GIS, the attribute values assigned to each soil series polygon were recoded to the appropriate K values based on values found in the Michigan Tech Guide. The resulting soils K-value map can be seen in Figure 6.

FIGURE 6 SOILS

AS USLE K VALUES



K VALUE	SOIL SERIES
.000	HOUGHTON, EDWARDS
.150	COLOMA
.170	TEDROW, SPINKS, BOYER
.200	LOCKE, METAMORA, WASEPI, GILFORD, CONOVER
.240	SEBEWA, HILLSDALE, HILLSDALE CHANERY
.280	ARKPORT, COLWOOD, BROOKSTON
.320	MATHERTON
.370	FOX, MIAMI, SLOAN

Using the LS factor values supplied in the Tech Guide, each gridcell was assigned an LS attribute value based on it's slope and the 125 foot slope length supplied by the local SCS office. Figure 7, illustrates the topography of the study area as expressed by the degree of slope.

The appropriate C values were assigned to each polygon as attribute values by locating the particular crop rotation in the C factor charts provided in the Michigan Tech Guide. Some assumptions needed to be made in order to use the SCS charts. One assumption was that fields were tilled conventionally in the spring with the crop residues remaining in the field. These assumptions, while introducing error, allowed the use of existing imagery and were realistically based upon limited field observations. Figure 8, represents the cover type/use file in the GIS. The individual land use polygons are not visible due to data aggregation by cover/use type.

The data layers representing the R factor (rainfall) and the P factor (support practices), have only one attribute value, were entered into the GIS using the proper USLE value. These maps are not illustrated due to their simplicity.

3. USLE Calculations

Because the data files representing the USLE factors were geographically referenced in the GIS, it was possible to spatially

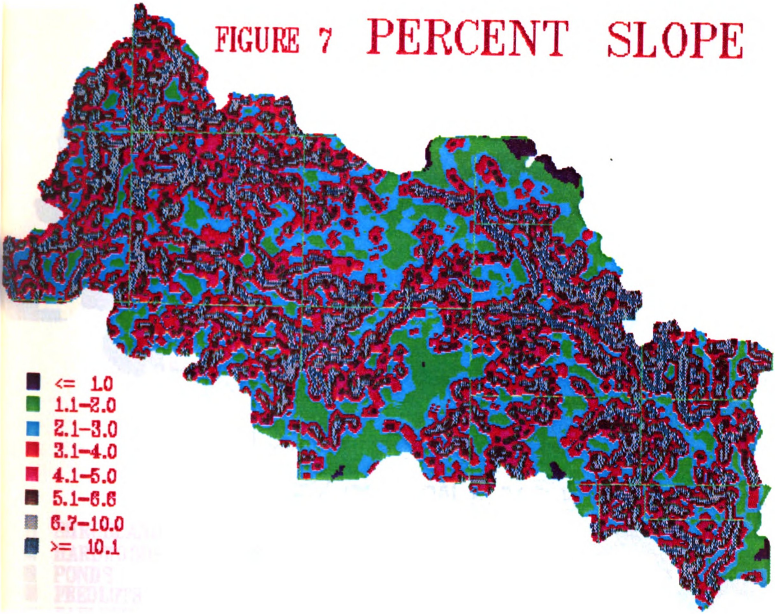


FIGURE 7 PERCENT SLOPE

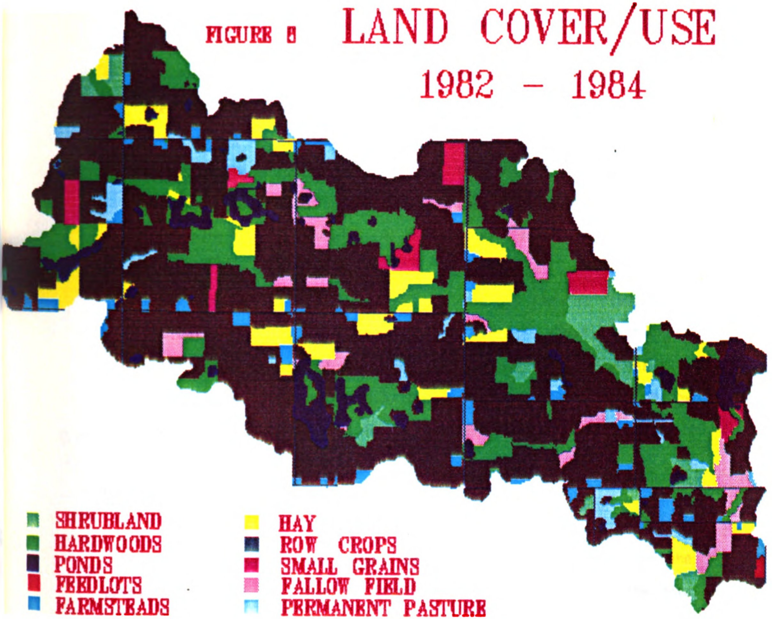


FIGURE 8
LAND COVER/USE
1982 - 1984
SHRUBLAND
HARDWOODS
PONDS
FEEDLOTS
FARMSTEADS
HAY
ROW CROPS
SMALL GRAINS
FALLOW FIELD
PERMANENT PASTURE

overlay these files gridcell by gridcell. The CRIES GIS software package offers the capability of multiplying data values in this overlay process. It was therefore possible to solve the equation A = RK(LS)CP by multiplying the numerical attribute values of each corresponding gridcell in all of the five USLE factor files. The results of this overlay process is a new file with each gridcell containing the USLE results (A) in units of tons per acre per year.

After developing a USLE data base in the GIS for the study area, the actual calculation of the equation averaged about one hour of machine time per township section (640 acres). This computer time was in large part determined by the type of GIS used (CRIES) and by the type of PC used to run the GIS (an IBM XT).

USLE Results

The completion of the survey system's Phase I is marked by the production of the map shown in Figure 9, the USLE Results. The data in this computer-generated map has been aggregated into four categories to better illustrate the results. For example, all of the acreage in colors other then green is eroding at rates exceeding the tolerance levels for those soils. While this information does narrow the conservationist's focus, the red acreage might represent higher priority targets because its erosion rate is at a very critical level, 16.1-20.0 tons per acre per year. Figures 10 and 11 graphically illustrate the USLE results. As can be noted a very small percentage (15%) of land area is eroding at rates over 10.0 tons per acre per year. The

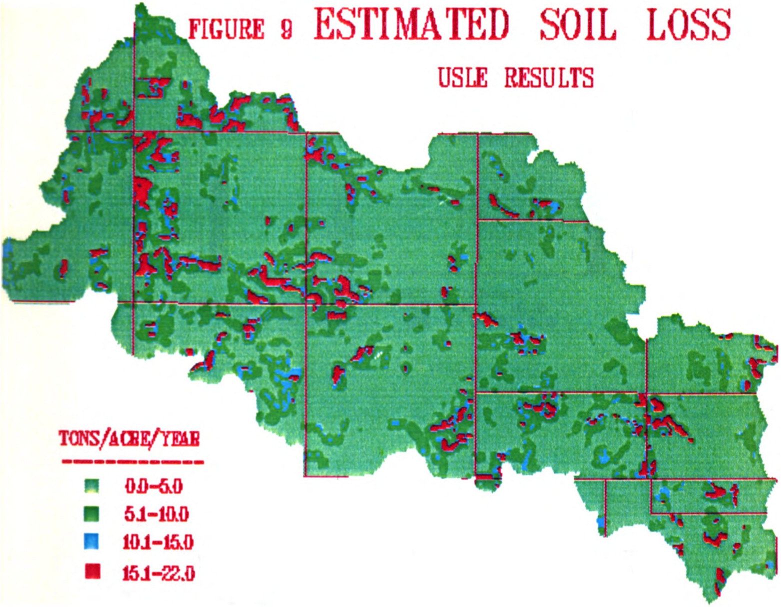


FIGURE 9 ESTIMATED SOIL LOSS
USLE RESULTS
TONS/ACRE/YEAR
0.0-5.0
5.1-10.0
10.1-15.0
15.1-22.0

Figure 10

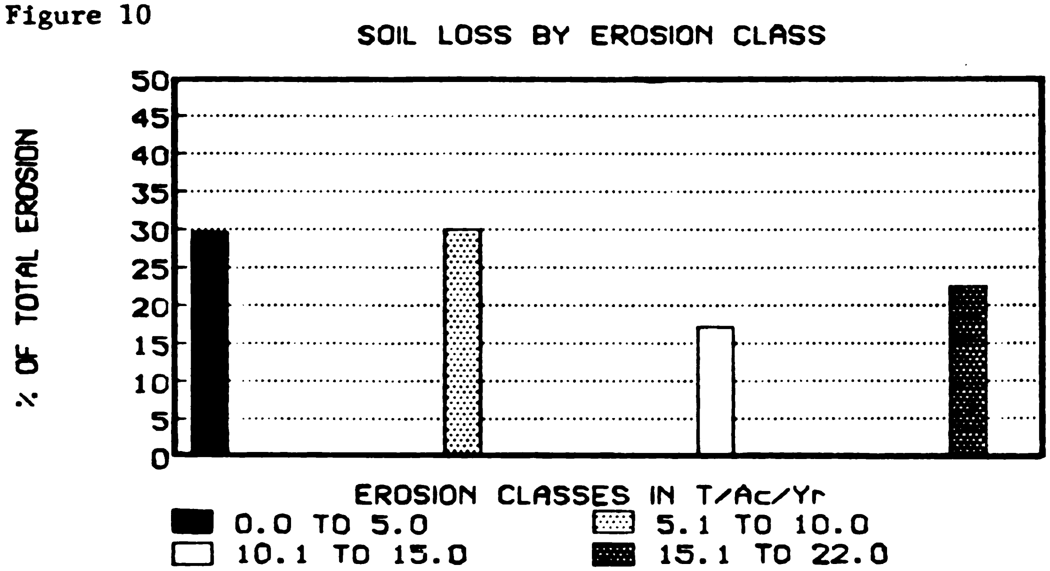
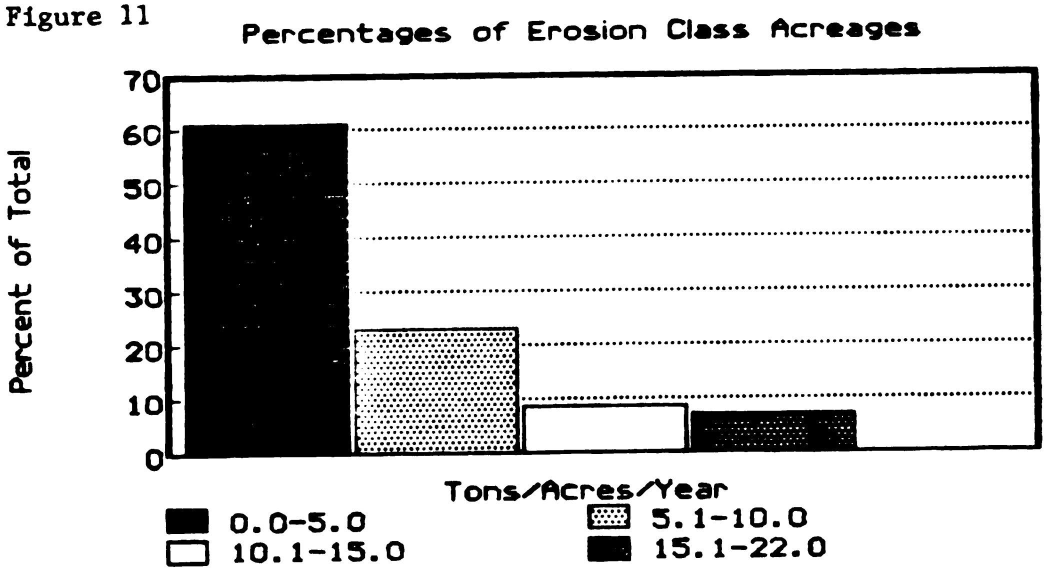


Figure 11



importance of targeting control resources is realized when it is noted that this 15% accounts for 40% of the total erosion and about 60% of the erosion over 'T' values.

Practical use of this information would include the production of a large working map for field use. The soil conservationist could use such a map in designing farm-scale management plans pointing out those areas in particular fields where erosion is at a critical stage. Farmer acceptance of suggestions based on this type of data should be very high since field observations demonstrate that its predictive power has an 88-94% accuracy when compared to field-based studies. (Morgan et al., 1978).

The on-site targeting provided by GIS generated USLE results would also be very useful in determining which farmers are a priority for the soil conservationist in his/her effort to transfer conservation tillage technology. This is easily done in the GIS by overlaying a property ownership map, such as a plat map, and then cross-tabulating the ownership information with the soil loss data.

CHAPTER IV

CRITICAL SEDIMENT CONTROL POINTS IN THE BEAN CREEK WATERSHED (PHASE II)

Introduction

The USLE results (the product of phase I) represent on-site targeting information useful in the control of soil erosion. To reach the stated objectives of this survey system, the soil loss data must be used to produce off-site information such as sediment yield predictions. Off-site sediment control targeting is also dependent on spatial data. Specifically, the locations and severity of concentrated stormwater flow in terms of sediment yield, must be identified to achieve efficient use of control resources.

The second phase of the erosion survey system consisted of the prediction of sediment yields based on the application of sediment delivery ratios to USLE erosion rate results for individual micro watersheds within the study area. This process and the determination of sediment control points were dependent upon the recognition and mapping of ephemeral stormwater drainage channels.

Methods

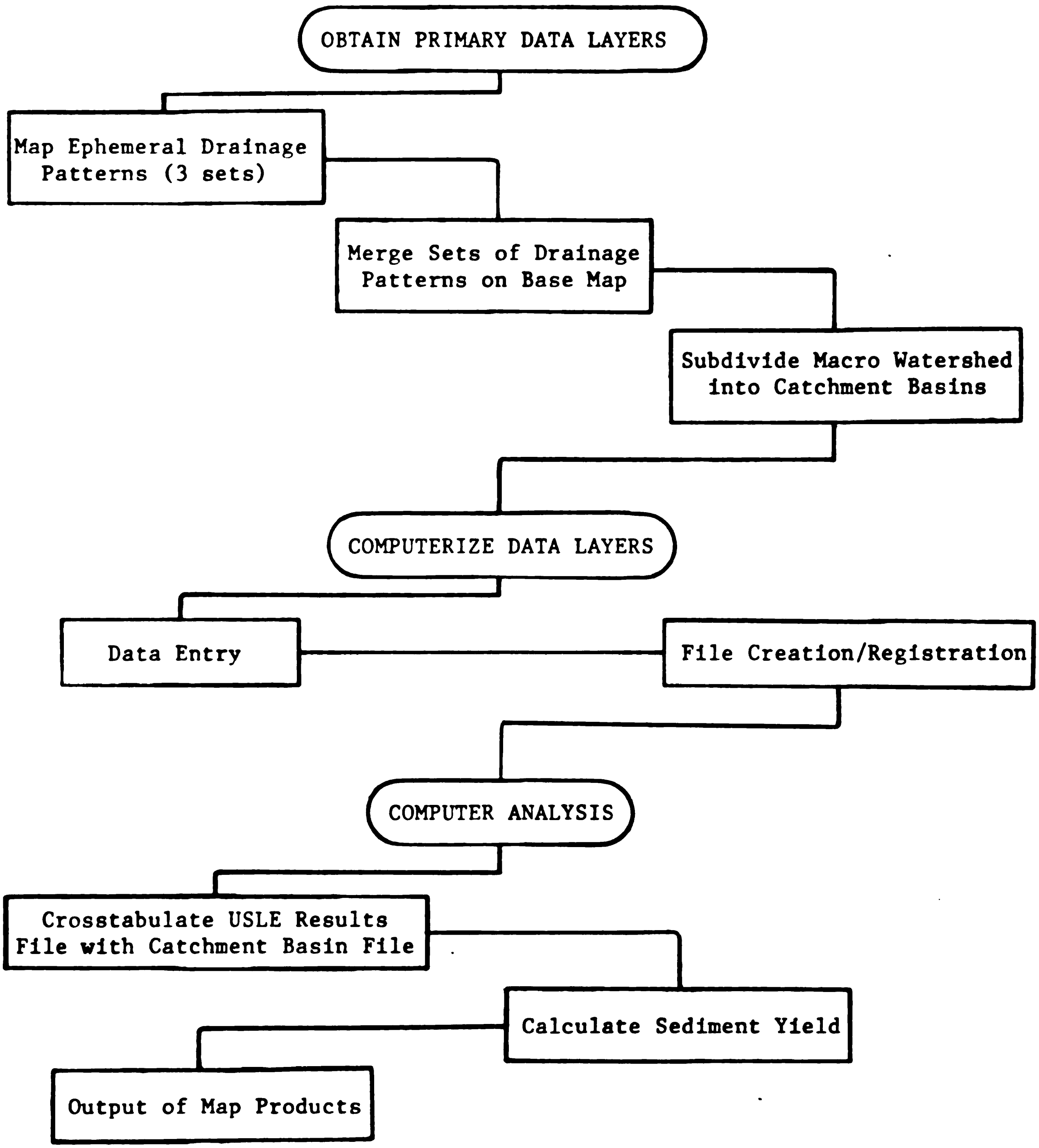
Producing Primary Data Layers

1. Ephemeral Drainage Pattern Mapping

USGS topographic maps are the best source commonly available in Michigan for drainage information having perennial and intermittent streams mapped with a high degree of accuracy. This data source however does not include the mapping of the ephemeral drainage network; those stormwater channels that flow only during storm events. These morphological features can be mapped from aerial photographs because they are clearly visible due to their high moisture content and tendency to collect organic matter (Ishaq and Huff, 1974).

During this investigation ephemeral stormwater channels were mapped using 1963, 1969 and 1978 mid-season aerial photographs. The 1963 and 1969 imagery were ASCS black and white aerials at a 1:20,000 scale, while the 1978 photographs were MDNR color infrared images at a 1:24,000 scale. Dense cover types such as hay crops often hide the presence of these channels. Crop rotations offered the opportunity to view fields under different cover conditions and necessitated the use of three separate years of imagery to complete this mapping.

Figure 12 Procedures for Determining Critical Erosion Control Points (PHASE II)



2. Merging Sets of Ephemeral Drainage Patterns

The ephemeral channels observed on these photographs were referenced to the USGS topographic base map for the study area using a zoom transfer scope. This was accomplished by transferring the ephemerals from one set of photographs to the base map and then using the next set to fill in the gaps in the dendritic patterns. The percentages of the total ephemeral stormwater channels that were mapped for each set of photographs can be seen in Table 2.

Table 2 Ephemeral Mapping Percentages by Photographic Type

Type of Imagery	Percent of Total
1963 ASCS Black and White	66.6%
1969 ASCS Black and White	25.0%
1978 MDNR Color Infrared	8.4%

Because the ultimate goal of this mapping process was the identification of critical edge-of-field erosion control points, the location of soil deposition areas was also an important morphological feature to enter into the GIS. These areas, often located at the toe of slopes and at ephemeral channel discharge points, can be considered excellent locations for sediment traps and retention ponds (Ditson, 1984).

3. Dividing the Watershed into Catchment Drainage Basins

As can be seen in Figure 13, the ephemeral channels often form classic dendritic patterns. The area drained by these ephemeral drainage channel networks can be viewed as micro watersheds or catchment basins. The divisions between these micro drainage basins within the study area, were determined by interpolating where these boundaries should be, based on the ephemeral drainage channel patterns and the USGS topographic contour lines. The boundaries of the catchment basins were also referenced to the study area base map. The catchment basins ranged greatly in size from the smallest being one acre to the largest being 264 acres (refer to Table 4).

Procedures To Computerize Data Layers

1. Data Entry

Once completed, the mapped ephemeral stormwater channels, areas of soil deposition, and the catchment basin boundaries were digitized and entered into the GIS. The GIS files representing these data layers can be seen in Figures 13 and 14. The channels and deposition areas shown in Figure 13, were mapped simultaneously with the surface waters found on the USGS topographic map. Together these topographic features represent the avenues which stormwater and it associated sediment load must travel.

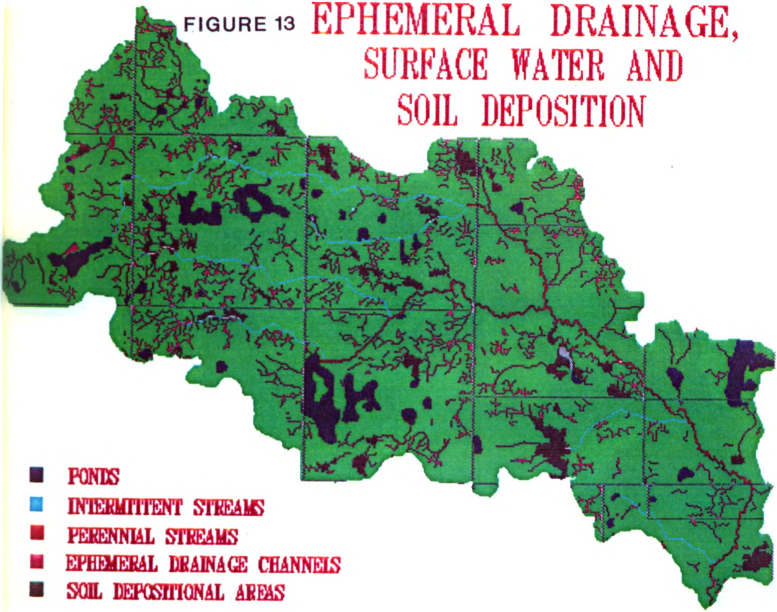
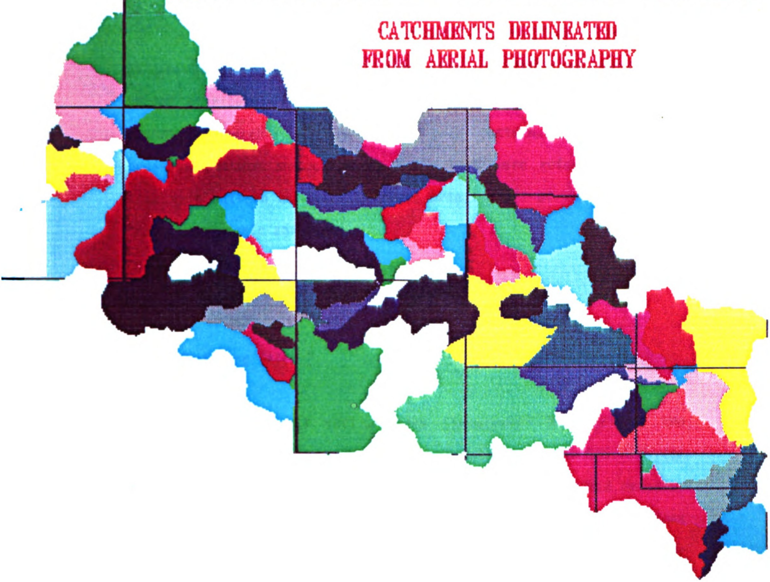


FIGURE 13 EPHEMERAL DRAINAGE, SURFACE WATER AND SOIL DEPOSITION

FIGURE 14 WATERSHED CATHMENT BASINS

CATCHMENTS DELINEATED FROM AERIAL PHOTOGRAPHY



2. File Creation/Registration

As was noted in Chapter III, maps that are digitized into a GIS become attribute files when they are entered into the GIS using a standard geographically referenced grid pattern. The ephemeral drainage pattern and catchment basin maps were referenced to the same grid pattern as the USLE files bringing all of the data layers into cartographic agreement.

Computer Analysis

1. Crosstabulating Files

An estimate of total soil erosion (tons/year) for each of the catchment basins was calculated by crosstabulating the GIS file for the catchment basins with the GIS file representing the USLE results. This procedure was accomplished using a GIS program which assigns the estimated soil loss rates to the gridcells within their respective catchment basins.

2. Calculating Sediment Yield

By utilizing the sediment delivery ratios provided by SCS in their Michigan Tech Guide, gross estimates of sediment yield can be obtained. These ratios, shown in Table 3, are rough estimates of the ratio of sediment delivered to a water body to the soil which was detached during rainfall events.

Table 3 Sediment Delivery Ratios

Drainage Area Acres	Sediment Delivery Ratio (DR)
0-1	1.00
1-5	.70
5-15	.60
15-16	.50
60-250	.40
greater than 250	.30

Source: SCS, Michigan Technical Guide, Section I-C, State-wide Water-75.

These ratios were assigned to each catchment basin according to catchment size and used to solve the equation:

$$DR = Y/A$$

or

$$(A)\ (DR) = Y$$

Where: DR = The delivery Ratio

Y = The catchment basin sediment yield in tons/ac/yr

A = Catchment soil loss totals (USLE results) in tons/yr

A realistic value for A was determined by summing the USLE values for each catchment provided by the crosstabulation and then dividing those totals by the number of acres in each catchment. The resulting average soil loss per acre per catchment was then multiplied by the number of acres in that catchment to reach the value of A, the total soil loss. Table 4, is a listing of all 102 catchment basins within the study area. It is designed to illustrate the size of each catchment, the catchment's area as a percent of the total study area, the catchment's average soil loss rate, and each catchment's sediment yield.

Table 4 Catchment Basin Sediment Yields

Catchment ID Number	Catchment Size Acres	Percent of Total	Ave. Soil Loss T./Ac./Yr.	Total Sed. Loss Tons/Yr.	Total Sed. Yield T./Yr.
1	17.0	.353%	4.85	82.45	41.2
2	43.0	.893%	3.26	140.18	70.0
3	27.0	.561%	.75	20.25	10.1
4	156.0	3.239%	2.20	343.20	54.8
5	41.0	.851%	3.43	140.63	70.4
6	33.0	.685%	1.64	54.12	27.9
7	4.0	.083%	2.55	10.20	7.1
8	40.0	.831%	3.65	146.00	73.0
9	94.0	1.952%	2.04	191.76	76.8
10	56.0	1.163%	1.62	90.72	45.4
11	145.0	3.011%	3.21	465.45	186.4
12	55.0	1.142%	2.73	205.15	102.5
13	20.0	.415%	5.80	116.00	58.0
14	14.0	.291%	7.92	110.85	66.5
15	7.0	.145%	.35	2.51	1.5
16	63.0	1.308%	1.15	72.15	28.9
17	47.0	.976%	2.04	95.94	48.0
18	64.0	1.329%	1.16	74.02	29.6
19	93.0	1.931%	1.88	174.89	70.0
20	62.0	1.287%	5.00	310.09	124.0
21	264.0	5.482%	4.72	1245.34	373.6
22	85.0	1.765%	3.38	286.96	114.8
23	24.0	.498%	4.52	108.56	54.3
24	22.0	.457%	.73	16.13	8.0
25	41.0	.851%	1.52	62.22	31.1
26	142.0	2.949%	2.67	379.45	151.8
27	16.0	.332%	2.0	31.98	16.0
28	35.0	.727%	1.46	51.14	25.6
29	48.0	.997%	.16	7.57	3.8
30	6.0	.125%	.97	5.79	3.5
31	8.0	.166%	0.00	0.00	0.0
32	39.0	.810%	2.28	88.78	44.4
33	85.0	1.765%	3.00	255.35	102.1
34	130.0	2.699%	1.97	256.78	102.4
35	1.0	.021%	0.00	0.00	0.0
36	19.0	.395%	2.67	50.65	25.3
37	25.0	.519%	.93	23.16	11.6
38	25.0	.519%	1.21	30.28	15.1
39	18.0	.374%	4.57	82.25	41.1
40	89.0	1.848%	2.11	188.21	75.3
41	4.0	.083%	1.46	5.85	4.1
42	14.0	.291%	.10	1.44	0.9
43	37.0	.768%	1.59	58.77	29.4
44	22.0	.457%	1.67	35.53	17.8
45	12.0	.249%	.03	0.40	0.0
46	35.0	.727%	1.74	60.82	30.4
47	39.0	.810%	4.92	191.85	95.9

Table 4 (cont'd.).

Catchment ID Number	Catchment Size Acres	Percent of Total	Ave. Soil Loss T./Ac./Yr.	Total Sed. Loss Tons/Yr.	Total Sed. Yield T./Yr.
48	209.0	4.340%	1.72	359.39	143.8
49	91.0	1.890%	3.99	363.33	145.3
50	11.0	.228%	6.17	67.86	40.7
51	16.0	.332%	6.97	111.52	55.7
52	13.0	.270%	4.93	64.17	38.5
53	48.0	.997%	3.15	151.31	75.7
54	18.0	.374%	2.98	53.58	26.8
55	22.0	.457%	1.10	24.24	12.1
56	30.0	.623%	4.43	133.02	66.5
57	60.0	1.246%	7.56	453.53	226.8
58	54.0	1.121%	5.76	311.26	155.6
59	8.0	.166%	3.94	15.77	18.9
60	19.0	.395%	2.00	37.93	19.0
61	32.0	.664%	.68	21.82	10.9
62	3.0	.062%	3.26	9.79	6.8
63	60.0	1.246%	3.72	223.11	89.2
64	23.0	.478%	4.14	95.26	47.6
65	8.0	.166%	1.13	9.07	5.4
66	49.0	1.017%	.61	29.79	14.9
67	37.0	.768%	2.87	106.25	53.1
68	48.0	.997%	5.50	263.94	132.0
69	4.0	.083%	5.12	20.48	14.3
70	1.0	.021%	8.01	8.01	8.0
71	26.0	.540%	8.60	223.71	111.9
72	160.0	3.322%	3.59	575.25	287.6
73	19.0	.395%	1.65	31.28	15.6
74	59.0	1.225%	7.49	442.24	221.0
75	26.0	.540%	.17	4.52	2.3
76	24.0	.498%	.09	2.24	1.1
77	148.0	3.073%	.96	141.80	56.7
78	15.0	.311%	4.13	62.55	37.2
79	3.0	.062%	4.22	12.65	8.9
80	15.0	.311%	4.53	68.88	40.8
81	44.0	.914%	6.20	273.52	136.5
82	66.0	1.370%	5.19	342.63	137.1
83	10.0	.208%	.31	3.09	1.9
84	26.0	.540%	.74	19.28	9.6
85	22.0	.457%	7.55	166.09	83.0
86	34.0	.706%	4.00	135.91	68.0
87	7.0	.145%	1.97	13.82	8.3
88	8.0	.166%	.88	7.07	4.2
89	1.0	.021%	0.00	0.00	0.0
90	17.0	.353%	8.76	148.93	74.5
91	135.0	2.803%	5.71	770.44	308.2
92	201.0	4.174%	2.56	515.18	206.1

Table 4 (cont'd.).

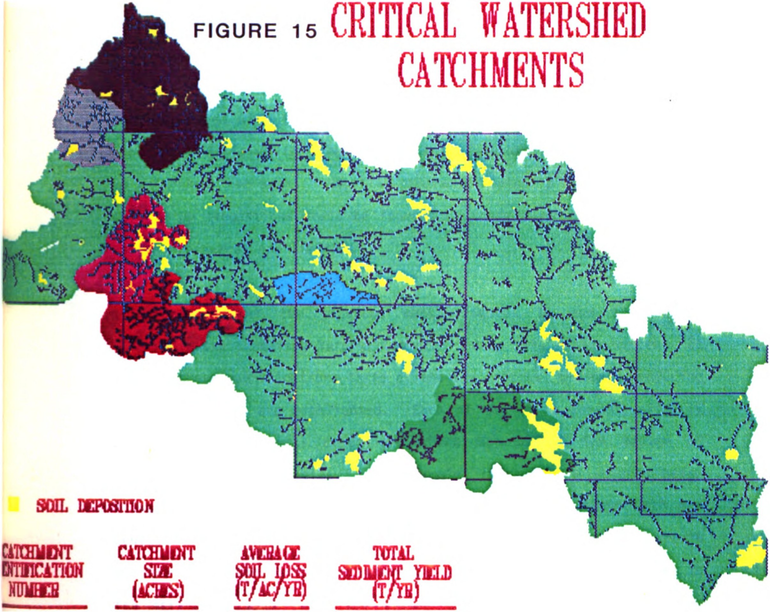
Catchment ID Number	Catchment Size Acres	Percent of Total	Ave. Soil Loss T./Ac./Yr.	Total Sed. Loss Tons/Yr.	Total Sed. Yield T./Yr.
93	19.0	.395%	.28	33.17	13.3
94	2.0	.042%	.24	0.47	.3
95	48.0	.997%	3.56	171.45	85.5
96	11.0	.228%	3.93	43.24	25.9
97	14.0	.291%	2.12	29.64	17.8
98	27.0	.561%	3.67	99.17	49.6
99	262.0	5.440%	3.98	1043.31	312.9
100	21.0	.436%	8.43	177.10	88.6
101	93.0	1.931%	6.79	631.73	25.27
102	23.0	.478%	3.39	78.03	39.0
TOTALS	4816.0	100%	3.06	14730.41	6456.8

Locating Critical Edge-of-Field Control Points

Targeting control resources will remain a policy problem but the policy questions will be influenced when objective comparisons can be made as can be noted in Table 4. These data can be sorted in many ways resulting in differing catchment basin ranking systems. For example, catchment basins might be ranked by size, average soil loss per acre, total soil loss, or from a water quality point of view, by total sediment yield. Any of these prioritizing schemes produces some interesting comparisons. For example catchments 48 and 49 have almost identical sediment yield values yet catchment 49 is draining only one/half the surface area of catchment 48. Or another comparison between catchment 71 and 77 reveals that catchment 71 is only 26 acres in size yet it produces almost 112 tons of sediment per year while catchment 77 is over 5 times as large (148 acres) yet produces only one/half of 94's sediment load (56.7 tons).

Using total sediment yield as the ranking criterion Figure 15 has been designed to illustrate the six highest sediment producing catchments. Using a GIS overlay of data layers the ephemeral stormwater channel network and soil deposition areas are also illustrated on this map. Critical control points can be chosen for selected catchment basins by noting these ephemeral patterns and areas of deposition. For example, sediment control structures such as sediment traps could be placed in areas where deposition is occurring and drop spillways could be built where ephemerals show gullying tendencies. This type of map product could also be used to estimate the quantity and placement of

FIGURE 15 CRITICAL WATERSHED CATCHMENTS



CATCHMENT ENTIFICATION NUMBER	CATCHMENT SIZE (ACRES)	AVERAGE SOIL LOSS (T/AC/YR)	TOTAL SEDIMENT YIELD (T/YR)
28	264	4.72	373.6
130	262	3.96	312.9
116	135	5.71	306.2
95	160	3.59	287.6
141	93	6.79	252.7
80	60	3.56	236.8

grassed waterways for the control of ephemeral stormwater channels in critical catchments.

The same six critical catchments shown in Figure 15, could have been overlayed with the USLE results. Using this type of map, control strategies designed to stop on-site soil detachment could be targeted to watershed "hot spots." No-till programs, contour plowing designs and cover crop suggestions could be focused on these targeted catchments if control resources are limited.

By magnifying the previous maps, Figures 16 and 17 further illustrate the targeting information provided by this survey system. In each of these magnifications three of the six critical sediment-producing catchment basins are highlighted. Each of the three present slightly different environmental conditions which may affect the design of erosion control strategies. For example, catchment 72 colored beige illustrates the classic dendritic ephemeral drainage pattern with one central concentrated flow channel running through the catchment basin eventually developing into an intermittent stream. Field observations in the spring of 1985 found the fields in this catchment basin to be conventionally plowed and in row crops. The main ephemeral channel had been perpendicularly plowed, up and down slope, creating serious furrow rill erosion.

Control of the erosion and sediment yield of catchment 72 might include protective cover crops in the "hot spots" shown in Figure 16. Additionally, the main ephemeral channel could be grassed to prevent

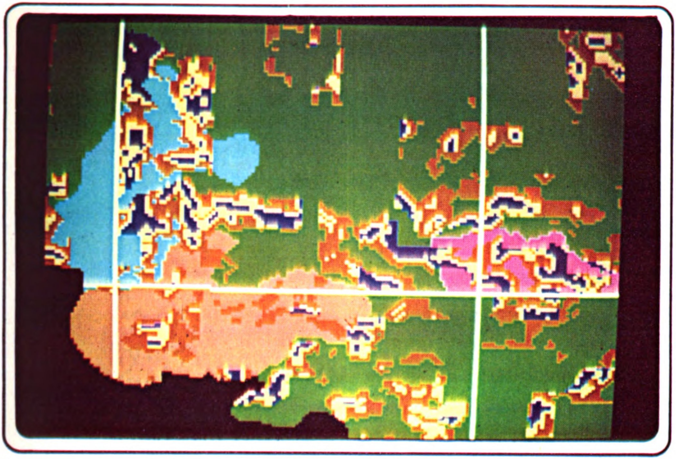


Figure 16 Critical Watersheds Enlargement I

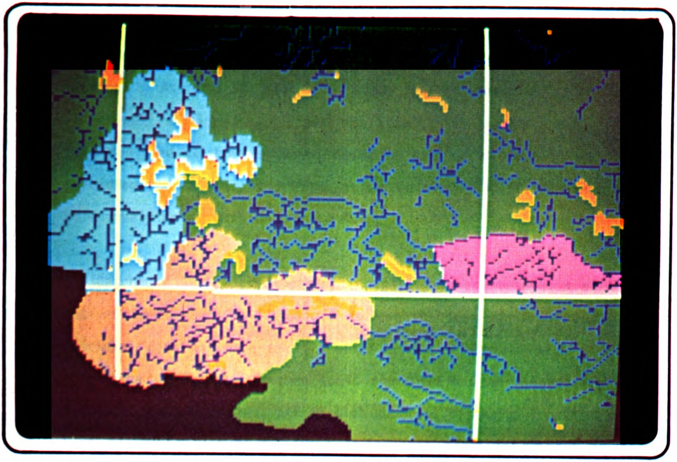


Figure 17 Critical Watersheds Enlargement II

gullying, and field shapes could be changed to encourage contour plowing. As can be seen in Figure 17, catchment 72 also has a rather well developed soil deposition area at its discharge end. A farm pond designed to trap sediment could be located at this control point providing recreation, an irrigation source, and wildlife habitat, while effectively preventing downstream damages.

Catchment 57, colored purple, in these figures presents a different set of management conditions. As can be seen in Figure 17, this catchment does not have a distinctive ephemeral channel pattern with a single control point. Rather it is characterized as the drainage area bordering an intermittent stream with numerous discharge locations. The best management practice needed to control off-site damages in this situation may be the establishment of a vegetative buffer strip parallel to the stream in combination with the construction of numerous small strategically located structures.

Catchment basin 91, colored light blue in Figures 16 and 17 illustrates an additional management scenario. While this catchment has a relatively high average soil loss rate, Figure 16 would suggest that the majority of this loss is occurring on one side of the north/south road dividing the catchment. A farm management plan designed to correct this catchment's problems could be tested by applying new cover type values to the fields on the critical side of the road and re-running the USLE. Further iterations of the equation would eventually reveal to both the farmer and soil conservationist the most advantageous mixture of management solutions.

Sources of Error

By definition, models are abstractions of reality, not reality itself. Conseouently, they are an approximation of the natural event which they model. In this study much of the data used to generate the USLE could have contained errors. For example, the 1928 soils map for Hillsdale County is known to be inadequate. Similarly, the default value used for slope length and assumptions made in C value determinations may have caused additional errors. As DeCoursey (1985) has pointed out, there is always danger in providing the user of models default values because it then becomes easier to use these rather than to obtain supporting information resulting in sizable error.

The model itself may also contain errors. Wichmeier (1976) has stated that soil losses computed by the equation must be recognized as the best available estimates rather then as absolute predictions. Some potential details and refinements of the model are necessarily sacrificed in the interests of utility. This is certainly true with the application of sediment delivery ratios to USLE results (Novotny and Chesters, 1981; Mass et al., 1985).

Other errors affecting the accuracy of the survey system may have occurred during the interpretation of aerial photographs in determining C values and the mapping of the ephemeral drainage network. Cover type mapping accuracies should improve as the interpreter gains experience. Improvements in remote sensing technology will also continue to eliminate errors. Stephens and Chilar (1981b) have already shown C value accuracies as high as 94% using satellite imagery.

There are always some additional inaccuracies encountered when handling large amounts of data from recording errors and machine errors. In spite of these errors, the tables and map products illustrated here provide an effective set of data for targeting erosion control resources. They should not be seen as definitive empirical resources on which to base structure design. They are rather the results of a screening mechanism designed to narrow the focus of the soil conservationist toward those areas where resources should be committed first.

CHAPTER V

SUMMARY, RECOMMENDATIONS, AND CONCLUSSIONS

Introduction

This investigation began with the premise that there still exist serious soil erosion problems in this country and that these problems occur both on and off the erosion site resulting in billions of dollars in damages. There was also a perceived need for a watershed survey system or screening mechanism that would identify critical erosion areas where control resources could best be dedicated.

The erosion problem and targeting needs were observed in Michigan as in other parts of the country, and it was in the context of a small critically eroding watershed that the research question was posed. Namely, could a practical economical watershed survey method using the USLE, remote sensing and a GIS analysis be designed that would provide farmers and professional soil conservationist meaningful data?

Answers to Research Questions

With the research objectives guiding the design, a watershed survey system has been applied to an unnamed tributary of Bean Creek. The survey system is practical in that its application would require very little training or specialized tools. The most specialized instrument used during this study would be the zoom transfer scope used to transfer the ephemeral drainage channels to the base map. Even this tool could be eliminated if 1:24,000 aerial photographs were used in conjunction with a lightable and USGS 7.5 minute topographic maps. The computer requirements needed to run the survey are the personal computers and printers found in some homes and most modern offices.

The survey system is economical since the data base is derived from existing sources. The aerial photographs, USGS topographic maps and SCS technical guides used in determining the USLE factor values and ephemeral drainage patterns already exist in SCS and ASCS offices. The CRIES GIS software package is also economical and requires a capital investment approaching the cost of a moderate typewriter.

The economies of the survey system are also illustrated by its staff and machine time requirements. After the data bases have been built the machine time needed to run the USLE equaled one hour per township section (640 acres). The manual photo interpretation and digitizing of data layers was very time intensive but this expenditure should be seen in light of its benefits. The product of this time investment is a computerized data base with a wide range of applications other then erosion surveys. Land use planning, zoning, crop yield predictions, crop inventories, property tax assessments, and educational applications are just a few of the uses that could be made of the same computerized data needed to run the watershed survey.

The USLE, remote sensing and GIS technology were found to be invaluable tools in identifying critical areas of erosion and their associated control points. Models generally, and the USLE specifically, allow the estimation of natural processes such as annual soil erosion without in situ measurements. It is the USLE used in conjunction with a GIS that provides the ability of this survey system to predict the system response to management decisions rather then just the ability to inventory the system.

Remote sensing and GIS technology are essential tools for gathering, capturing and analyzing the data needed to calculate the USLE on a watershed basis. In this study the USLE was applied to 202,000 fifty by fifty foot units of land using most of the same data sets as used during field applications of the model. The costs associated with manually repeating this task with field work are obviously large.

The utility of the tables and maps produced by this erosion survey system have already been discussed. They are straightforward and easy to understand. This attribute should aid their acceptance and the implementation of management decisions. The ultimate objective of this investigation was to provide a means to target erosion control resources. This objective has been reached. The maps provided in chapters III and IV illustrate areas of critical erosion and their edge-of-field control points. The two phases of the survey provide both on-site and off-site control targets. Such a system should prove to be a valuable tool to both farmers and professional soil conservationist.

Recommendations for Future Research Efforts

Wide-scale application of the erosion survey system developed during this research should be preceded by indepth field verification and subsequent refinements. First, the survey's USLE results should be compared to field-generated results to test their validity. Special attention should be given to the accuracy of the remotely captured USLE data sets as compared to those derived in the field. Secondly, the predicted sediment yield estimates should be tested against field data for individual catchment basins. Additional research in this area could result in site-specific sediment delivery ratios calibrated geographically. Novotny and Chesters (1981) have stated that both delivery ratio determinations and upland gross erosion estimates are unreliable if calibrated and verified field measurements are not used. A third test of validity would be an analysis of the catchment basin ranking order.

Some suggestions for refinements can be made based upon the experience gained through this research. As Stephens and Chilar (1981a) have pointed out, the accuracy of the USLE C values can be greatly improved by utilizing aerial photographs taken specifically for that purpose. Assumptions concerning time of plowing and amounts of residue left in fields could be avoided if timely imagery was available. ASCS should consider using color infrared film instead of regular color in their annual crop inventory slides as a small step in this direction.

Special imagery could also greatly improve ephemeral channel and soil deposition area mapping. As has been mentioned earlier, this may provide a means to computer generate slope length values for the USLE. For example, if a high percentage of ephemeral drainage channels were accurately mapped, the computer, using the GIS could "search" from each grid cell within a catchment to either an ephemeral channel or an area of deposition and then assign the distance found to that grid cell. This would essentially create a USLE L value data layer thus avoiding the use of a default value.

This investigation has found that ephemeral drainage channel mapping can provide new insights into the watershed system. This data could aid the calibration of sediment delivery ratios through the investigation into two factors known to affect the sediment delivery process. According to Novotny and Chesters (1981), two of the factors controlling sediment delivery ratios are:

- Channel density: the ratio of total stream length within the system divided by the area of the basin,
- The bifurcation ratio: the ratio of number of streams of any given order to the number in the next higher order.

As can be seen, the mapping and digitization of the ephemeral drainage channel network and the subsequent statistical analyses run on a GIS could produce accurate estimates of these factors.

If agencies such as the SCS desire practical screening methods for resource targeting they need to pursue the creation of resource data bases. In Michigan, the MDNR and SCS are beginning to build computerized data bases that would be applicable to the erosion survey technique developed during the research. MDNR is in the process of mapping and digitizing land cover data which could supply USLE C values. At the same time SCS has began the digitization of modern soils maps for entry into GIS. The same kind of effort could be put into the digitization of USGS topographic maps. If these digital data sets existed and were made available the erosion survey system designed during this investigation would be very practical. Roadblocks to this effort would appear to center mainly around the perceived usefulness of the computerized data and the resulting financial program support. The demonstration of the practical applications of the computerized data bases would "advertise " the value of these projects and the usefulness of computerized data.

Further Comments

Chester and Schierow (1985) point out that persistent erosion problems are associated with the implementation of control technologies. Legal, economic, social, psychological and institutional questions likewise impede development of effective management strategies. The questions and implementation problems are in many ways related to our lack of knowledge concerning where and to what extent soil erosion and sedimentation are taking place.

The 1985 Food Security Act recently passed through Congress offers another attempt at controlling erosion through the use of economic incentives. This bill, for example, would allow farmers to receive payment for converting highly erodable land to a conservation reserve. It would also deny farm subsidies if crops are grown on new land without conservation practices (Henshaw, 1985). As Gray (1986) has pointed out however an objective evaluation by SCS or ASCS is needed in determining what land is to be allowed into the conservation reserve.

The need for a survey system designed to identify critical areas of soil erosion and their associated control points is clear. This investigation suggests one application of the benefits of modeling, remote sensing and geographic information system analysis. It is hoped that this study may lead to additional efforts that will eventually satisfy that need.

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