MODELLING LAND USE CHANGE AND NONPOINT SOURCE POLLUTION POTENTIAL USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

THESIS

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In this study Geographic Information System (GIS) technology was integrated with remote sensing techniques in order to determine the potential for nonpoint source pollution in the Lake Palestine and Cedar Creek Reservoir watersheds of North Central Texas. The Universal Soil Loss Equation was used to determine soil erosion potential from the watersheds, and export coefficients were used to estimate nutrient loadings into the reservoirs. Future urban growth for the study area was predicted from satellite imagery using a spatial computer modelling program called FUTURE. The land use file derived from this model was combined with other spatial data layers in a GIS model to calculate potential nonpoint nutrient and sediment loads for the watershed.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The rapid expansion of computer technology in the areas of spatial modelling and digital remote sensing has created a valuable tool for watershed management. In this study Geographic Information System (GIS) technology was integrated with remote sensing techniques in order to determine the potential for nonpoint source pollution in the Lake Palestine and Cedar Creek Reservoir watersheds of North Central Texas. The Universal Soil Loss Equation (USLE) was used to determine soil erosion potential from the watersheds, and export coefficients were used to estimate nutrient loadings into the reservoirs. Future urban growth for the Cedar Creek Reservoir watershed was predicted using a spatial computer modelling program called FUTURE. The accuracy of this model was assessed using temporal satellite data of the Lake Palestine watershed. Land use files derived from the FUTURE model were combined with other spatial data layers (i.e. soils, rainfall, slope, etc.) in a GIS model to calculate potential nonpoint nutrient and sediment loads for the study area.

The study area is located east and southeast of Dallas, Texas and west and south of Longview, Texas (Figure 1). The

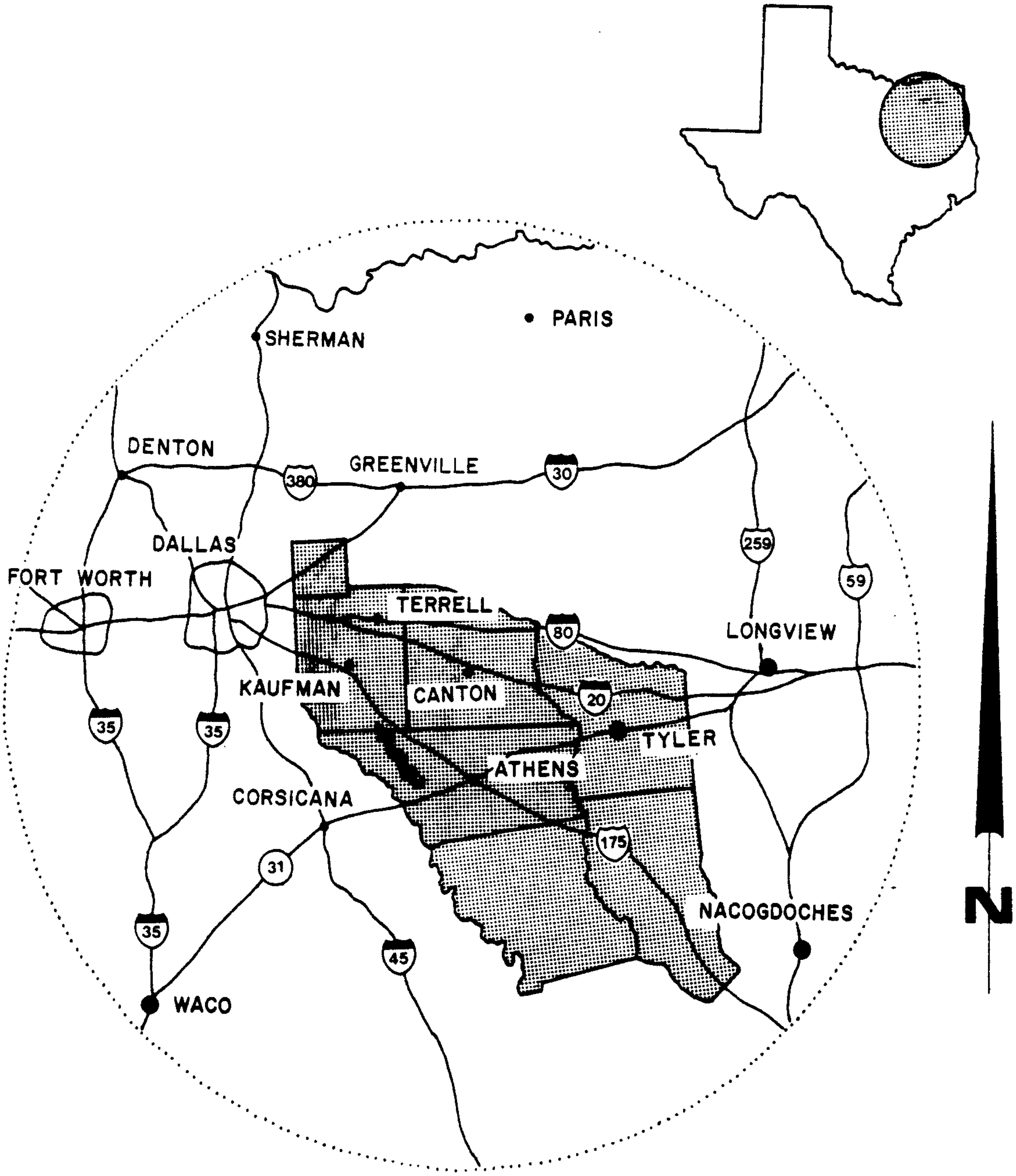


Figure 1: Location of the study area.

two adjacent watersheds analyzed in this study, the Lake Palestine and the Cedar Creek Reservoir watersheds, are similar in both size and character. Because temporal satellite data were available for the Lake Palestine watershed, this area was chosen to assess the ability of the FUTURE program to accurately predict urban growth. Emphasis of this research is on the calibration and testing of the FUTURE model on the Lake Palestine watershed. An additional goal of this research was to use the FUTURE model to assist in the prediction of nonpoint source pollution loadings into the Cedar Creek Reservoir watershed in the year 2010.

The FUTURE model was applied to a 1988 classified land use file of the Cedar Creek Reservoir watershed to predict growth in the area for the year 2010. The land use file generated by the model was used to estimate the nonpoint source pollution potential for the watershed. Cedar Creek Reservoir watershed was chosen over the Lake Palestine watershed for prediction of the nonpoint source pollution potential because of its location relative to the city of Dallas metroplex. The nearness of the Cedar Creek Reservoir watershed to the expanding urbanization of the Dallas area makes nonpoint source pollution analysis of the watershed more critical than in the Lake Palestine watershed.

Lake Palestine watershed comprises portions of Van Zandt, Henderson, Cherokee, Anderson and Smith counties (Figure 2) while Cedar Creek Reservoir watershed is located

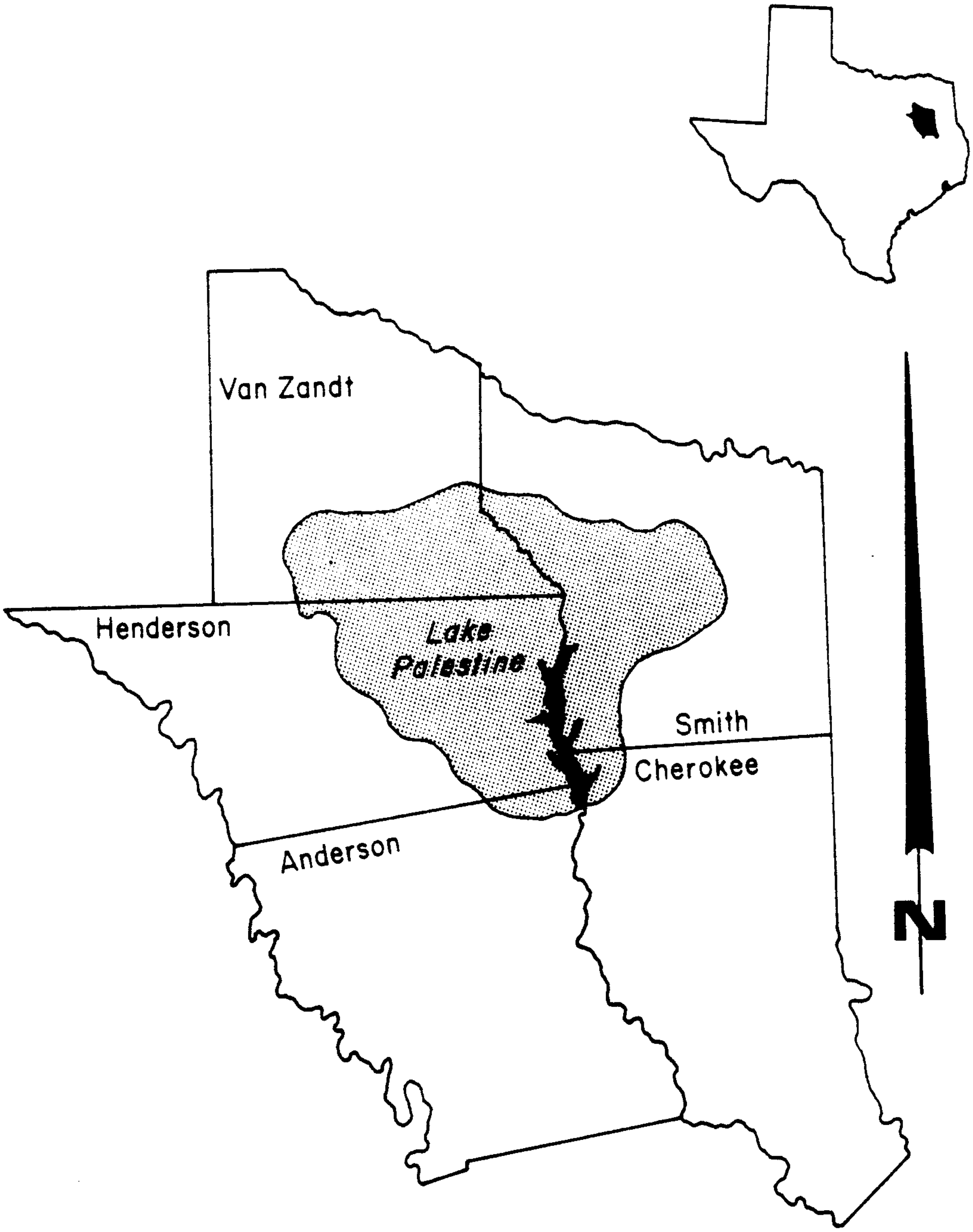


Figure 2: Location of the Lake Palestine Watershed.

within portions of Rockwall, Kaufman, Van Zandt and Henderson Counties (Figure 3). Watersheds surrounding the Dallas-Fort Worth, Texas metroplex are experiencing a number of rapid changes accompanying urban and suburban growth. Much of the former rural lands have experienced urbanization, leading to increased pressure on water distribution and treatment facilities. Water use for the four counties that draw water from Cedar Creek Reservoir is shown in Table 1 (Texas Water Development Board, 1989). Figure 4 illustrates the population growth which has occurred in the counties comprising the study area from 1975 - 1985 (Texas Almanac, 1975, 1989).

Accompanying urbanization is an increase in water demand and a general deterioration of water quality due to an increase in suspended solids and algae growth. The area lakes are of vital importance to sustained economic well being, and as this area continues to develop the pressure on water resources is expected to increase. The prevention of further water quality deterioration will rely heavily on an in-place water quality monitoring system.

The problems of nonpoint source pollution on water quality are becoming more apparent as urbanization reduces the amount of pasture and forest lands. Nonpoint source pollution describes situations in which a specific pollutant, loading into receiving water can not be pinpointed. Diffuse pollutants gradually accumulate in the

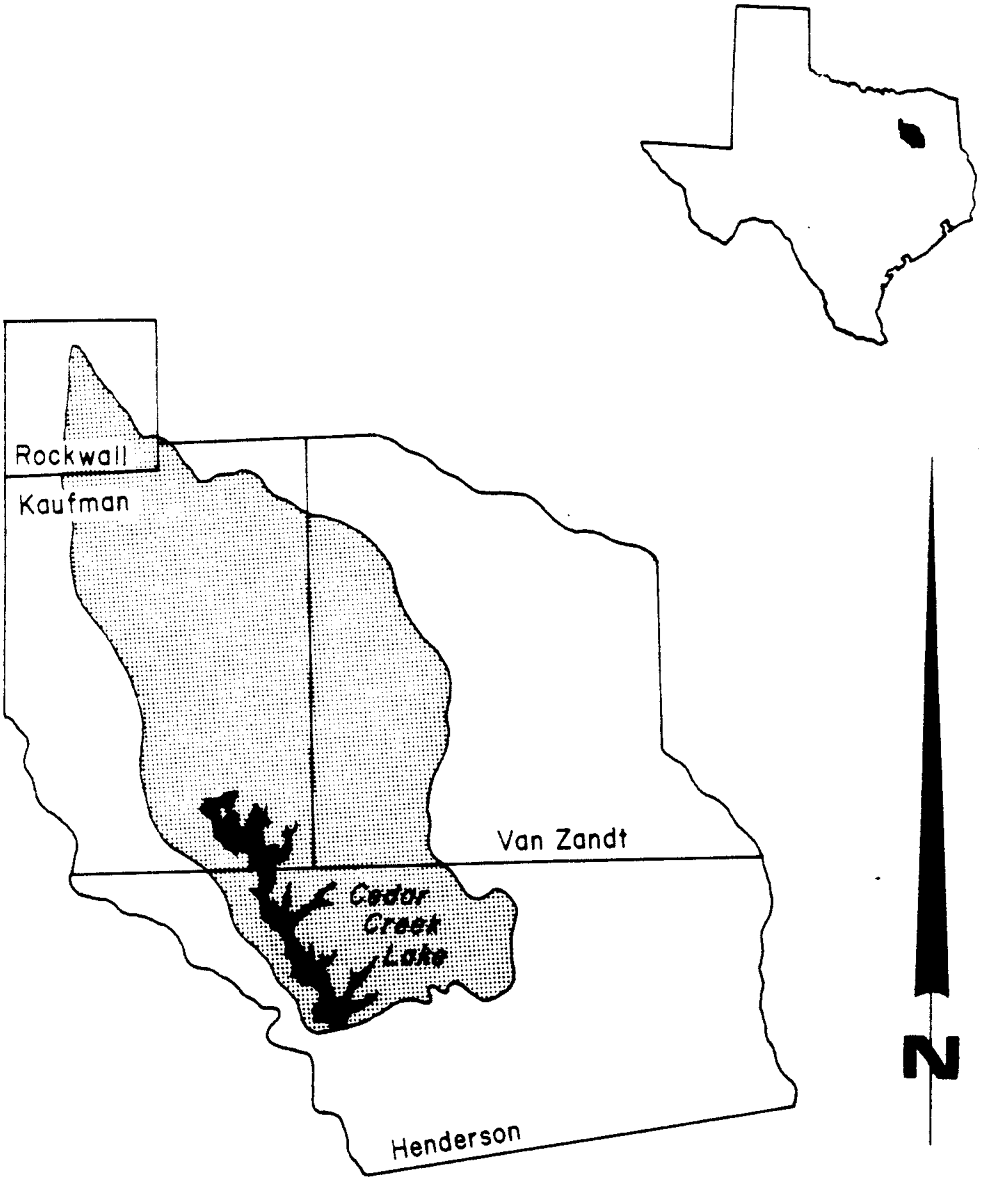
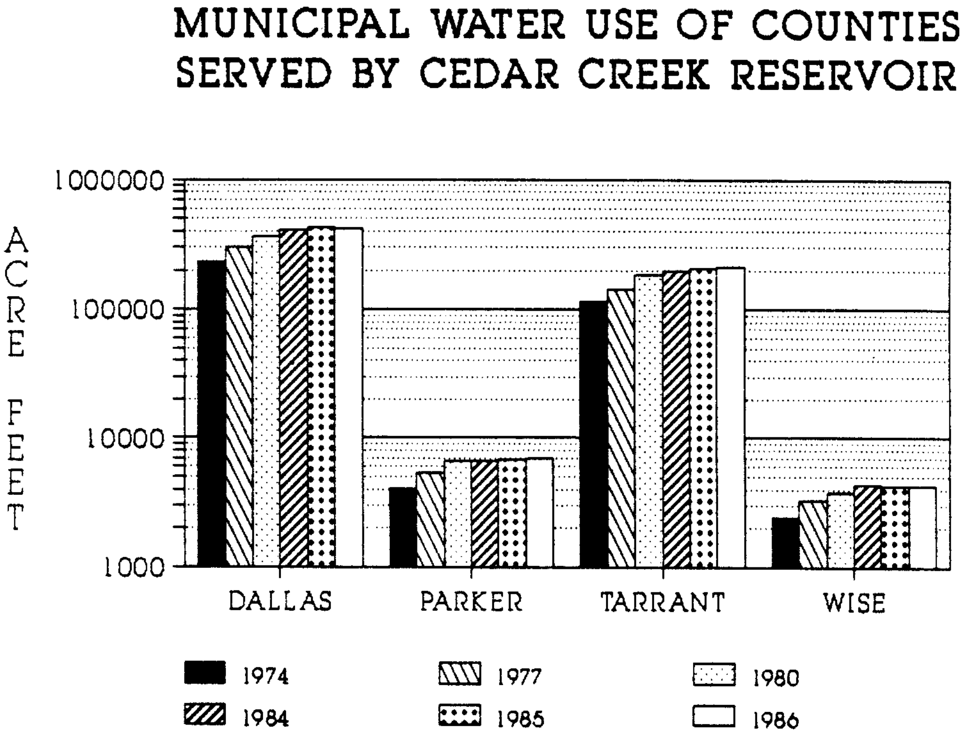
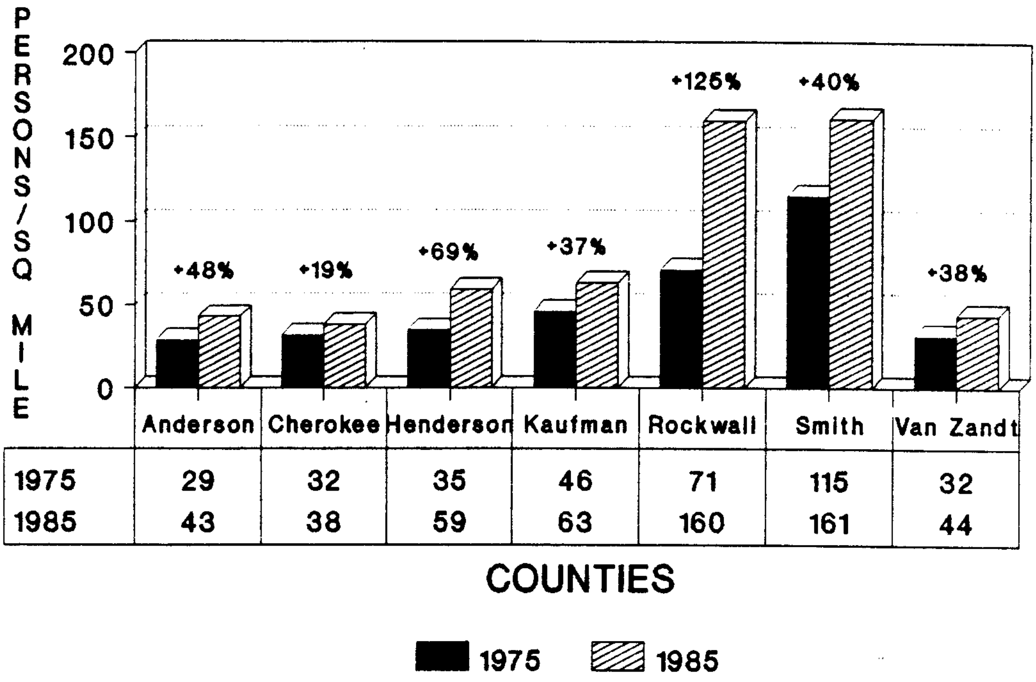


Figure 3: Location of Cedar Creek Reservoir watershed.

Table 1: Municipal waters use for counties served by Cedar Creek Reservoir (TWDB, 1989).



POPULATION DENSITY OF STUDY AREA IN PERSONS PER SQUARE MILE



	Anderson	Cherokee	Henderson	Kaufman	Rockwall	Smith	Van Zandt
1975	29	32	35	46	71	115	32
1985	43	38	59	63	160	161	44

NUMBERS ABOVE COLUMNS ARE PERCENT CHANGE

Figure 4: Population density of the study area in persons per square mile (Texas Almanac, 1975, 1989).

watershed, but also of monitoring changing conditions over time. Satellite data were acquired for this study and used to generate land use summary maps showing the various land cover categories representative of the study area. Land use is one factor which has been shown to have an impact on the overall water quality of a reservoir (Browne and Grizzard, 1979). Once accurate land use maps of the study areas were obtained, a GIS was used to incorporate them into a model with other pertinent ancillary data.

A GIS is a computer-based tool which permits the user to integrate, analyze, and model geographically referenced data. The capability to spatially manipulate data is an important tool for deriving information useful to the management process. Diverse data such as topography, rainfall, soils and land use can be combined as maps within a GIS, permitting examination and assessment of spatial relations among various themes (Coulson and Meyers, 1987).

Many models have been developed to predict nonpoint pollution loading rates. Sediment loss models were developed with the intent purpose of predicting surface erosion. Some of these models are very site-specific, which makes them difficult to apply to large areas, while others are very generalized. One of the most popular and widely used of the sediment erosion models is the Universal Soil Loss Equation (USLE).

Developed in 1954 by the Agricultural Research Service in cooperation with Purdue University, the USLE is used to predict average soil loss, over time, from agricultural plots under controlled crop and management practices. Recent studies have indicated that the USLE can be successfully applied to large areas, such as watersheds, with the use of a GIS (Atkinson, et al. 1988, 1989, Groome, 1989). This study uses the USLE to predict surface runoff and export coefficients as a means of addressing nutrient input into Cedar Creek Reservoir and Lake Palestine. No attempt was made to validate the nonpoint source pollution estimates obtained using these prediction methods. The utility of applying the FUTURE generated land use file to a real problem is shown in this study.

GIS activities for this study involve the integration of land use maps, with other spatial layers, as inputs to model nonpoint source pollution. The USLE examines the interrelationship between these spatial layers, expressed numerically, to yield an annual estimate of sediment loss in tons per acre. Land use maps for this study were generated from Landsat digital satellite imagery.

To assist in the prediction of urban growth in the study area, the FUTURE model was developed (Nelson, 1989). The use of this model was fundamental to obtaining a realistic representation of the predicted land use change. An accuracy assessment procedure was performed on the FUTURE model to determine the degree to which it accurately represents growth. This assessment was based on both visual and quantitative comparisons with several satellite images of the Lake Palestine watershed over time. Some modifications to the FUTURE program were necessary to obtain a growth map that more accurately portrays the development occurring in the study area.

In summary, the goals of this study were:

A. To use remote sensing analyses to obtain accurate land use maps of the study area.

B. To incorporate the satellite derived land use files, with other relevant ancillary data of the study areas, into a GIS for modelling of nonpoint source pollution potential.

C. To verify, on the Lake Palestine watershed, the ability of the FUTURE model to predict urban growth over a set period of time.

D. To estimate the urban growth that will occur in the Cedar Creek Reservoir watershed, and to use the FUTURE model to predict this urban growth of the watershed in the year 2010.

E. To use the resulting land use file from the FUTURE model as input into the USLE model to estimate erosion, and export coefficients to estimate nutrient loadings to the Cedar Creek Reservoir in the year 2010.

F. To modify the FUTURE program to better predict land use change and, subsequently, repeat the final steps of the process.

The hypothesis set forth for this study is that future land use change can be accurately and easily modelled from a classified satellite image file by using a computer based cellular automation model. This study shows the utility of such a model by applying the resulting land use file to the prediction of nonpoint source sediment and nutrient loadings using the USLE and nutrient export coefficients. By using the FUTURE model to predict urban growth in a watershed other than the one it was verified in, I hope to show the utility of the model to other areas at the same time creating a more stringent and rigorous test of the model.

CHAPTER 2

LITERATURE REVIEW

Modelling

Modelling is an attempt to manipulate a specific set of variables in order to duplicate a natural process. Three basic types of models exist in geography; 1) Iconic - which are realistic scale representations of the phenomena being examined (e.g. air photos, satellite images, scale models), 2) Analog - which are representations of coded information (e.g. maps on which different kinds of shading represent various real world properties), and 3) Symbolic - which are abstract representations of real world properties (e.g. diagrams, flow charts, or math models) (Lierop, 1986). Each of these models was used to convey different types of information. The satellite imagery used to identify land use is an example of iconic modelling. The various thematic maps (i.e. soil, rainfall, and slope), as well as the FUTURE model, represent analog models. The Universal Soil Loss Equation (USLE) is a good example of a symbolic model type.

Geographical Modelling

A geographic information system lends itself readily to spatial modelling. Theoretically, there is no limit to the number of data layers which can be incorporated into a GIS. A GIS allows the user to efficiently manipulate and analyze spatial data in order to create these models. While models are never an exact duplication of nature, they do allow the user an efficient means of understanding and simulating the processes at work in nature by simplifying some of the complex relationships that exist. The increased speed, accuracy, and storage and output capabilities of computers have greatly improved the efficiency of the model building process (Wheeler, 1988).

A GIS is capable of handling large volumes of spatial data (Marble and Peuquet, 1983). Geographical factors such as land use, soil moisture and population distributions, which can be determined by remote sensing, can be merged with digital data, such as soil maps (Nichols, 1975). Further manipulation can then be made relative to other digital data sets. Through the use of a GIS, a complete geographic picture can be assembled which takes into account many factors affecting a particular situation.

The rapid change in land use patterns and ever increasing spatial mobility have created many challenges for planners and model builders. Controlling or understanding these rapid changes is difficult. One reason for this difficulty is that most modelling methods concentrate on the analysis of only one specific (spatial) activity at the expense of more comprehensive multidisciplinary approaches.

A benefit of models is their ability to assist in the prediction of future events. Comprehensive models should attempt to address all aspects of the system being simulated (McCoy, 1982). In reality, however, this is not possible. A model that attempts to simulate these settlement systems is essentially attempting to predict the consequences of human activity.

A broad understanding of post-war human settlement trends and mobility patterns is helpful to any land use modelling effort. Post-war trends can be generalized as; 1) urbanization, 2) large scale sub-urbanization and general urban decay, and 3) the beginning of an urban revival (Lierop, 1986). These developmental trends often increase the amount of urban and residential area at the expense of forest, pasture and agricultural lands. With an understanding of these trends, it becomes possible to predict potential change for a given land use by establishing a relationship with the other components of the system.

There have been a number of theoretical spatial modelling methods developed in geography, each for specific purposes. For example, Christaller's central place theory, was developed in 1933 to predict regional economic trade patterns (Wheeler and Muller, 1986). This model stated that human settlements occur in predictable patterns around a central market area. Central places are settlements that function as market centers for their complementary regions. A localized model for commercial agriculture was proposed by Von Thünen with his location theory. Von Thünen suggested that, with all other environmental factors being equal, farm products that achieve the highest profit will outbid all others in the competition for location. Von Thünen's theories have been modified and applied to broad regions as well as to specific locations (Wheeler and Muller, 1986). While these are good theoretical indicators of locational pattern development, they fall short of actually modelling regional growth.

One theoretical approach to land use change prediction is Markov chain analysis (Robinson, 1978). Land use prediction using the Markov modelling method examines the present land use category and predicts the likelihood that it will change. This probability of change is conditional on the land use category in the immediately preceding time period. This is called a first order Markov model. Robinson (1978) questioned "... how far into the past land use patterns provide significant information about present or future patterns".

By applying Markov analysis techniques to an area of Akron, Ohio, Robinson concluded that a significant amount of information can be obtained from first order analyses. Robinson's conclusions on Markov chain analysis are significant to this study because the FUTURE model uses observations concerning the previous land use patterns as a guide for land use prediction.

D. W. Harvey (1969) described one type of theoretical model of settlement development introduced by Bylund (1960) called colonization models. Bylund's model examined the processes governing the development of new settlements in Lappland to create a spatial pattern. After analyzing the development patterns for the region, Bylund determined the factors that most influenced these patterns and established rules that governed future development based on past trends. A grid of equal sized cells of arbitrary values was overlain on a land use map and simulations were performed to model the spread of settlement around an initial set of settlements. Distinct similarities were noted between Bylund's simulations and an actual map of dispersion in the area. While this is a very simplistic example of a deterministic model, it does illustrate how colonization models might be modified to some advantage.

Although a number of statistical models exist for estimating human settlement patterns (Huggett, 1980; Lierop, 1986; Burks, 1966), they are all theoretical and relatively complicated in nature. This makes them impractical for most real world applications. A priority for the design of the FUTURE model used in this study was that it be simple, yet possess dynamic modelling capabilities. This research attempts to predict spatial urban growth in the Cedar Creek

Reservoir watershed with the FUTURE computer modelling program by Nelson (1989).

The FUTURE model used in this study is a cellular automation model, whereby dynamic simulations are performed in a raster based GIS environment. In a cellular automation model, individual cells in a spatially referenced file have the potential for change as they interact with their surrounding cells. The basic premise of this type of model is that "... complex systems can arise as a result of interactions between simpler components of the system" (Itami, 1988). John Conway's "Game of Life" (Gardner, 1970) was the first example of this concept. Conway's model was originally designed for use on paper, however it has since been modified for computers. Conway's game is based on a grid system of cells (pixels) that exist in either an "on" or "off" state. Three predetermined rules are established for the survival of each cell (Gardner, 1970):

1. A cell survives to the next generation if it is surrounded by two or more live cells (nurtured).
2. A cell dies if it is surrounded by four or more live neighbors (crowded out) or if it has less than two live neighbors (loneliness).
3. A cell is born to the next generation if it has exactly three live neighbors (optimum conditions).

The center cell of a 3 X 3 pixel window is examined in relation to its 8 surrounding pixels. The rules are applied to each pixel in turn, creating a new file of the next "generation" of cells (Itami, 1988). This concept was used in the development of FUTURE. A general description of the rules established for the FUTURE program used in this study is included in the method and materials section of this study.

Dynamic modelling techniques have been developed for more realistic simulations of actual conditions. Itami (1988) postulated that dynamic modelling could be accomplished with a GIS by using and altering the concepts of cellular automation established by Conway. Couclelis (1985) determined that the rules for Conway's "Game of Life" could be altered to relax its limitations. Couclelis noted that the space being evaluated does not need to be infinite nor does this area need to be square in shape; any irregular polygon shape can be evaluated by the model. It was also determined that the cells do not have to exist in just an "on" or "off" state, but can exist within a range equal to the range of cell values in each overlay layer. The sampling window also does not need to be defined identically (i.e. the same shape) for each area being examined. The influenced area does not have to be comprised of only adjacent cells. Transition rules can be altered for each cell being examined, and these rules can be applied at different time intervals (Itami, 1988).

Burrough, et al. (1988) termed this type of model a process model. One problem he noted with this type of model is that it is often validated using only "... a small number of highly detailed, location-specific observation points and thus may not predict well for large areas." The success of a process type model is often dependent upon the amount of data available for the area being studied. It is tempting to input data into the model without considering the scale, nature or "intrinsic suitability". It is necessary to examine the data being input for suitability and accuracy before including it directly into a GIS for modelling purposes.

Modelling For Watershed Management

Browne and Grizzard (1979) studied sources of nonpoint water pollution in 928 watersheds. They found a significant correlation between stream nutrient concentrations and general land use. As a result of this interrelationship, research has focused on means for describing the movement of nutrients from areas of differing land use to waterbodies. The purpose of this section is to present a general review of models that were used in this study to predict nonpoint pollution loading rates.

The extensive use of water quality models since the late 1960's has had a great economic impact on the planning and design of water treatment facilities. Of 141 state agencies and consulting firms queried by questionnaires, 86%

indicated they were currently using mathematical models in planning, design and operation of water resource systems (Austin, 1986). Of the models used, 48% addressed surface water quality. Recognizing the importance of sedimentation, many models are oriented to quantifying erosion rates. In a paper on the economic cost of reservoir sedimentation, Crowder (1987) estimated national current damage expenses to range from $310 million to $1.6 billion per year on a 1980 basis. Forster, Bardos and Southgate (1987) reported that if conservation programs for soil erosion reduction on cropland in Ohio were 25% successful, annual water treatment costs for the removal of total suspended solids (TSS) from potable water would fall by $2.7 million. These studies emphasize the need to describe the movement of nonpoint source pollution within a watershed and to enable the water manager to target critical areas where nonpoint pollution control efforts could reduce overall costs.

Reckhow, Butcher and Morin (1985) considered that the use of models should begin with careful examination of the prime objectives to be achieved. The primary objective relates to improving decisions about a particular watershed management scheme. In addition, the costs of information as well as the ultimate value of the information obtained should be considered. Model developers need to know the level of information and format required by decision makers as well as provide on-going education of the decision maker in order to make the information more useful (Austin, 1986).

Nonpoint Source Pollution Modelling

The following section briefly describes several nonpoint source pollution models which are used in watershed management. These models either predict erosional rates, estimate nutrient additions to waterbodies with erosional rates, or use export coefficients to predict nutrient inputs to waterbodies. The nonpoint source pollution models described here represent only those used in this study, and it should be noted that many other such models exist and are widely used.

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) model is a surface runoff model used extensively to estimate soil loss from small areas. Originally, the USLE was designed to describe erosion from cropland; specifically long-time average soil loss for specified conditions. The estimates generated by the USLE are most accurate for medium-textured soils, slope lengths of less than 122 meters, gradients of 3 to 18 percent, and consistent cropping and management systems that have been represented in erosion plot studies. In addition to cropland, factors for construction sites have been formulated, enabling the model to be more applicable for multi-use watersheds. The equation predicts the average annual soil loss for a 22 year rainfall cycle, although seasonal estimations may be made with adjustments of the Rainfall and Runoff Factor (Wischmeier and Smith, 1978).

Five major factors are considered in the USLE: rainfall frequency, duration and seasonal distribution; soil susceptibility to detachment and transport by water; slope length and grade; type of vegetation cover; and land management practices. By using these factors, average annual soil loss is computed with the following equation (Wischmeier and Smith, 1978):

$$A = R \times K \times L \times S \times C \times P$$

where:

A = Average Annual Soil Loss per unit area (tons/acre-year)
R = Rainfall and runoff factor
K = Soil erodability factor
L = Slope-length factor
S = Steepness factor
C = Cover and management factor
P = Support practice factor

All factors are unitless numbers derived by Wischmeier and Smith (1965; 1978). They were determined by considering the ratio of soil loss in fields of varying rainfall, soil, slope-length, slope-steepness, cover and management practices to that of a unit plot which was 22.1 meters long with a slope of 9 percent kept continuously in clean-tilled fallow. In most cases, the factors range between 0 and 1, unless under a given situation the erosion would be greater than that of the unit plot. Rainfall and runoff is the dominant factor and values generally decrease from the Gulf states towards the western states. Since the amount of soil loss (A) in this equation is the product of the factors outlined above, characteristics which would increase soil loss are expressed as increasing numbers. Following is a brief discussion of each of these factors.

i. Rainfall and Runoff (R) Factor

Effects of a rainfall event are quantified by the R factor. The R values used for the USLE are based on a 22 year storm cycle, and therefore represent a 22 year average annual value. This unitless number represents not only the amount of rainfall in an area, but also the rate of runoff and the intensity of the storms.

ii. Soil Erodability (K) Factor

A soil's susceptibility to erosion was expressed as the K factor. A soil's erodability is a function of a number of its physical and chemical properties. In general however, the higher the silt content of the soil the greater the resistance of that soil to erosion and the higher the K value.

iii. Slope-Length (L & S) Factors

The slope length refers to the distance a given sediment particle travels from its point of origin to a point where the slope gradient decreases enough for deposition to occur. Although these factors are treated as separate in the original equation, they were combined into a single topographic factor (L) for this study. The slope-length is a function of topographic gradient.

iv. Cover and Management (C) Factor

The C factor is used to describe the effect land use has on surface erosion. Each pixel has a land use class associated with it, and for the sedimentation analyses, each land use class was assigned a C factor which numerically reflects its ability to resist erosion. In general, the greater the potential for erosion of a land use class the higher the C value that class will receive.

v. Support Practices (P) Factor

This factor refers to the contouring, terracing, tilling or other methods which are implemented to reduce the amount of soil loss from an area. Areas under some type of support practice are given P values ranging from 0.05 to 0.9. Areas which are not under some type of support practice are given the value of 1.0.

Misuse of the USLE

Wischmeier (1976) warned against the misuse of the USLE but did not discourage its use, provided that certain precautions were taken. Applying the equation to situations for which the factor values cannot be determined from existing data with accuracy is a misuse. In addition, complex watersheds must be divided into areas for which representative values of the input factors can be defined. Pelletier (1985) considered the spectral, spatial and temporal characteristics of remotely sensed data useful for models such as the USLE requiring a knowledge of land use, cover and condition when calculating soil loss or sediment yield.

Sediment Yield

Although the USLE was designed to predict soil loss from sheet and rill erosion, a sediment delivery ratio is needed to predict what portion of sediment that is moving over an area actually reaches the water body (Shelton, 1978). The following equation describes how the sediment delivery ratio was applied (Wischmeier, 1976):

Sediment Yield=(USLE erosion)x(sediment delivery ratio)

Sediment yield of a watershed is determined by the equation:

$$Y=S_d\Sigma X_k A_k$$

where: Y = annual sediment yield (tons/year)

X_k = erosion from source area k as determined by USLE

A_k = area of source area k

S_d = watershed sediment delivery ratio as a function of a watershed drainage area obtained from a published relationship (Mills, et al.,1985).

The relationship of soil loss from the USLE and the sediment delivery ratio is the basis for many of the sediment loss, sediment attached nutrient models which followed the USLE.

Export Coefficients

Export coefficients are a means of addressing nutrient input to a water body from diverse sources including wastewater discharges, land runoff, the atmosphere (precipitation and dry fallout) and ground water (principally nitrogen) (Rast and Lee, 1983). The use of nitrogen and phosphorus coefficients is based on the assumption that for given land use or geographical conditions, a specific rate of export of nutrients will result (Clesceri, Curran and Sedlak, 1986).

Rast and Lee (1983) suggested that export coefficients were useful to provide estimates of the amount of nutrients expected to enter a water body. These estimates were derived from land uses categorized into the general areas of commercial/industrial, agriculture, forest and wetlands. Rast and Lee (1983) adopted national average coefficients based on coefficients obtained from studies primarily by

Uttormark, Chapin and Green (1974). The nutrient export load is determined by multiplying the nutrient export coefficient by the area of that land use.

Nutrients

Nutrients (nitrogen and phosphorus) have been a matter of great concern for many years (Loehr, Martin and Rast, 1980; Porcella, et al., 1974; Rast and Lee, 1978; Sawyer, 1947; Vollenweider, 1968). Nuisance algal growths and accelerated eutrophication of surface waters have also received considerable attention as researchers determined the sources to be excessive phosphorus and nitrogen. Estimation of nutrient loadings to a reservoir is particularly important to the reduction of the potential impacts of the problem.

Past studies have attempted to estimate nutrient loadings to a reservoir by examining water quality and flow data from the watershed tributaries. This stream flow and nutrient concentration data, however, is often unavailable for the reservoir of interest, and collection of this type of data is expensive and time consuming. Use of nutrient export coefficients has evolved as a principle method for estimating nutrient loads when stream data is nonexistent. These coefficients represent the masses of nutrients exported per unit of land area per year. Various land use categories have different values for the coefficients. Rast and Lee (1983) generated export coefficients which are national averages and generally applicable to many U.S. waterbody systems. They also limited the delineation of land use to commercial/ industrial, rural/agricultural (including cropland and grazing pasture), forest and wetland categories. Table 2 provides these coefficients of total phosphorus and nitrogen (Rast and Lee, 1983), which were used in this study.

Satellite Data

As digital satellite data became more available to the public sector, its usefulness in water quality and resource assessment became apparent. These data are inexpensive when compared to the cost of conventional aerial photography. Temporal resolution is also improved since site revisitation time for Landsat satellites is a little over two weeks (Slater, 1985).

Digital satellite data have advantages and disadvantages over conventional aerial photography. Because satellites can record a number of distinct spectral bands simultaneously and these images can be mathematically manipulated, many types of information can be obtained from a single scene. The use of computers has made the large amounts of data generated by satellites manageable and has reduced overall analysis time.

Digital satellite data are somewhat restricted by

Table 2: National average nutrient export coefficients (Rast and Lee, 1983).

NUTRIENT EXPORT COEFFICIENTS

PHOSPHOROUS

LAND USE	gm/m2	kg/ac	lb/ac
URBAN	0.1	0.4047	0.8924
RURAL/AG	0.05	0.2024	0.4463
FOREST	0.01	0.0405	0.0893
ATMOSPHERE	0.025	0.1012	0.2231

NITROGEN

LAND USE	gm/m2	kg/ac	lb/ac
URBAN	0.5	2.0235	4.4618
RURAL/AG	0.5	2.0235	4.4618
FOREST	0.3	1.2141	2.6771
ATMOSPHERE	2.4	9.7128	21.4167

CONVERSIONS: kg/ac ▪ gm/m2 • kg/1000gm • 4047m2/acre

lb/ac ▪ gm/m2 • kg/1000gm • 4047m2/acre • 2.205lb/kg

(RAST & LEE, 1983)

spatial resolution, thus limiting their usefulness for very detailed surface analysis (Phillips, et al., 1986). The Landsat Multi-Spectral Scanner (MSS) has a spatial resolution of 80 x 80 meters (Slater, 1985; Colwell and Hicks, 1985). It has been used successfully for many studies of water quality (Carpenter and Carpenter, 1983; Verdin, 1985) and the prediction of trophic state (Wezernak, Tanis and Bajza, 1976; Lillesand, 1983). The seven band Thematic Mapper (TM) scanner has higher spatial (30 x 30 m), spectral and radiometric resolution than the MSS data. Because of these refinements, Solomonson (1984) suggested that the TM scanner is twice as effective as the MSS.

Historically, the use of remote sensing data for watershed monitoring has been aimed more towards land use changes and their effects on the hydrology of a watershed, or the extraction of curve numbers for their use in hydrologic models (Rango et al., 1983; Still and Shih, 1985). Digital satellite data are used to gather the same basic information as aerial photography, yet the application has typically fallen short of integration into a true watershed management program. Many past applications have lacked a system for merging individual data sets to form a comprehensive data base from which management decisions could be made. With the advent of Geographical Information Systems (GIS) it became possible to create such data bases.

GIS are capable of handling large volumes of spatial data (Marble and Peuquet, 1983). Geographical factors such as land use, soil moisture and population distributions that can be determined by remote sensing can be merged with numerical data, such as digital soil maps (Nichols, 1975). Further manipulation can then be made relative to other data sets. Through the use of a GIS, a complete geographic picture can be assembled, which takes into account many factors affecting a particular problem in a given area.

Remote Sensing and Geographic Information Systems

To date, little work has focused on the applications of remote sensing technologies towards watershed management. Most applications were concerned with water quality assessment, prediction and monitoring. The full utilization of remote sensing data for the purpose of management (i.e. nonpoint loading detection, mitigation and monitoring) has only recently become the subject of scientific investigation.

Smith and Blackwell (1980) integrated Landsat MSS data, digital terrain data, conventional maps and ground data to form a data base to be used for managing the water quality of Lake Tahoe. Rapid urban development within the Lake Tahoe basin had caused concern about the effect on water quality. The data base was developed to aid in locating and limiting nonpoint loading areas. Through the use of the Image Based Information System (IBIS), individual data sets were rectified to a base map and stored as data planes or overlays. This provided a method for monitoring and archiving basin characteristics over time. Smith and Blackwell (1980) noted that for water quality projects, the study of lakes and watersheds must have dimensions to accommodate the resolution of the Landsat (TM) scanner. This system will require several years of operation to yield tangible results, however preliminary indications are encouraging.

A similar project to the initial portion of this research was recently completed for the nine watersheds of the City of Dallas, Texas' drinking water supply system (Atkinson et al., 1988, 1989, Groome, 1989). Phase I of the project involved the four Western Watersheds, Grapevine, Lavon, Lewisville, and Ray Roberts. Phase II addressed the five Eastern Watersheds, Lavon, Tawakoni, Fork, Ray Hubbard, and Palestine. Three sets of MSS satellite data, between 1974 and 1989, were collected and analyzed for each phase of the project. The use of these satellite images allowed a unique perspective of the land use change that occurred in the watersheds. Nutrient and sediment loadings from these watersheds were calculated for each of the satellite images using the method described in this study.

Another study involving nonpoint source pollution loadings to the Cedar Creek Reservoir watershed using remote sensing and GIS technologies was recently completed for

Tarrant County Water Control and Improvement District Number 1 (Atkinson, Walker, and Dickson, 1989). Thematic Mapper satellite data from April, 1988 were used to determine land use for the watershed. Results of the nonpoint source pollution analyses of this area are presented in this study.

Summary of Remote Sensing Applications

One aspect of watershed management involves the reduction of the detrimental effects of land use trends on water quality. To do this, watershed managers must be aware of (1) the existing land uses in the watershed, (2) how land uses have changed over time, and (3) where "critical" areas occur so that best management practices can be employed. Remote sensing holds promise as an effective and efficient method of data gathering, as well as a monitoring tool for future changes in the physical characteristics of a watershed. A GIS can facilitate the decision making process by processing, and analyzing information in a clear, and concise manner.

CHAPTER 3

METHODS AND MATERIALS

Introduction

A summary of the equipment and techniques used to assess the accuracy of the FUTURE model in the Lake Palestine watershed and in the prediction of current and future critical nonpoint source pollution areas in the Cedar Creek Reservoir watershed is described in this chapter. A brief description of the satellite image processing and GIS procedures used in this study follow. The emphasis of this section is on the actual methodology used in the study rather than on the specific computer programs employed.

Computer Software and Hardware

All satellite image processing and GIS analyses for this study were performed on the Earth Resources Data Analysis System (ERDAS). ERDAS is a raster or grid cell based package, which contains modules designed to enhance, classify, rectify, and statistically analyze images and to perform basic GIS functions (ERDAS, 1986). ERDAS software (versions 7.1 and 7.2) is installed on an IBM AT personal computer (PC) system, used as the processing platform for this study. The hardware configuration of this system is as follows:

- IBM PC AT with an 80 megabyte hard disk
- IBM monochrome monitor
- 12" Mitsubishi RGB color monitor
- Revolution Number Nine imaging processing board
- Panasonic KPX-1524 dot-matrix printer
- Tektronix 4696 color ink-jet printer
- Cipher 9 1/2" magnetic tape drive
- Calcomp 9100 digitizer tablet

A schematic diagram of this hardware configuration is shown in Figure 5. Some of the more time and memory intensive computer programs were performed on the VAX mainframe computer of the University of North Texas (ERDAS version 7.0 and 7.1).

Satellite Imagery

Landsat satellite data were used to determine land use in the study areas. Landsat satellite platforms orbit the earth in circular, sun-synchronous orbits at altitudes of approximately 800 kilometers and pass over the same point once every 16 days. Electromagnetic energy reflected from the earth is recorded by the satellite with a multispectral scanner functioning as a spectroradiometer. Both Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) satellite data were used in this study.

Analyses of land use patterns in the Lake Palestine

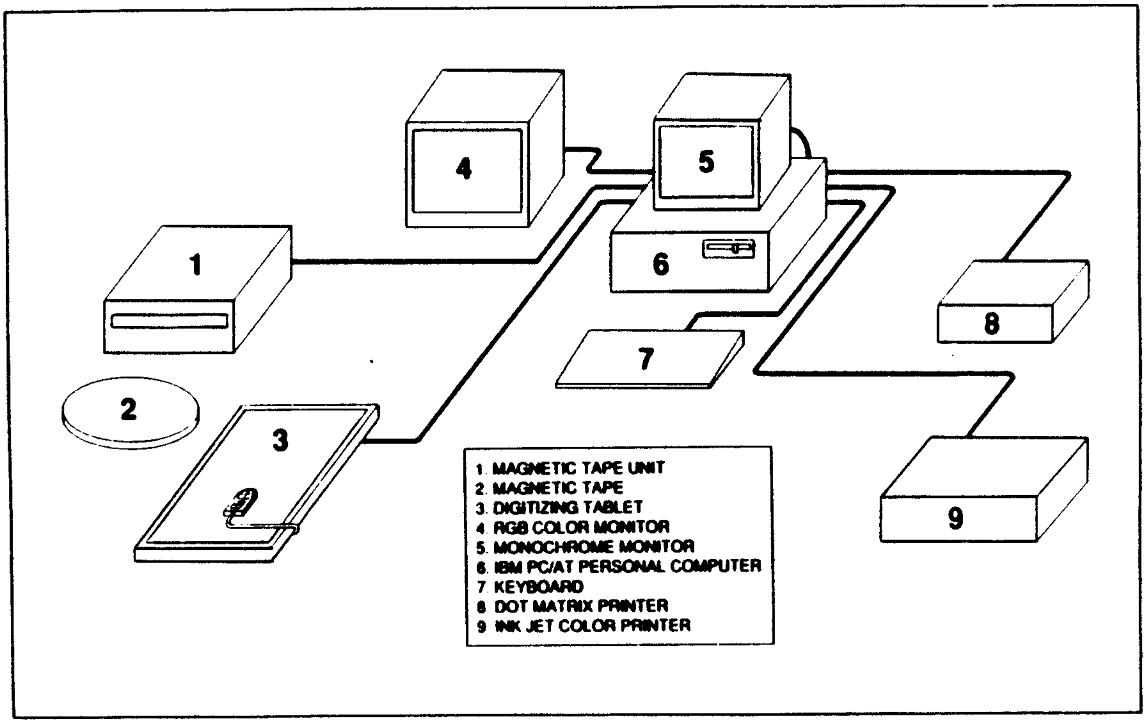


Figure 5: Schematic diagram of ERDAS configuration.

watershed was performed using Landsat MSS data. Multispectral Scanner data has a spatial resolution of 80 x 80 meters and measures reflected energy in four bands of the electromagnetic spectrum. Thematic Mapper satellite data were used to identify land use in the Cedar Creek Reservoir watershed. With TM data, energy in seven discrete wavelength bands of the optical range is measured with a spatial resolution of 30 x 30 meters. These data are transmitted back to earth and stored digitally as brightness values for each cell of the bands. These 6400 and 900 square meter grids represent the smallest area for which data are collected. This "smallest area" is the instantaneous field of view (IFOV) of the scanning system, and is often referred to as a "pixel" (picture element).

Electromagnetic energy is commonly considered to span the spectrum of wavelengths from 10^{10} um to 10^{-10} um, however the wavelengths between .30 to 15.0 um, the optical wavelengths, are of greatest interest in remote sensing (Swain and Davis, 1978). Bands monitored by the Thematic Mapper sensor correspond to 3 visible, 2 near-infrared, 1 mid-infrared and 1 in the thermal-infrared region of the electromagnetic spectrum. Figure 6 (USGS, 1984) lists the seven TM bands, their wavelength ranges, and suggested applications for each of the bands. The four Multispectral Scanner bands correspond to 2 visible and 2 in the near-infrared bands of the electromagnetic spectrum.

BAND	SPECTRAL RANGE	PRINCIPAL APPLICATIONS
1	0.45-0.52 μm	COASTAL WATER MAPPING; SOIL/VEGETATION DIFFERENTIATION; DECIDUOUS/CONIFEROUS DIFFERENTIATION
2	0.52-0.60 μm	GREEN REFLECTANCE BY HEALTHY VEGETATION
3	0.63-0.69 μm	CHLOROPHYL ABSORPTION FOR PLANT SPECIES DIFFERENTIATION
4	0.76-0.90 μm	BIOMASS SURVEYS; WATER BODY DELINEATION
5	1.55-1.75 μm	VEGETATION MOISTURE MEASUREMENT; SNOW/CLOUD DIFFERENTIATION
6	10.4-12.5 μm	PLANT HEAT STRESS MEASUREMENT; OTHER THERMAL MAPPING
7	2.08-2.35 μm	HYDROTHERMAL MAPPING

Figure 6: Summary of the seven spectral bands of Landsat TM satellite data (USGS, 1984).

Two quarter scenes of Landsat TM satellite data from April 13, 1988 (Figure 7) were used to identify land use in the Cedar Creek Reservoir watershed. Landsat MSS data from July 27, 1974 and July 6, 1988 were used for temporal analyses of the Lake Palestine watershed (Figure 8). By comparing these two satellite images of the same area it was possible to quantify the urban growth occurring in the Lake Palestine watershed during the 14 year period from 1974 to 1988.

Image Processing

The first step of processing the satellite imagery was identification and isolation of subsets of the study area from the entire images. By viewing the image and identifying known points that lie outside of the watershed boundary, it was possible to accurately subset a portion of the image containing the entire study area. Subsetting the image is one way to reduce the volume of data that must be handled, thus decreasing computer processing time.

Interpretation of remote sensing data requires analyses of information contained in data bases composed of multiple bands. Thematic Mapper data, consisting of seven bands, is difficult to work with both conceptually and with respect to computer space and time. In order to reduce the dimensionality and thus volume of data, Principal Component Analysis (PCA) was performed on the Thematic Mapper data.

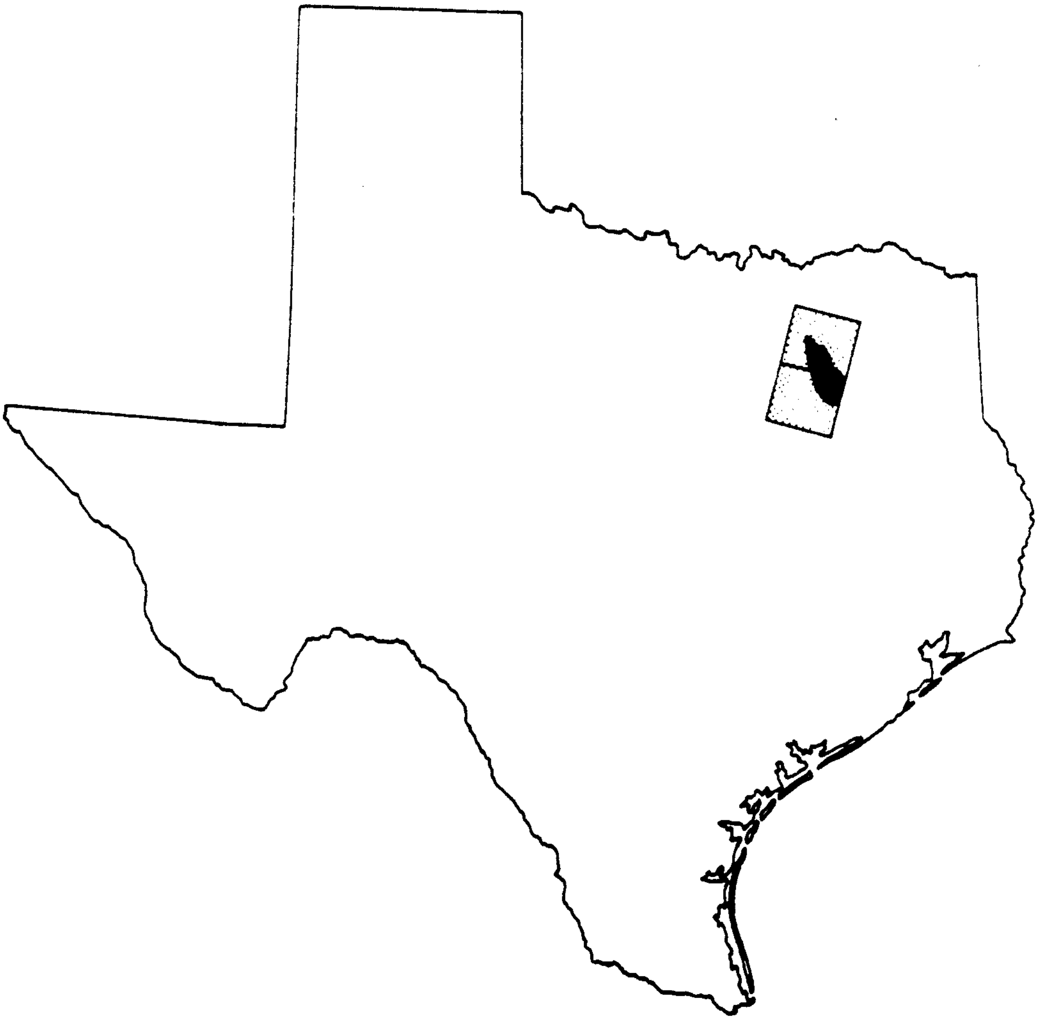


Figure 7: Location of the Landsat TM scences, April 13, 1988.

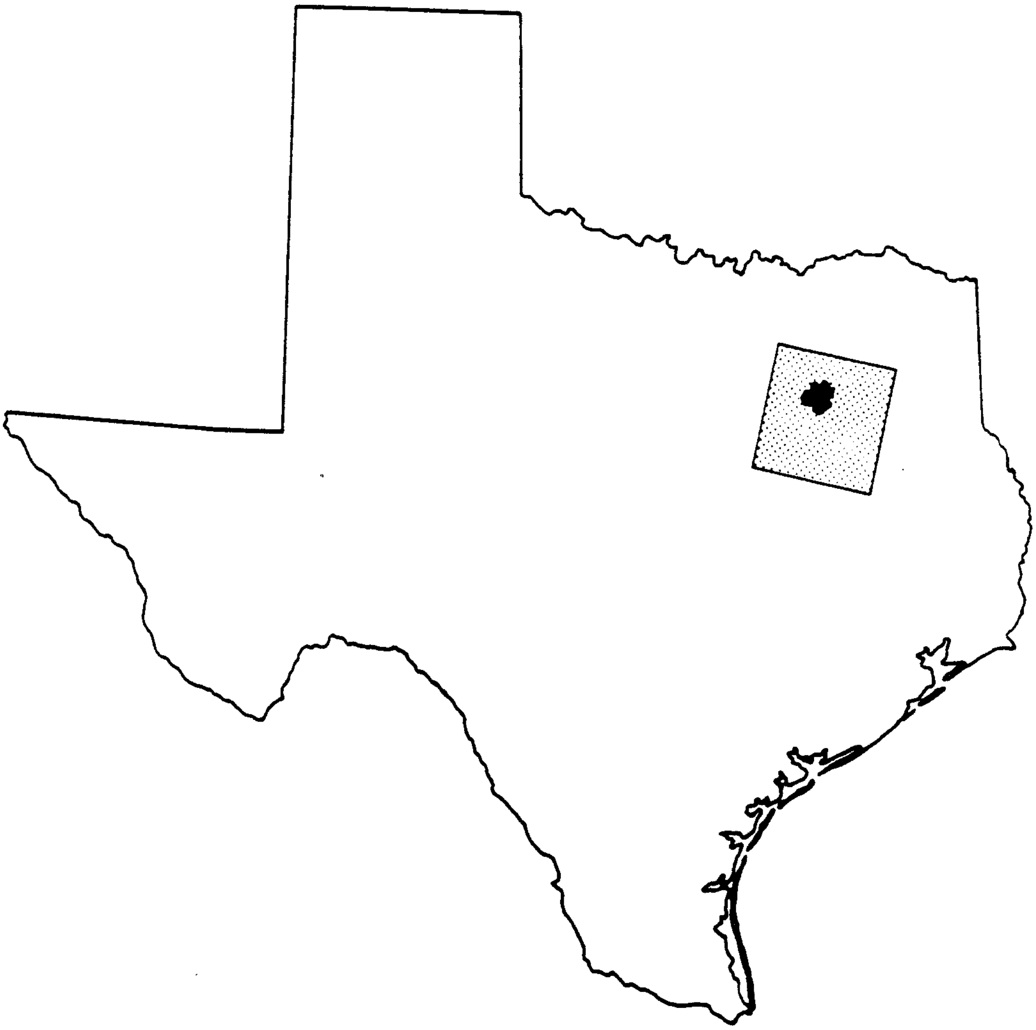


Figure 8: Location of Landsat MSS satellite images, July 6, 1974 and July 27, 1988.

PCA involves the application of a transformation to a correlated set of multispectral data (Jensen, 1986). Through the use of PCA, information in the six channel TM scene (the thermal bandwas not used in the analysis) was represented in three transformed principle component bands. This is possible due to the high degree of interband correlation among the spectral bands of TM images. The intrinsic dimensionality, or true volume of information in an image is contained in less space than that required by the original number of bands. Over 98% of the total variation in the original TM image was represented in these three principle component bands (Figure 9).

Geometric rectification was performed on the digital images to correct for distortions caused by altitude and attitude variations in the satellite platform. The process of geometric rectification involves relating known ground control point (GCP) pixel coordinates from the image with their map coordinate counterparts on 1:24000 U.S. Geological Survey topographic maps (Jensen, 1986). For example, highway intersections (also dam spillways or bridges over rivers) can easily be identified in both the map and the image, as can other easily identified structures . A series of these common points were recorded, and a correlation coefficient between the map and the image was generated. The correlation coefficient was then used to "georectify" the image to the coordinate system of the map, which in this

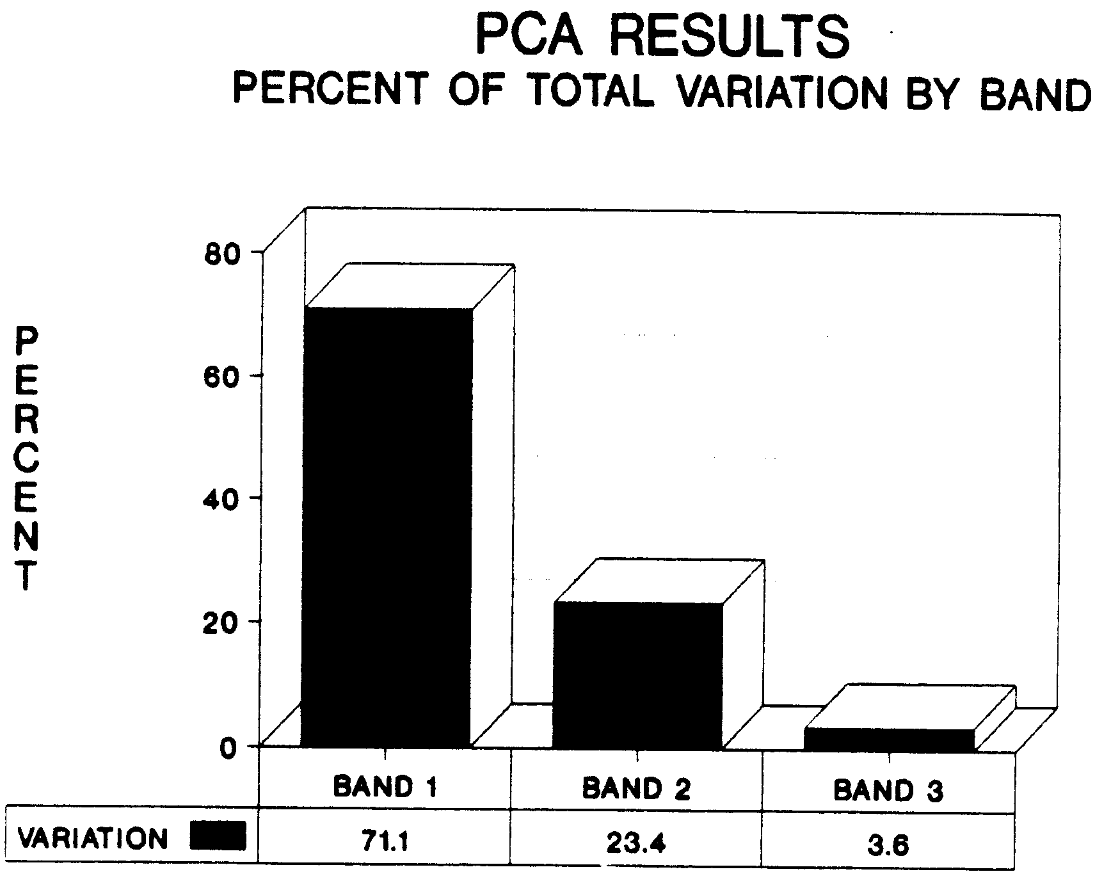


Figure 9: Results of Principle Component Analysis (PCA) on the Landsat TM satellite data.

case was Universal Transverse Mercator (UTM). From this point on, all data entered into the GIS was also georectified to UTM coordinates. For example, soil association boundaries were first determined from Soil Conservation Service County Soil Surveys and then transferred into the GIS through a digitizing tablet.

ERDAS software allows for classification of digital satellite data into land use categories. Information on the current land covers in the study area was extracted by using digital image processing analyses. An unsupervised classification methodology was used to determine the land use classes for the Cedar Creek Reservoir watershed. This approach involves multidimensional algorithms which search for "natural" clusters based on the spectral properties of the pixels (Figure 10). The brightness value of each pixel was examined in relation to the pixels within a certain radius of it. Pixels within this radius, which had a brightness value within a predefined range, were grouped together. This process was repeated until all pixels had been grouped. Each pixel was then assigned to one of the groups by a minimum-distance to means classifier (Jensen, 1986). The pixel being examined was assigned to the group whose mean value was closest to that pixels brightness value. Pixel clusters were then grouped manually to represent particular land use categories. Manual grouping of the pixels into land use classes was accomplished by

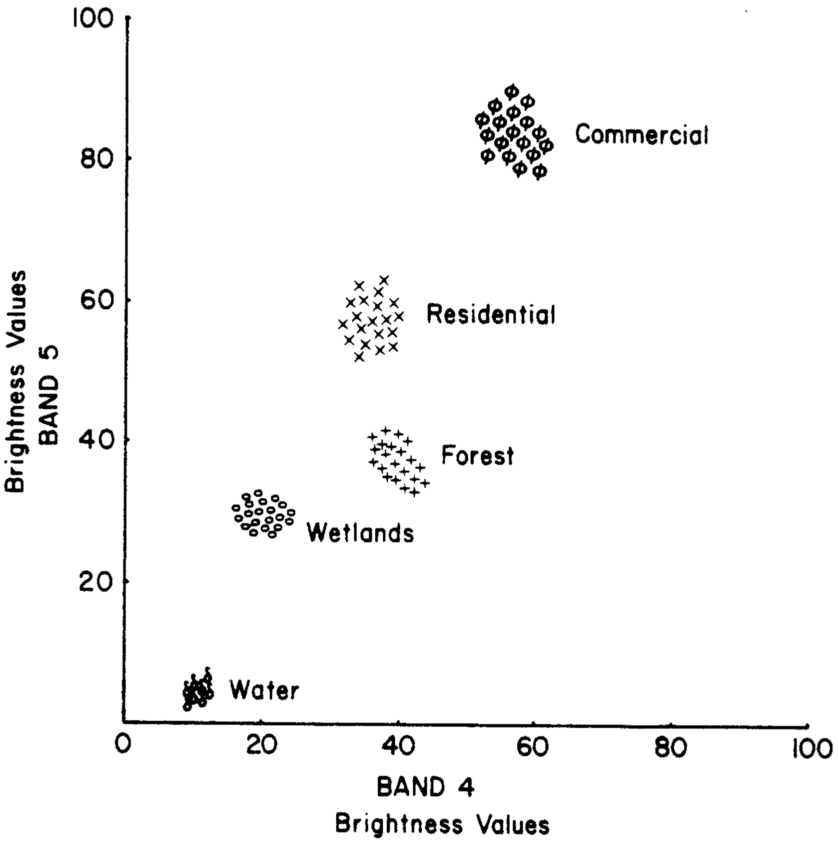


Figure 10: "Natural" clustering of pixel values based on spectral characteristics.

comparing the computer generated pixel clusters to known areas verified by ground truthing.

Land use categories in the Lake Palestine watershed were obtained with a combination of unsupervised and supervised classification techniques. Supervised classification involves examining the reflectance or spectral patterns of pixels of known land uses and using that information to classify all unknown pixels. For example, water typically has moderate energy levels in the infrared bands. This pattern is called water's spectral signature. Each land use has its own characteristic signature. By recording the spectral pattern of representative groups of the land uses of interest, a 'dictionary' of these signatures was compiled. These spectral signatures were added to the clusters of pixel values created in the unsupervised procedure before being grouped manually into land use categories.

Verification of the land use classifications was accomplished by ground truthing. This process involved confirming that areas classified to a particular land use category on the image actually represent that land use in the field. Areas representing each of the land use categories, as well as areas which were questionable in the image classification, were checked in the field. Results of the ground truthing procedure confirmed that the land use classifications for both the Cedar Creek watershed and the

Lake Palestine watershed were accurate.

Modelling With FUTURE

The emphasis of this research was on determining if development could be accurately predicted with the computer based FUTURE model. A method of modelling growth was required to create a usable land use map for input into the USLE. The land use file generated by the FUTURE program was used to predict future sediment and nutrient loadings to Cedar Creek Reservoir.

FUTURE (Nelson, 1989) is a computer program which predicts urban and residential development. The FUTURE program uses an ERDAS compatible GIS land use file as input. The original GIS file was obtained by classifying a Landsat satellite image. Land use change is modelled by first assigning land use categories different weights, depending on their relative effect on urban and residential development in adjacent areas. Next, each pixel is analyzed and either retains the same land use category, or is changed to another category based on the logic rules within the FUTURE program.

Rules For The FUTURE Model

The first factor to be considered by the FUTURE program is the existing land use category for the center cell within a 3 x 3 window of pixels. If the land use value represents water, transportation, wetlands or an already developed area then the model assumes that the value will not change. If, on the other hand, the present land use value represents agriculture, pasture, or barren land then the possibility for development exists. If a pixel meets the established rules for development, then the surrounding land use categories are analyzed to determine the relative potential for development. A pixel representing agriculture, for example, which is surrounded by other pixels of the same value, is much less likely to be developed than is a pixel representing agriculture which is surrounded by urban and residential pixels. The 3 x 3 pixel sampling window is passed over the entire file generating a new land use file based on these assumptions. The FUTURE program can be run any number of times on these new land use files in order to reach the desired amount of predicted growth, with each successive iteration generating more urban/residential growth.

Various land use categories from the original satellite based land use classification are assigned weights to assist in determining whether a pixel will change values. Pixels classified as urban or residential receive a weight of 3, while pixels representing transportation have a weight of 1.75 and agriculture, pasture and barren pixels have no weight. Using this weighting scheme, urban pixels are 3 times as likely to induce development as are pasture pixels.

If the center pixel meets the rules for change (i.e. it is either agriculture, pasture or barren) and the total of the weights of the adjacent pixels is greater than or equal to 8, and less than or equal to 15, then it is reclassified to represent new growth. If these conditions are not met, the center pixel retains its original classification value. In subsequent iterations of the FUTURE program these new growth pixels are weighted the same as urban/residential.

Cutoff weights of 8 and 15 were derived through a process of trial and error to represent local growth trends. It was determined that if the sum of these weights exceeded 15 then urban development became too "easy" and an unrealistically high degree of development occurred. If, on the other hand, the sum of the weights fell below 8 urban development was too small; not accurately portraying the actual growth that was occurring.

Figure 11 graphically illustrates how the FUTURE model works on an imaginary matrix of cells. In this example the center cell has a land use value of 2 (agriculture), which means it has the potential for urban development. This pixel is surrounded by two transportation cells, two agriculture cells, two urban cells, and one water cell. Weights for these various land use classes are shown in the center window of the diagram. The sum of these weights is 9.5, which is between the established upper and lower limits of 8 and 15. In this example, the center pixel meets all

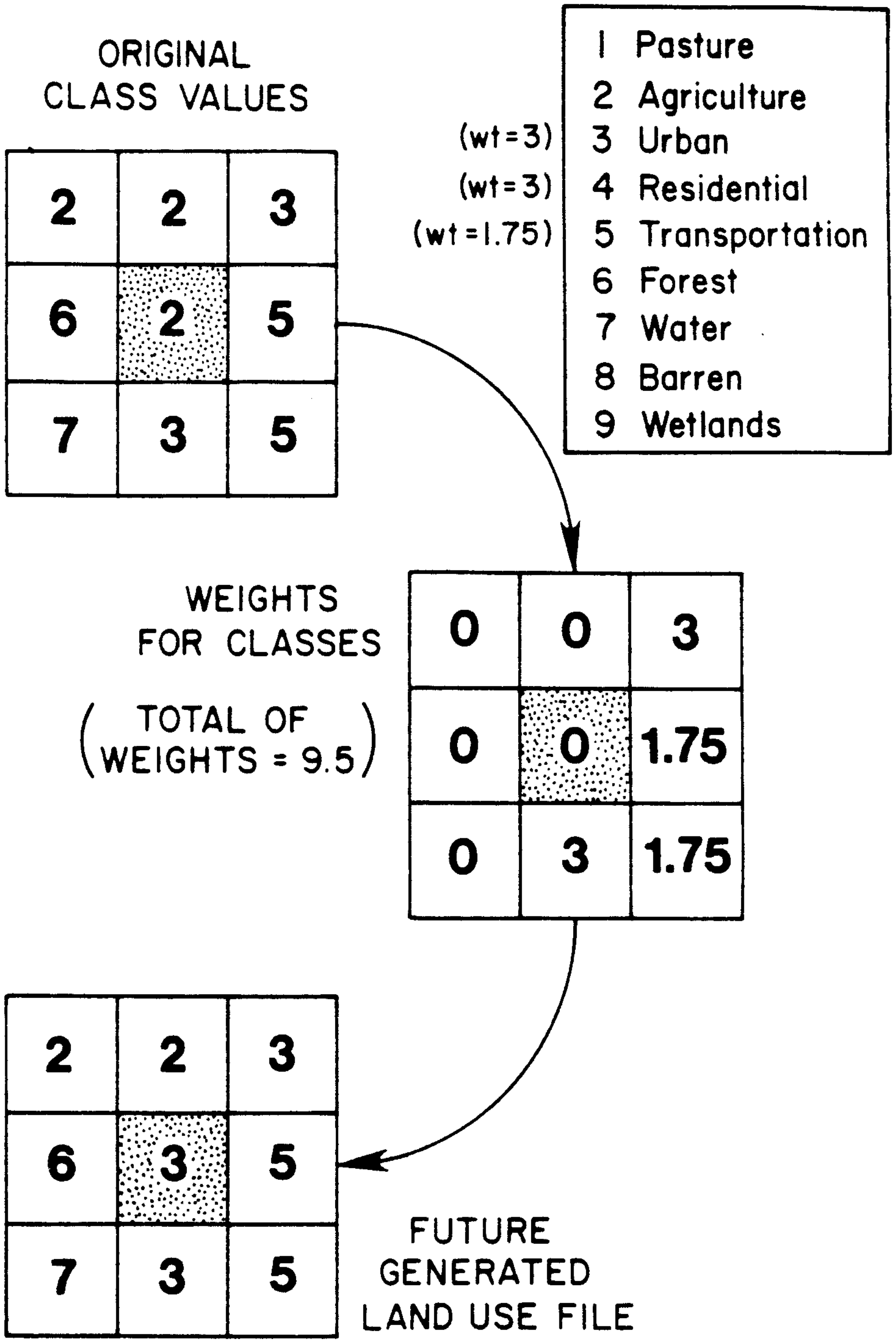


Figure 11: Example of the FUTURE model on an imaginery matrix of cells.

the rules for development established within the program and will, therefore, change values from agriculture to urban.

Nonpoint Source Pollution Loadings

i. Sedimentation

Soil loss estimates from the study area were obtained from the Universal Soil Loss Equation (USLE). For each factor (except the support practice factor), a GIS file was created and stored as a digital data base. The support practice factor was set equal to 1 for every pixel. Setting the support factor to 1 was required because this kind of information is site specific and could not be determined by remote sensing or with conventional, readily accessible sources of data. Since every pixel was equal in terms of this factor, no area was discriminated against in terms of excess or reduction in erosion.

The data used to calculate the percent slope and length were obtained in the form of U.S. Geological Survey Digital Elevation Model (DEM) computer tapes. Elevations within the study area ranged from approximately 107 meters above mean sea level in the Lake Palestine watershed to approximately 168 meters above mean sea level in the Cedar Creek Reservoir watershed. The degree of slope for the study area ranged from 0 to just over 18 degrees, with over 95 percent of the area having a slope less than 6 percent. Slope data were computed by examining the difference in elevation from each pixel to each surrounding pixel. The greatest difference in elevation determined the slope of that pixel.

Soil erosion values were derived from the Soil Conservation Service's County Soil Survey for Anderson, Cherokee, Henderson, Kaufman, Rockwall, Smith and Van Zandt counties. These erodability factors ranged from 0.17 to 0.43. Rainfall intensity factors (R), as they pertain to the Cedar Creek Reservoir and the Lake Palestine watersheds, were taken from the isoerodent map presented in Wischmeier and Smith (1978). The unitless R factor ranged from 320, for the western portion of the study area, to 340 for the eastern areas.

For the study area, C factors were averaged for each land use, and the average applied to the appropriate category. In general, the greater the potential for erosion of a land use the higher the C value that category received, with a maximum value of 1.0. Accordingly, barren and disturbed areas, such as construction sites with little or no vegetative ground cover have a high C value. Pastures, rangeland and idle land were given C factor values that reflected the height and amount of ground and vegetative cover available to intercept raindrops and retard soil movement. Similarly, the C factor values for wooded or forested lands reflect the average amount of understory and overstory and also consider cleared forested areas. Urban and suburban areas are generally characterized by little exposed soil and are therefore given low values. However, due to the increase in water velocity moving across the urban surface, the values given are not nearly as low as those of a cover type more dominated with vegetative ground cover. For this study, residential areas were assigned a C factor of 0.2, while commercial and industrial areas were assigned a C factor of 0.1. Table 3 provides a list of the different C factor values for the various cover types delineated within the study area.

Each factor used in the USLE was stored as a separate GIS data base. Since each data layer was registered to the UTM coordinate system, they could be merged into one summary data base which represented average annual soil loss. This process involved sequential steps, building up to the final data base of soil loss.

Figure 12 illustrates the sequence of multiplications performed within the GIS to derive the soil loss estimates. First, the rainfall factor file was combined with the soil erodability factor file to create a rainfall/soil file. Next, the rainfall/soil file was merged with the slope file to create a rainfall/soil/slope file. Each of these intermediate files was multiplied by a scaling factor of 0.1 in order to keep the values of the resulting file below 256 classes (i.e. an 8 bit data file). This process was repeated until all data bases were merged into the final USLE data base. For each pixel in the final USLE file the

Table 3: Cover factors used in the USLE.

CROP/COVER TYPE	C VALUE
PASTURE	0.3
AGRICULTURE	0.5
COMMERCIAL/URBAN	0.1
RESIDENTIAL	0.2
TRANSPORTATION	0.1
FOREST	0.1
BARREN	0.9
WATER/WETLANDS	0.0

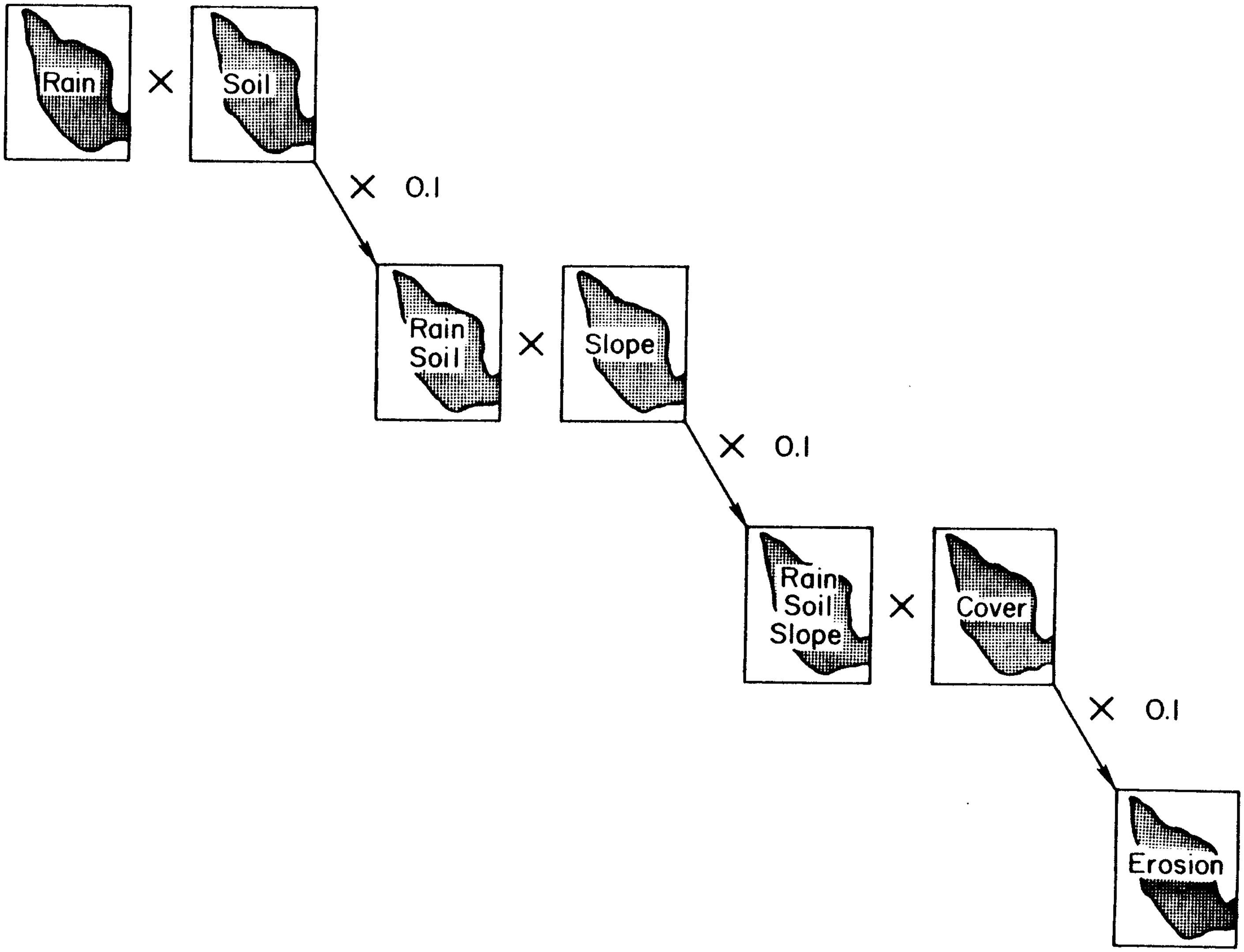


Figure 14: Sequence of Multiplications Performed Within ERDAS to Derive Soil Loss Estimates.

total annual erosion was stored. Total erosion in the watershed was determined by summing the average annual erosion for all pixels in the watershed. Areas within thewatershed were grouped according to their relative potential for erosion.

The USLE predicts average annual soil loss, not the sediment which reaches a waterbody. Since a major goal of this study was to determine the impact of nonpoint source pollution to Cedar Creek Reservoir, a sediment delivery ratio factor was used to estimate sediment yield due to surfaceerosion (Figure 13, Mills, _et_ _al_., 1985). This factor accounts for loss of sediment through deposition and filtering. While many variables, including watershed shape and the number of catchment basins within the watershed, have an effect on the amount of actual sediment delivered, the delivery ratio used in this study is a nonlinear function of watershed size which averages these variables over many watersheds. As watershed size increases, the sediment delivery ratio decreases. For a 1 km^2 watershed the sediment delivery ratio is 0.35, while a 1000 square kilometer has a sediment delivery ratio of 0.055. Once the total erosion was estimated using the USLE, the size of the watershed was used to determine the appropriate sediment delivery ratio, and sediment yield was estimated by multiplying the total erosion by the sediment delivery ratio.

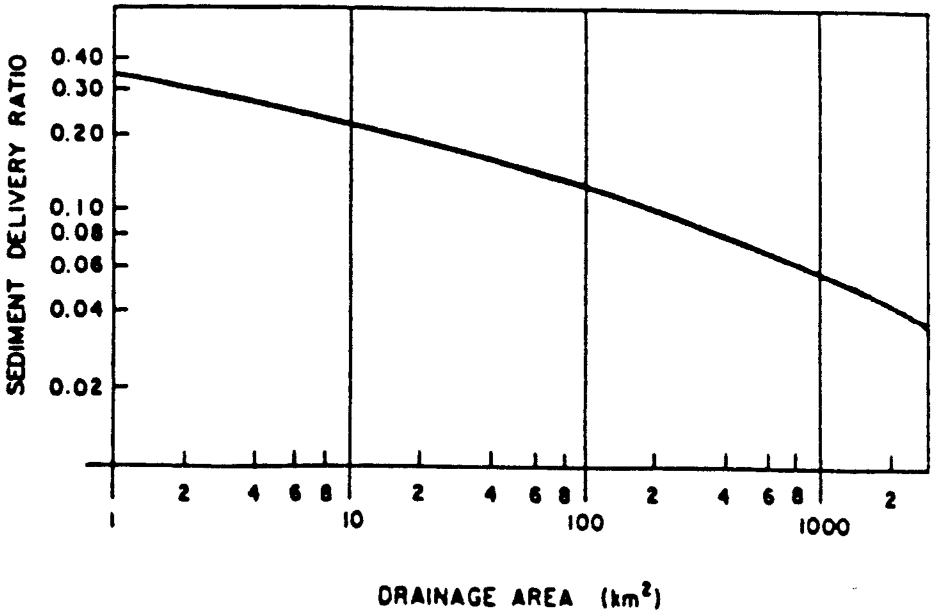


Figure 13: Sediment delivery ratio as a function of watershed drainage area (Mills, et al, 1985).

ii. Nutrients

Nutrients (nitrogen and phosphorus) were examined alongwith sedimentation as representative measures of nonpoint source pollution potential in the study area. Rast and Lee's (1983) national average export coefficients (Table 2, page 31) were multiplied by the corresponding acreage of the various land use categories to determine nutrient loadings to the reservoirs. Values resulting from this procedure represented the amount of nonpoint phosphorus and nitrogen, in kilograms, loading into the reservoirs.

CHAPTER 4

RESULTS

Introduction

An assessment of the ability of the FUTURE model to predict growth in an accurate manner is presented in this section of the paper. Assessment of the FUTURE model was performed with respect to the type and location of projected growth. It was necessary that the FUTURE model accurately predict not only the amount of urban growth expected to occur in the watershed, but also where this growth will occur. Both of these requirements had to be met in order for the FUTURE model to be considered a realistic predictor of urban growth.

Quantitative Assessment Results

Before the model was run, some attempt had to be made to estimate the amount of growth that the model should predict. Satellite imagery was available for the Lake Palestine watershed for the periods 1974 and 1988. Comparison of land use files classified from the satellite images covering the Lake Palestine watershed allowed quantification of the actual land use change that has occurred in the area in the recent past.

A comparison of the area statistics generated from the classified satellite images of the Lake Palestine watershed from 1974 and 1988 is shown in Table 4. The dominant changes in land use in the Lake Palestine watershed is a 9.1 percent decrease in forest and a 600.5 percent increase in barren land from 1974 to 1988. Urban growth (a combination of the urban and the commercial classes) in the watershed increased by 49.7 percent from 5364 acres in 1974 to 8030 acres in 1988. One run of the FUTURE model on the 1974 land use file simulated the amount of urban growth in the watershed, generating a total of 8020 acres of urban growth.

Examination of the land use percentages by category for the two satellite images and the FUTURE model revealed a shortcoming of the model. The model was designed to simulate urban growth and failed to consider the deforestation that was occurring in the watershed. To account for this weakness new rules were established within the FUTURE model to account for the encroachment of pasture into forested areas. If a given pixel was classified as forest and five or more of the adjacent pixels were pasture or agriculture then the value of that cell changed to pasture. This modified FUTURE model is hereafter referred to as the FUTURE2 model.

A comparison of the Lake Palestine watershed land use percentages by category derived from the FUTURE and the FUTURE2 models with the 1974 and 1988 satellite land use

Table 4: Comparison of land use in the Lake Palestine watershed between 1974 and 1988.

LAKE PALESTINE WATERSHED
LAND USE ACREAGE FOR 1974 AND 1988

LAND USE	1974	1988
WATER	24170	27983
PASTURE	184050	191347
AGRICULTURE	26911	35121
FOREST	293164	266555
TRANSPORTATION	4468	4458
BARREN	772	5408
COMMERCIAL	547	598
URBAN	4817	7432

Figures derived from satellite imagery

values is shown in Table 5. Both models predicted the amount of urban/commercial growth in the watershed equally well. The rules established within the FUTURE2 program to predictthe deforestation that was occurring in the watershed, made it a more accurate predictor of forest than the unmodified FUTURE model. This increase in prediction accuracy for the forest class with the FUTURE2 model came at the expense of the accuracy of the pasture category. Pixels that met the rules established within FUTURE2 for deforestation were changed to pasture causing an overestimation of the pasture category. Because of this the FUTURE model appears to be a better predictor, quantitatively, of pasture, than the FUTURE2 model.

Nonparametric rank correlation analyses showed a significant correlation between the 1988 satellite derived land use percentages and both the FUTURE model ($\underline{R}$ = .857) and the FUTURE2 model ($\underline{R}$ = .857) percentages. Land use percentages from both of the FUTURE and the FUTURE2 models had the same correlation coefficients ($\underline{R}$ = .929) when compared with the 1974 satellite derived land use percentages. Results of these statistical tests are in Appendix A. These tests showed that the relative order of the various land use categories had not changed significantly over time or with subsequent runs of the FUTURE model.

Comparison of the percent change between the actual

Table 5: Comparison of land use percentages between the 1974 and 1988 satellite image classifications and the FUTURE and the FUTURE2 models.

PALESTINE WATERSHED
ACTUAL vs. MODELLED PERCENTAGES

	ACTUAL PERCENTAGES		MODELLED PERCENTAGES	
	1974	1988	FUTURE	FUTURE2
WATER	4.49%	5.19%	4.49%	4.49%
PASTURE	34.15%	35.51%	34.04%	42.13%
AGRI.	4.99%	6.52%	4.72%	4.72%
FOREST	54.40%	49.46%	54.35%	46.26%
TRANS.	0.83%	0.83%	0.83%	0.83%
BARREN	0.14%	1.00%	0.09%	0.09%
COMMER.	0.10%	0.11%	0.10%	0.10%
URBAN	0.89%	1.38%	1.39%	1.39%

ACTUAL PERCENTAGES DERIVED FROM SATELLITE IMAGERY

1974 and 1988 satellite image classifications and between the 1974 classification and each of the models is seen in Table 6. Nonparametric rank correlation analyses was performed on these percent change figures in an attempt to derive a single measure of which model was a better predictor of overall growth. The resulting R values from these analyses were extremely low because while the analyses were examining overall land use change, the FUTURE models were only modelling urban growth and deforestation. Results of these statistical tests are shown in Appendix A.

Visual Assessment Results

Visual comparison of the 1988 land use file with the FUTURE generated land use file allowed for a subjective assessment of the location of the predicted growth. Subsets of the study area were randomly chosen for visual comparison between the FUTURE generated land use file and the 1988 satellite derived land use file. Selective subsets around urban areas were then examined. Urban growth predicted by the FUTURE model appeared realistic, occurring along transportation routes and near existing urban settlements (Figure 14). Comparison of the FUTURE generated land use file with the original land use file revealed the weakness of the model noted previously in the quantitative assessment section; the need to model the deforestation occurring in the watershed. Results of the visual effect of this

Table 6: Comparison of percent change between the 1974 and the 1988 satellite image classifications and between each of the FUTURE models.

PALESTINE WATERSHED PERCENT LAND USE CHANGE OF MODELLED CLASSES

	PERCENT CHANGE		
	1974* - 1988*	1974* - FUTURE	1974* - FUTURE
FOREST	- 9.08%	- 0.09%	- 14.96%
URBAN	63.43%	55.13%	55.13%

* NUMBERS DERIVED FROM SATELLITE IMAGERY

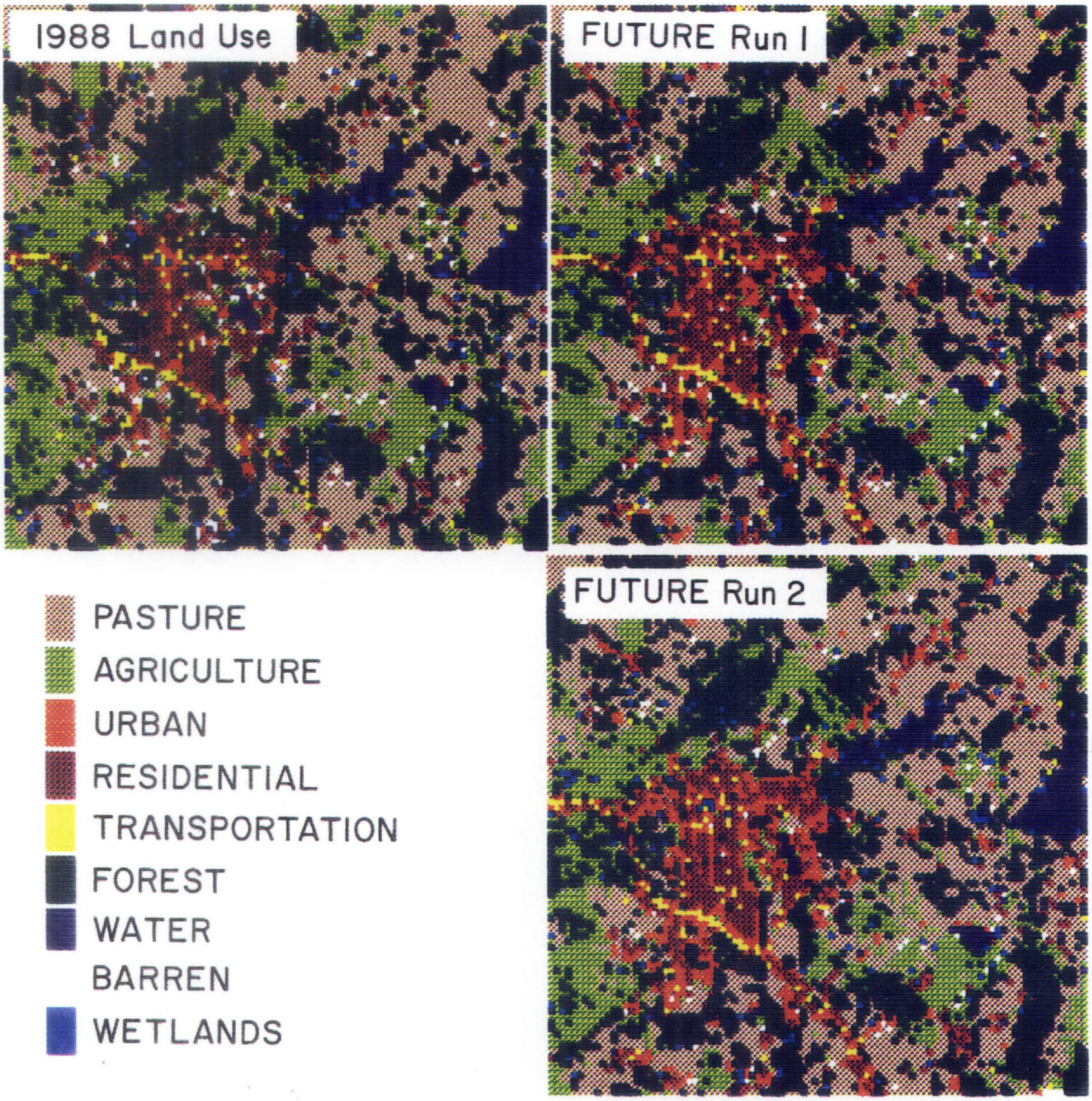


Figure 14: Subset of land use file showing location of urban growth predicted with the FUTURE model.

modification are seen in Figure 15. A decrease in forest (shown in dark green) from the 1974 file to the 1988 file is apparent.

Another method of visual accuracy assessment was performed on the entire watershed by comparing the 1988 land use file to the land use files generated by each version of the FUTURE model (Figure 16). Areas in white in these images represent areas that were not the same class values in the 1988 file and the FUTURE generated files. While the amount of change between these two images is small, more change is apparent in the image representing the FUTURE model than in the FUTURE2 model. Visual examination of these figures revealed that the FUTURE2 model gave a more accurate representation of the actual growth that has occurred in the Lake Palestine watershed than did the unmodified FUTURE model.

Testing FUTURE With the USLE

One test of the accuracy of the FUTURE models was performed using the USLE. The 1974 satellite derived land use file for the Lake Palestine watershed was used as input into the FUTURE model. Satellite derived land use data were also available for the Lake Palestine watershed in 1988. The FUTURE and the FUTURE2 models were run on the 1974 land use file to approximate the amount of urban growth found in the 1988 land use file. This growth was approximated very

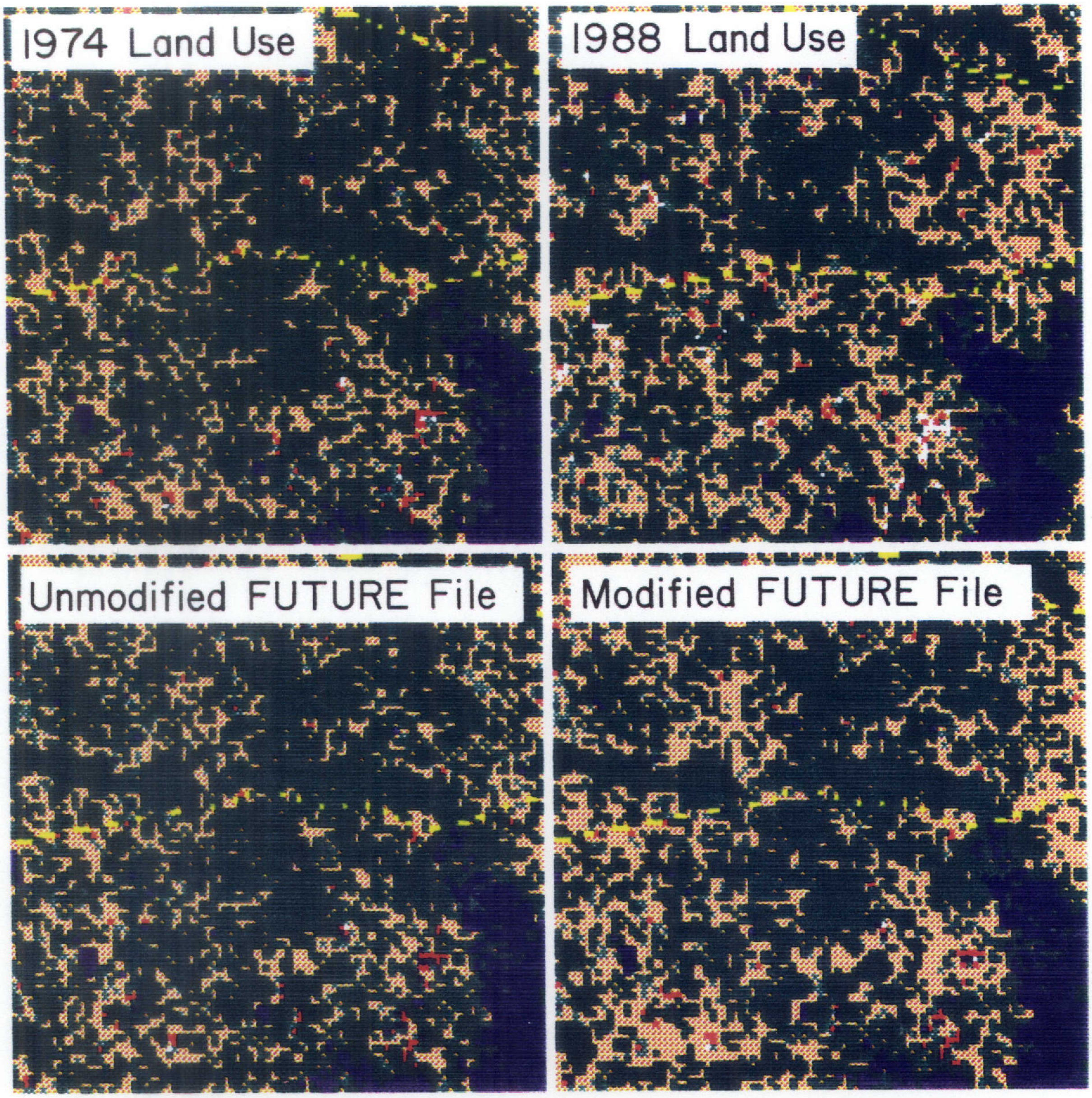


Figure 15: Visual effects of the deforestation modification to the FUTURE model.

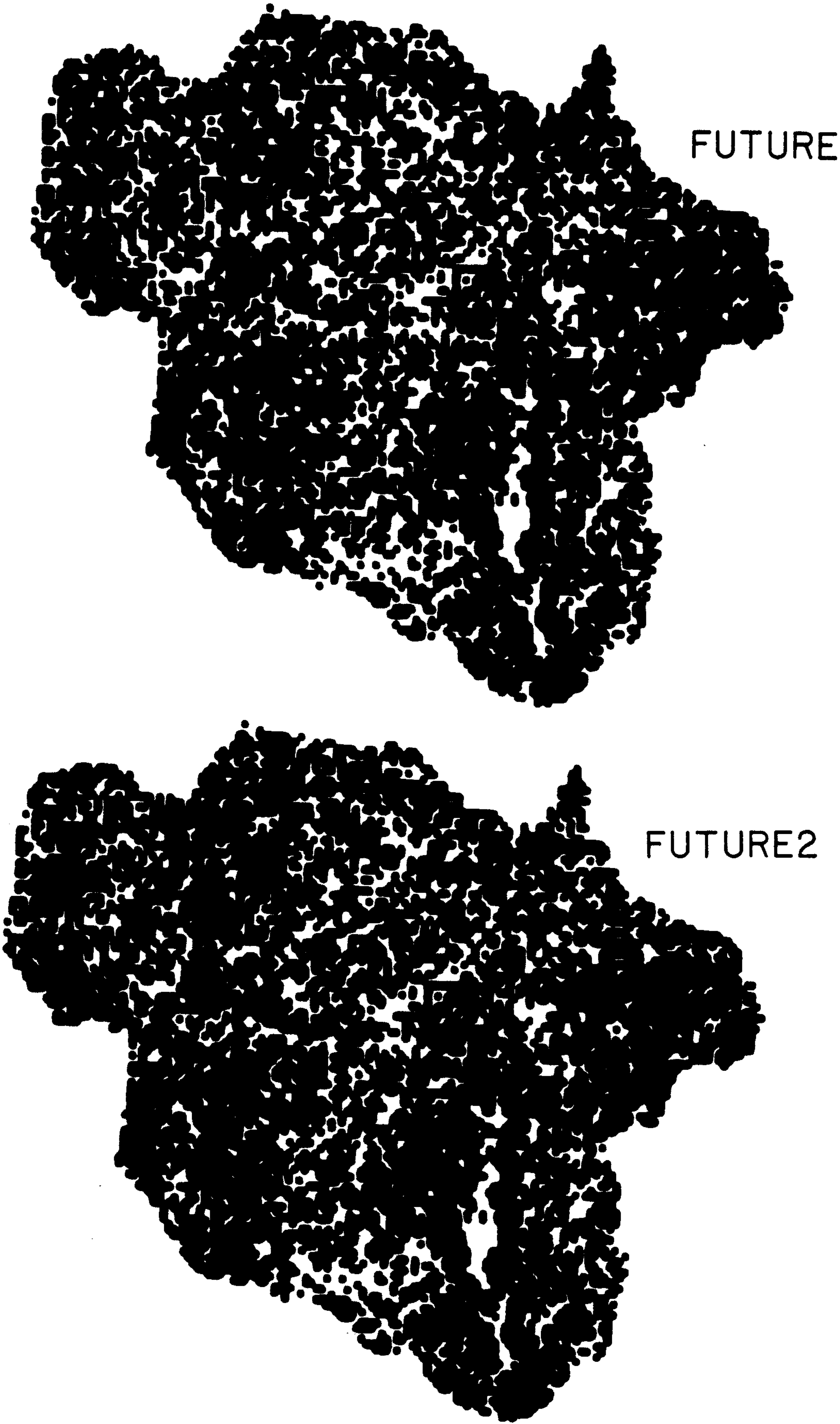


Figure 16: Visual assessment of amount of change between the 1988 satellite image and the FUTURE models.

closely with one run of each of the FUTURE models.

The USLE was run on the 1988 land use file, the FUTURE generated land use file and the FUTURE2 land use file for Lake Palestine in order to compare the results. All other files used as layers into the USLE model were identical (i.e. rainfall, soils, and slope). If the growth predicted by the FUTURE model accurately represents the actual growth that occurred, then the results of the two USLE runs should be similar. The results of these comparisons are summarized in Figure 17. The FUTURE model predicted 89.6% of the 1988 total sediment erosion predicted using the USLE, while the FUTURE2 model predicted 97.4% of the 1988 sediment erosion. For the purpose of estimating nonpoint source sediment erosion, the FUTURE2 derived land use file was obviously a better predictor of the actual growth that occurred in the Palestine watershed over the 14 year period. For this reason, the FUTURE2 model was considered a more realistic predictor of land use than the FUTURE model for the Cedar Creek Reservoir watershed.

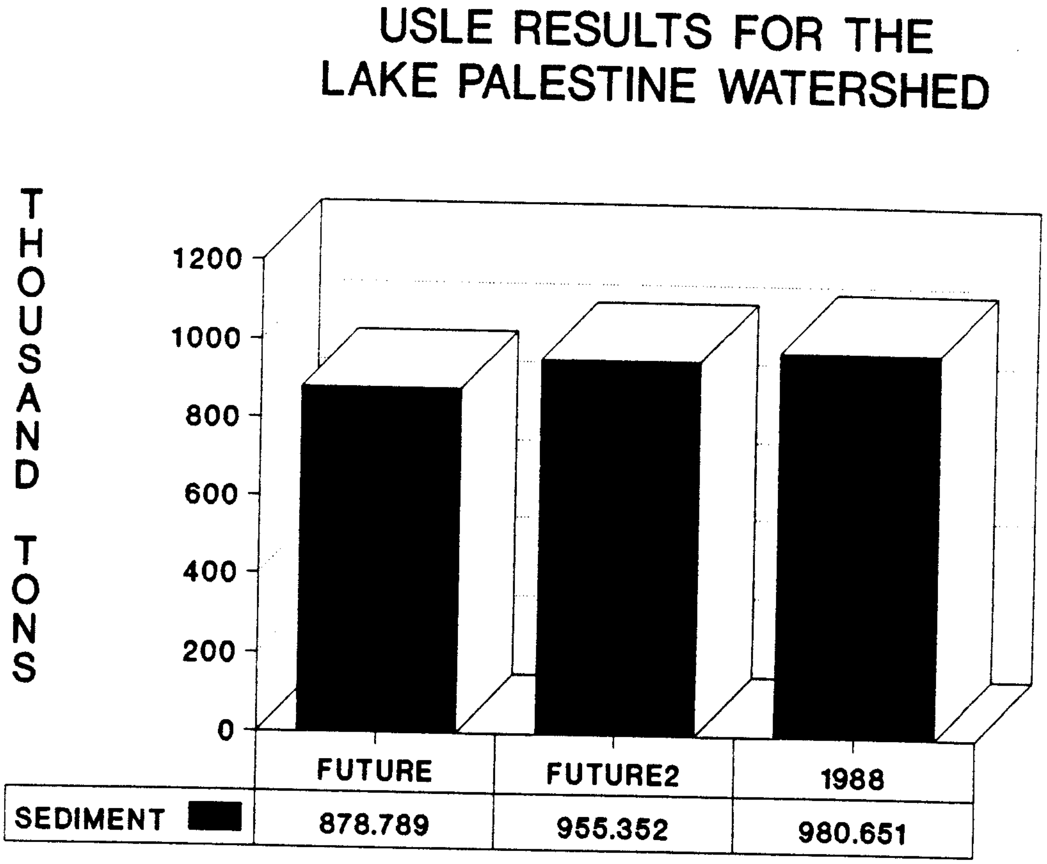


Figure 17: Comparison of USLE results on actual and predicted land use files for the Lake Palestine watershed.

CHAPTER 5

FUTURE PREDICTIONS

Introduction

Nonpoint source pollution estimates derived from analysis of the 1988 satellite imagery are presented in this chapter for comparison with predicted estimates for the year 2010. Also included is a comparison of point versus nonpoint nutrient loadings to the watershed in 1988. A primary goal of this research was to use the land use file generated from the FUTURE model to assist in the prediction of nonpoint source pollution loadings to the Cedar Creek Reservoir watershed in the year 2010. A discussion of the methodologies employed in determining a growth estimation for the year 2010 in the watershed is presented here. Presented next in this chapter are the results from nonpoint source nutrient and sediment loadings to the Cedar Creek Reservoir watershed derived from the FUTURE land use files. Finally, is a comparison of the nonpoint source pollution estimates obtained from the FUTURE model with the estimates obtained from analyses of the 1988 classified satellite imagery of the watershed.

1988 Nonpoint Source Pollution Estimates

Analyses of the 1988 satellite image of the Cedar Creek Reservoir watershed indicate the severity of the nonpoint source pollution problem. Figure 18 shows the areas of erosion potential from 1988. Estimated sediment yield to the reservoir totaled 20,736 tons of sediment for the year 1988. Nitrogen loadings totaled 1,477,297 kilograms and total phosphorus loadings were 88,927 kilograms for the same time period.

Comparison of 1988 Point to Nonpoint Nutrient Totals

Comparison of the 1988 nonpoint nutrient loading estimates with reported point nutrient discharge data from the Texas Water Commission Self-Reporting 1988 Data for the watershed are shown in Figure 19. Data presented in this figure give an indication of the relative severity of the nonpoint source pollution problem in the study area. Nonpoint nitrogen loadings far outweighed the point nitrogen loadings (96% for nonpoint and 4% for point). For phosphorus loadings, the nonpoint loadings accounted for 77 percent of the total while the point loadings accounted for 23 percent of the total. Combined point and nonpoint pollution loadings totaled approximately 1,536,604 kilograms of nitrogen and 115,610 kilograms of phosphorus for the year.

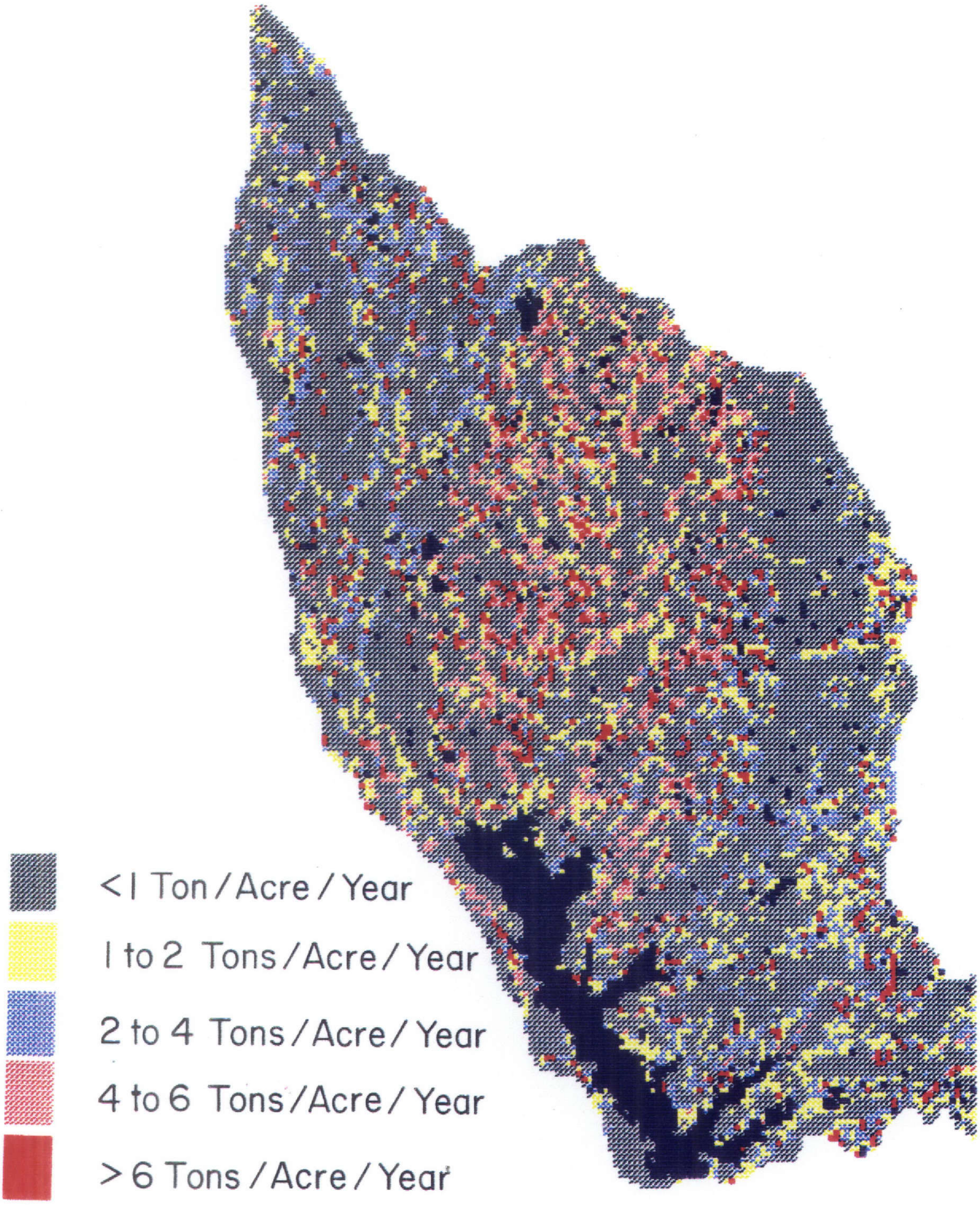


Figure 18: Areas of predicted erosion in 1988 in the Cedar Creek Reservoir watershed.

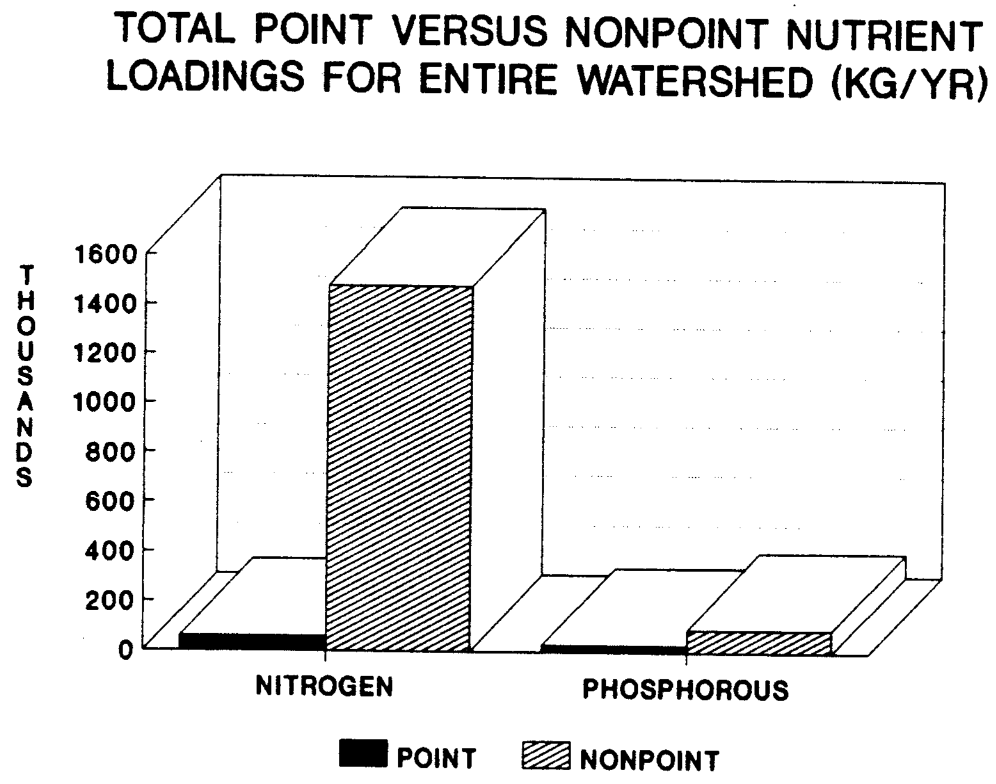


Figure 19: Comparison of point to nonpoint source pollution loadings for the Cedar Creek Reservoir watershed (TWC, 1988).

Growth Estimation

Because of a difference in the initial classification schemes used for the two watersheds, urban and commercial land use categories in the Lake Palestine watershed correspond to urban and residential land use categories in the Cedar Creek Reservoir watershed. Urban and commercial development in the Lake Palestine watershed increased by approximately 49.7 percent over the 14 year period, representing a growth rate of approximately 3.6 percent per year.

These growth estimates were extrapolated to the year 2010 to produce an approximation of the growth predicted to occur in the Cedar Creek Reservoir watershed. By assuming the same rate of growth for the Cedar Creek Reservoir and the Lake Palestine watersheds, it was possible to project the amount of urban growth for the study area into the future. The calculation of this urban growth projection is presented in Appendix B. Using this methodology, it was determined that the study area should experience an increase in urban and residential growth of approximately 78.1 percent during the 22 year period from the year 1988 to the year 2010.

The FUTURE model predicts growth in stages, and can be run any number of times in order to reach the target acreage. FUTURE was run two times in order to estimate the 78.1 percent projected urban growth development (an increase of 12,102 acres) for the Cedar Creek Reservoir watershed. Results obtained from sequential runs of the FUTURE model on the 1988 land use file are summarized in Figure 20. An underestimation of 1365 acres of urban growth was obtained with the second run of the FUTURE model and these estimates were used for the nonpoint source pollution calculations for the year 2010 in this study. The predicted location of the various land use classes in the year 2010 is seen in Figure 21.

Nonpoint Source Pollution Loadings in the Year 2010

Once a file was created by the FUTURE model to represent land use in the Cedar Creek Reservoir watershed in the year 2010, it was used in the future prediction of nonpoint source pollution estimates for the area. In order to predict nonpoint source sediment erosion from the Cedar Creek Reservoir watershed for the year 2010, the USLE was run using the FUTURE2 derived land use file with the other spatial layers (i.e. soils, slope, and rainfall). The results of this procedure are seen in Figure 22. Nonpoint source sediment loadings to the reservoir were calculated by multiplying a sediment delivery ratio by the USLE derived erosion figures. Nonpoint nitrogen and phosphorus loadings to the Cedar Creek Reservoir watershed for the year 2010 were estimated by using the FUTURE2 derived land use figures and Rast and Lee's (1983) nutrient export coefficients.

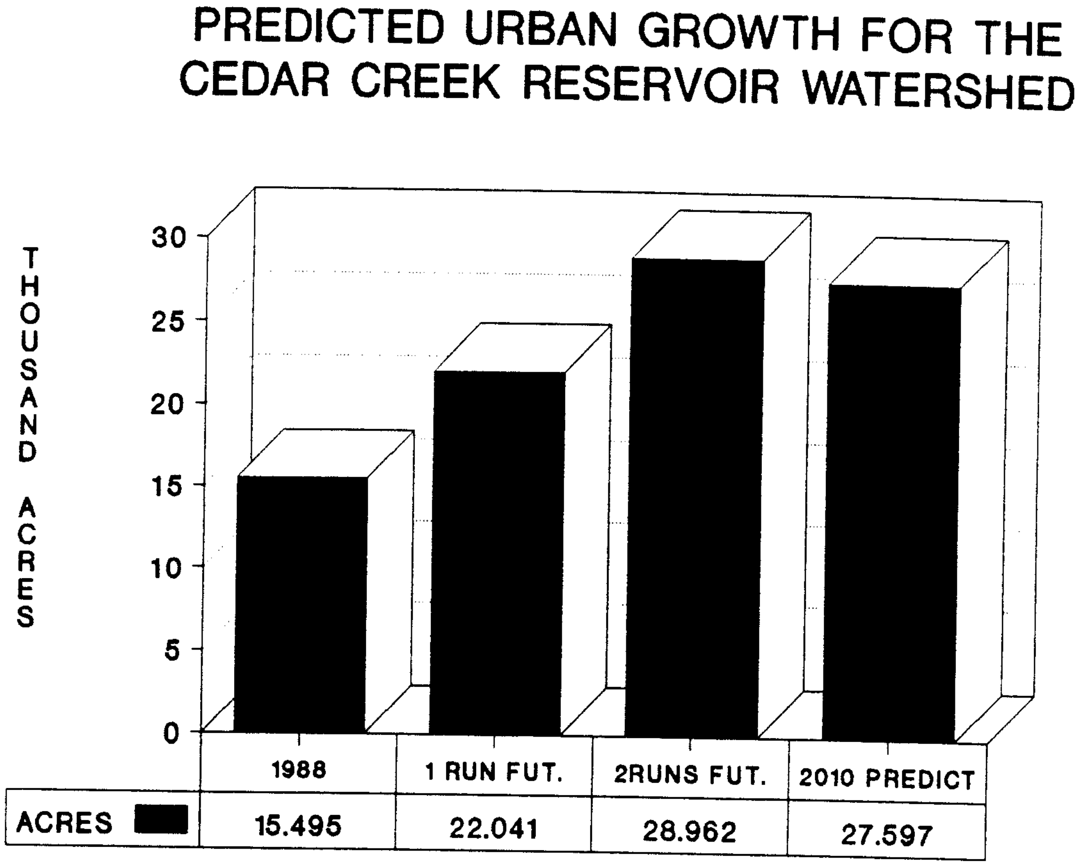


Figure 20: Predicted urban growth for the Cedar Creek Reservoir watershed.

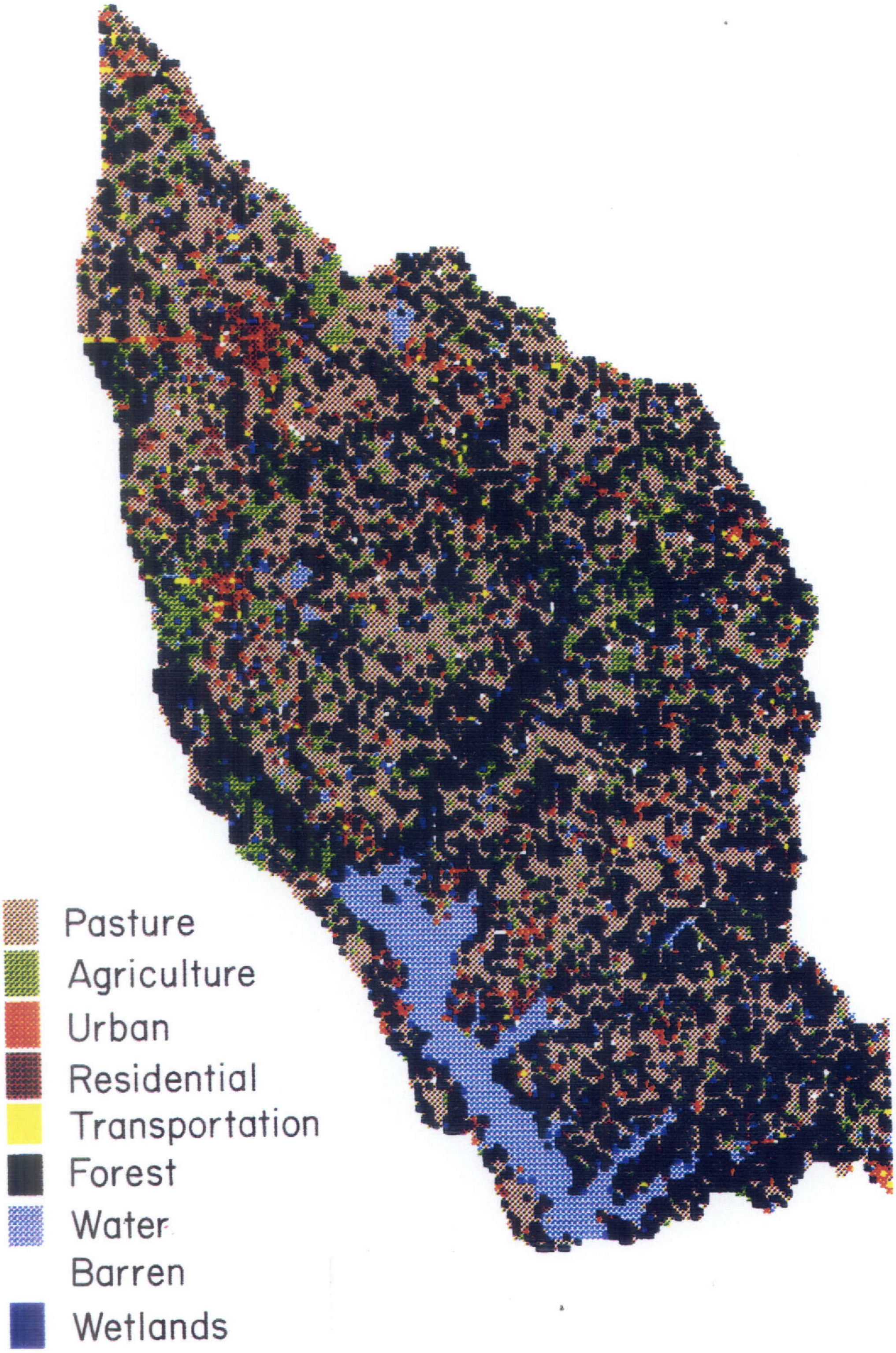


Figure 21: Predicted land use for the Cedar Creek Reservoir watershed in the year 2010.

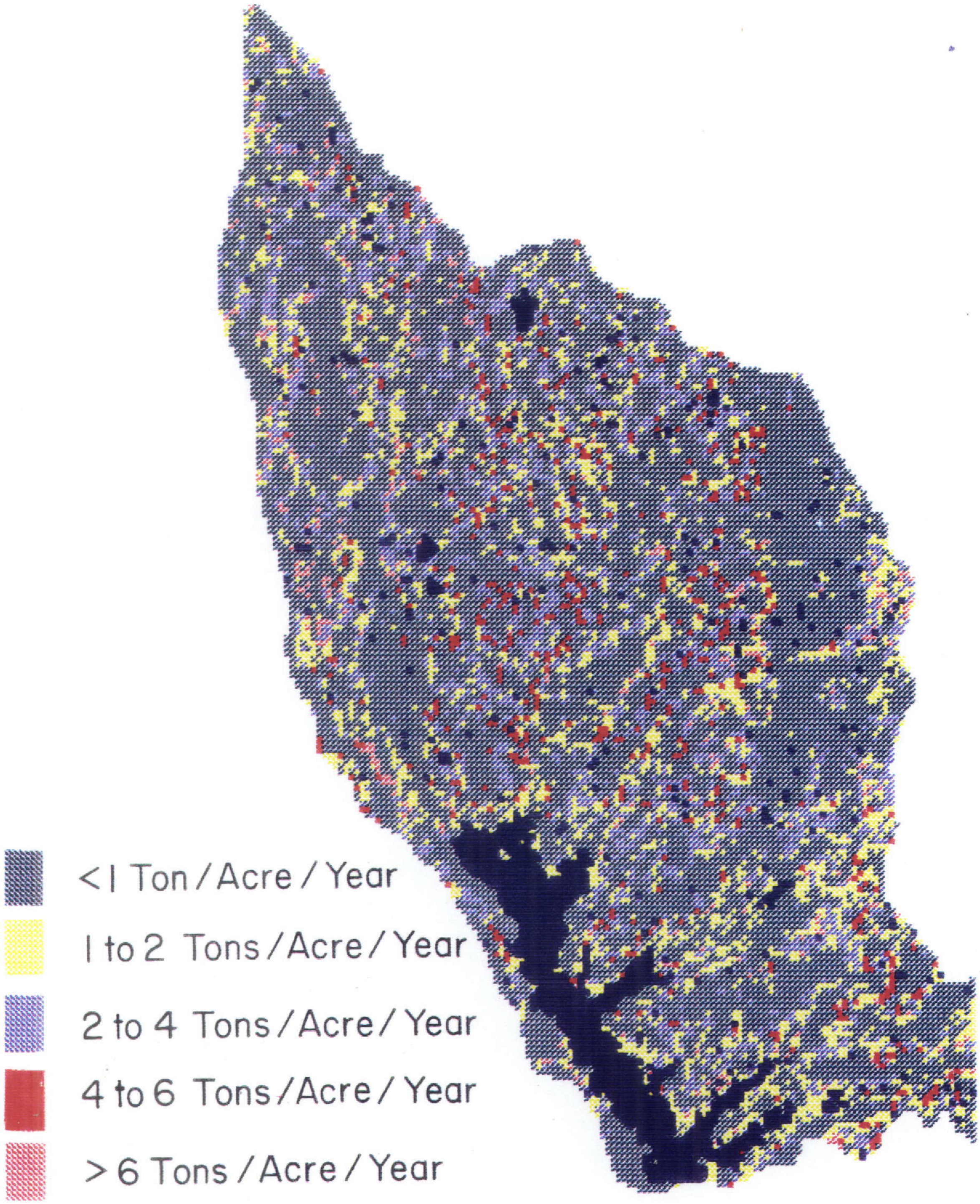


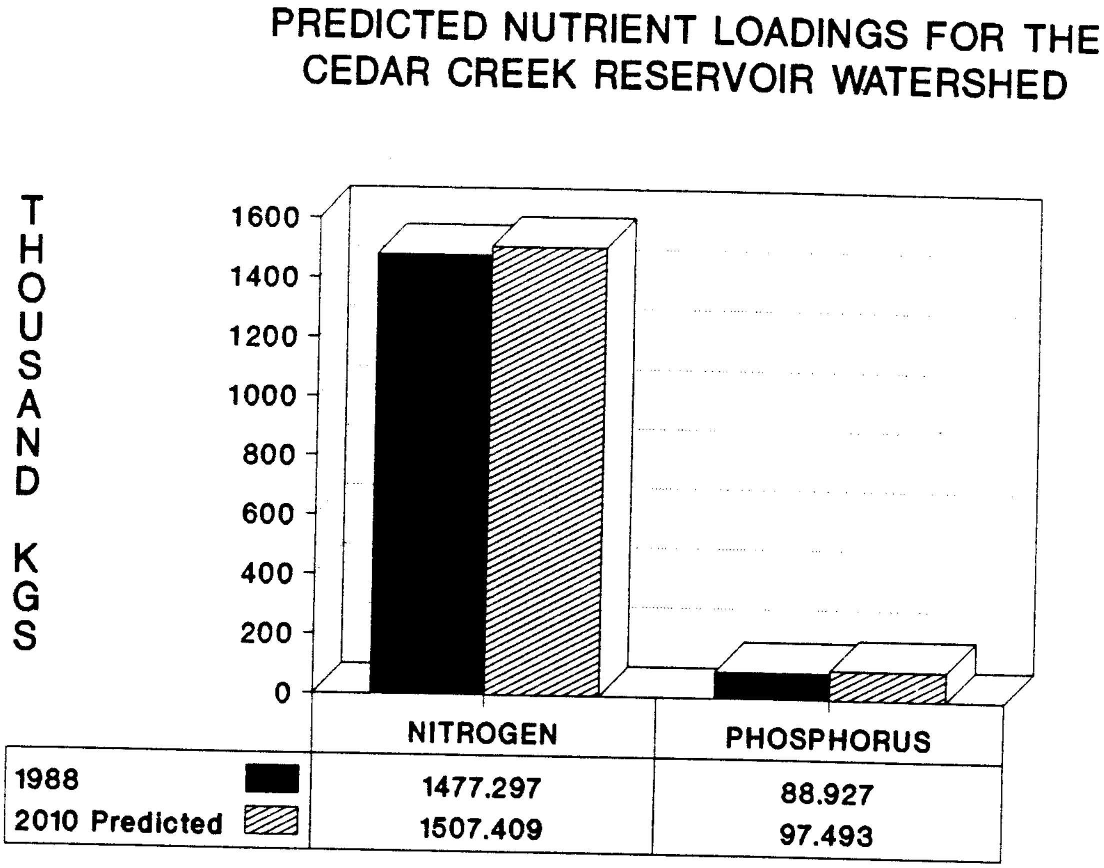
Figure 22: Areas of predicted erosion in the Cedar Creek Reservoir watershed in the year 2010

FUTURE Derived Nonpoint Source Pollution Estimates

The FUTURE2 derived land use figures were used as a basis for the estimation of future nonpoint sediment and nutrient loadings into Cedar Creek Reservoir. Using the USLE and sediment delivery ratios described in this study, it was estimated that approximately 21,444 tons of sediment will be loading into the lake in the year 2010. Nonpoint nitrogen loadings in the year 2010 were estimated to total 1,507,409 kilograms, while nonpoint phosphorus loadings were estimated to be 97,493 kilograms.

Comparison of Nonpoint Source Pollution Estimates

A comparison of the nonpoint source nutrient estimates derived from the 1988 land use file to the predicted estimates for the year 2010 derived from the FUTURE2 land use file is shown in Figure 23. An increase in both nitrogen and phosphorus loadings is predicted from 1988 to 2010. Predicted nonpoint source nitrogen values are predicted to increase approximately 2 percent from 1988 to 2010, while phosphorus values are predicted to increase approximately 8.8 percent during the same time period. Sediment loadings to Cedar Creek Reservoir are also predicted to increase from 1988 to 2010. A 3.3 percent increase in sediment loadings to Cedar Creek Reservoir is predicted from 1988 to 2010 (Figure 24).



	NITROGEN	PHOSPHORUS
1988 ■	1477.297	88.927
2010 Predicted ▨	1507.409	97.493

Figure 23: Comparison of nonpoint source nutrient loading estimates to Cedar Creek Reservoir.

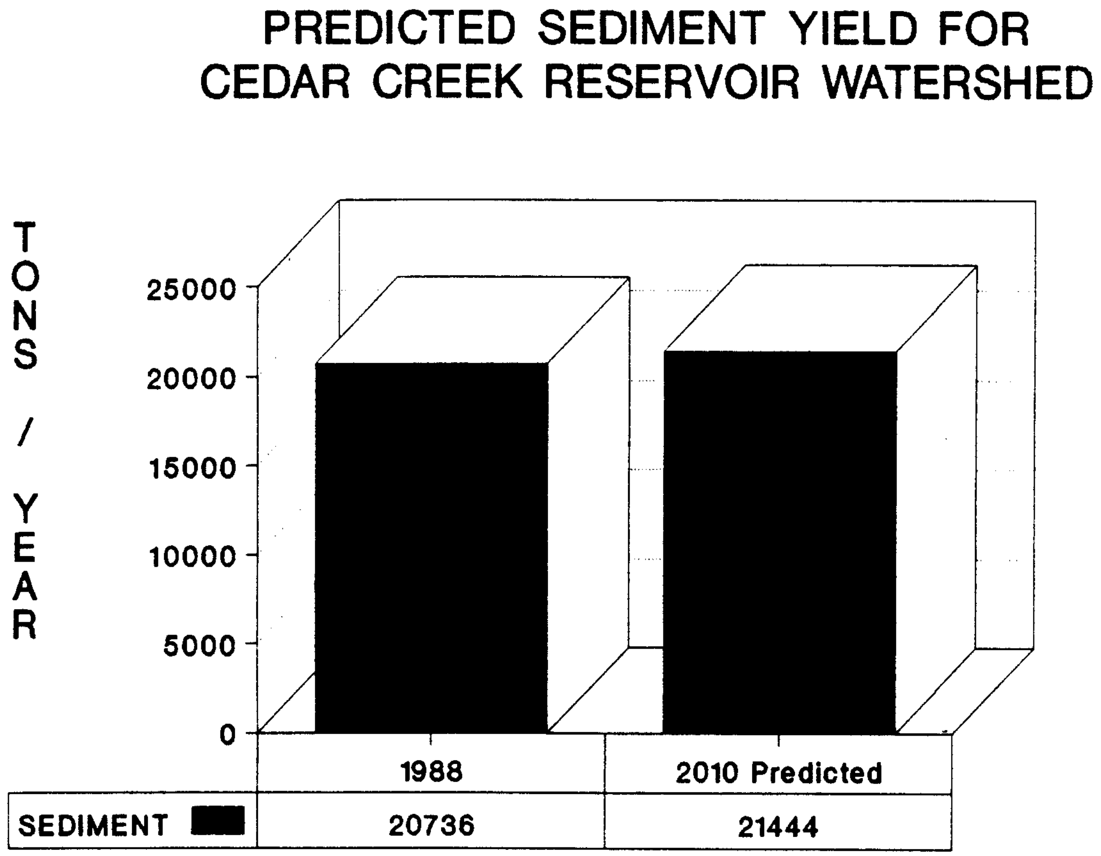


Figure 24: Comparison of nonpoint source sediment loading estimates to Cedar Creek Reservoir.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Summary

The general hypothesis set forth in this study was that land use change can be estimated simply and accurately from a classified satellite image with a microcomputer based cellular automation model. Nelson (1989) developed the computer based FUTURE model for this study to spatially estimate urban growth. It was shown in this study that a land use file obtained from a modified version of the FUTURE model can be used as a realistic representation of future urban growth. Modifications to the FUTURE program were necessary to account for the deforestation that was occurring in the study area. This modified program was referred to as FUTURE2. Confirmation of the hypothesis was made by comparing the new growth predicted by the FUTURE2 model, both quantitatively and visually, with actual growth revealed by temporal satellite coverage of the same area.

Accuracy assessment of the FUTURE2 model considered not only the amount of urban/residential growth that was generated, but also where this growth actually occurred. The degree to which the FUTURE2 model accurately predicted the amount of urban/residential growth within the watershed was determined by comparing land use results obtained from the model with actual land use values obtained from satellite imagery. Visual comparison of the original classified land use file with the FUTURE2 generated land use file allowed for subjective verification of where this growth was actually occurring. An understanding of the local growth patterns and trends is important in designing a model that accurately predicts growth. In the study area, development generally occurred along transportation routes and around established urban/residential centers.

A practical application for the FUTURE2 model was the prediction of future areas of nonpoint source pollution potential in the Cedar Creek Reservoir watershed. By incorporating the FUTURE2 generated land use file into a GIS with the digital layers of rainfall intensity, soil erodabilty, and slope in the USLE, it was shown that the erosional potential for an area can be predicted into the future. Similarly future nutrient loadings for the Cedar Creek Reservoir watershed were estimated by multiplying export coefficients by the areas of the appropriate land use values predicted by the FUTURE2 model.

Areas of greatest nonpoint source pollution potential, predicted with the help of the FUTURE2 model, can be targeted by watershed managers for special consideration. Control measures such as wet detention basins, designed to trap nutrients loading into the surface water during rainfall events, and improved cropping measures to slow sedimentation, can be targeted to predicted trouble spots to obtain optimum benefits.

Special Considerations

Several factors must be considered when examining the overall accuracy of the FUTURE generated land use file. The accuracy of the original land use classification is one important consideration. The FUTURE model makes assumptions based on the original land use classification. The accuracy of the output FUTURE file can be no more accurate than the input land use file. Any errors in the original classification are amplified as subsequent iterations of the FUTURE model create additional land use files. Appropriate ground truthing methods should be employed in the classification phase of the satellite data to ensure that the final image classification is as accurate as possible.

Before the actual classified land use file is produced the initial land use classification scheme must be considered. Decision rules established within the FUTURE model can be altered to more accurately reflect the changes that are occurring in a particular area. A knowledge of the interaction of the various land use categories is important when establishing the rules for the FUTURE program. Class values and the weights of the various land use categories can and probably should be modified within the FUTURE program in different areas or under different circumstances.

Spatial resolution of the sensor is another important consideration to the overall accuracy of the model. The 80 x 80 meter spatial resolution of Landsat MSS satellite data is too coarse to distinguish all but the largest transportation routes. Isolated human settlements may be too small for delineation with coarse resolution sensors. Accurate identification of these areas is particularly important to the FUTURE model because urban development often occurs along transportation routes and around pre-existing human settlements. The FUTURE model tends, therefore to encourage urban development along transportation routes and around existing developments. Misclassification of the satellite data limits the ability of the FUTURE model to create an accurate land use file.

A spatial resolution that is too fine may also create potential problems when using the FUTURE model. An increase in spatial resolution can allow for a detailed land use classification, however, often times an increase in detail does not bring with it a corresponding increase in usable information. Determination of certain diverse signature land use classes, such as residential which is composed of grass, trees, concrete and roofing materials, sometimes becomes difficult as a result of an increase in spatial resolution. This confusion may result in a misclassification, and a subsequent reduction in the usefulness of the FUTURE model.

The version of the FUTURE model used in this study utilized a 3 x 3 pixel matrix as an examination area for the sampling window. The size of this sampling window can be enlarged within the FUTURE program to examine areas further away from the center cell. New and more complex rules can then be established to model the interaction of the cells in this matrix. A modification of this type assumes that the operator has a good understanding of the land use dynamics of the study area.

The FUTURE Model and Existing Models

Markov chain analysis (Robinson, 1978) and Bylund's (1960) colonization model, described earlier, are two theoretical models used to predict settlement patterns. Some of the fundamental concepts introduced in these models and in Conway's "Game of Life" (Gardner, 1970) were adapted and modified to operate in a computer environment. A numerical land use file and a knowledge of the land use dynamics of the study area are required before this program can be utilized in an optimum way. Results presented in this study suggest that the FUTURE program can be used to simply and accurately estimate land use change.

Other Applications for the FUTURE Program

The versions of the FUTURE model used in this study predicted urban and residential growth around transportation routes and existing development and also predicted general deforestation. Land use patterns in another area may reflect completely different trends. Some areas may be experiencing urban decline along with an increase in barren land (desert regions, for instance). With a thorough understanding of the land use dynamics of a particular study area, the FUTURE model can be modified to model these conditions by establishing decision rules to reflect these circumstances.

The FUTURE program may be a useful tool for any application where land use prediction is the objective. This study showed the utility of using the FUTURE2 derived land use files for the prediction of potential nonpoint source pollution areas. Other possible applications for the program include prediction of loss of endangered species habitat, the loss of wetlands by urban encroachment, as well as numerous regional and urban planning applications.

The input files for the FUTURE program do not necessarily have to be land use files. Any numerically expressed file that has a predictable development process, such as successive vegetation, can theoretically be modelled using the FUTURE program. One possible application for this model is prediction of population trends. With an understanding of future population trends, it becomes possible to predict many related occurrences such as power and water usage. Other examples of potential applications for the FUTURE program include prediction of marketing trends and prediction of traffic flow in an urban area.

Conclusions

In order to create a realistic representation of the real world, a land use model must attempt to predict more than one land use category. Because of the interrelated nature of land use classes, a thorough grasp of the land use dynamics of the study area is required before rules predicting the outcome of these interactions can be established. Rules established for a given study area at one time need to be evaluated and modified to account for the dynamic nature of land use.

Ultimate validation of any future prediction model can only be accomplished by examining the study area in the future to see if the predictions made were accurate. If the FUTURE model is an accurate predictor of growth, the Cedar Creek Reservoir watershed land use in the year 2010 should appear very similar to the land use file created in this study. This is the most rigorous test of any prediction model.

As more of the earth's surface is developed, the challenge to plan and manage our natural resources becomes increasingly important. The ability to predict land use change, simply and realistically, over a large area makes the FUTURE program a valuable planning tool. By determining areas of future urban growth potential through the use of a prediction model, planners are able to target potential trouble spots which can be monitored for special consideration.

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APPENDIX A

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                                   SAS

                          CORRELATION ANALYSIS

                 3 'VAR' Variables:  PCT1    PCT2     PCT3

PCT1 = PERCENT CHANGE BETWEEN 1974 & 1988 SATELLITE LAND USE

PCT2 = PERCENT CHANGE BETWEEN 1974 SATELLITE & UNMODIFIED FUTURE

PCT3 = PERCENT CHANGE BETWEEN 1974 SATELLITE & MODIFIED FUTURE

                            Simple Statistics

     Variable          N        Mean       Std Dev        Median

     PCT1              8    87.98875     207.56981      12.55000
     PCT2              8     1.18875      25.74370      -0.04500
     PCT3              8     2.29000      27.71526             0

                Simple Statistics

     Variable       Minimum     Maximum

     PCT1          -9.08000   599.35000
     PCT2         -39.77000    55.13000
     PCT3         -39.77000    55.13000
```

```
                          CORRELATION ANALYSIS

   Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 8

                         PCT1            PCT2            PCT3

      PCT1            1.00000        -0.17078        -0.04880
                       0.0             0.6860          0.9087

      PCT2           -0.17078         1.00000         0.70000
                       0.6860          0.0             0.0532

      PCT3           -0.04880         0.70000         1.00000
                       0.9087          0.0532          0.0


                          CORRELATION ANALYSIS

Kendall Tau b Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 8

                         PCT1            PCT2            PCT3

      PCT1            1.00000        -0.11339        -0.03780
                       0.0             0.7024          0.8987

      PCT2           -0.11339         1.00000         0.60000
                       0.7024          0.0             0.0495

      PCT3           -0.03780         0.60000         1.00000
                       0.8987          0.0495          0.0
```

```
                         CORRELATION ANALYSIS

         4 'VAR' Variables:  PCT88     PCTUM     PCTMM     PCT74

                           Simple Statistics

Variable              N          Mean        Std Dev          Median

PCT88                 8      12.50000       19.01242         3.28500
PCTUM                 8      12.50125       20.38021         2.94000
PCTMM                 8      12.50125       19.67505         2.94000
PCT74                 8      12.49875       20.43248         2.69000

           Simple Statistics

Variable        Minimum        Maximum

PCT88           0.11000       49.46000
```

```
                         CORRELATION ANALYSIS

                 Simple Statistics

       Variable          Minimum         Maximum

       PCTUM             0.09000         54.35000
       PCTMM             0.09000         46.26000
       PCT74             0.10000         54.40000

   Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 8

                     PCT88          PCTUM          PCTMM          PCT74

   PCT88            1.00000        0.92857        0.92857        0.97619
                      0.0           0.0009         0.0009         0.0001

   PCTUM            0.92857        1.00000        1.00000        0.97619
                     0.0009          0.0            0.0           0.0001

   PCTMM            0.92857        1.00000        1.00000        0.97619
                     0.0009          0.0            0.0           0.0001

   PCT74            0.97619        0.97619        0.97619        1.00000
                     0.0001         0.0001         0.0001          0.0
```

```
                          CORRELATION ANALYSIS

                 Simple Statistics

      Variable            Minimum          Maximum

      PCTUM               0.09000         54.35000
      PCTMM               0.09000         46.26000
      PCT74               0.10000         54.40000

                          CORRELATION ANALYSIS

Kendall Tau b Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 8

                  PCT88            PCTUM            PCTMM            PCT74

PCT88            1.00000          0.85714          0.85714          0.92857
                  0.0              0.0030           0.0030           0.0013

PCTUM            0.85714          1.00000          1.00000          0.92857
                  0.0030           0.0              0.0005           0.0013

PCTMM            0.85714          1.00000          1.00000          0.92857
                  0.0030           0.0005           0.0              0.0013

PCT74            0.92857          0.92857          0.92857          1.00000
                  0.0013           0.0013           0.0013           0.0
```

APPENDIX B

Calculation of Urban Growth Potential for the Study Area:

Percent change in urban and commercial land in Lake Palestine watershed from 1974 - 1988:

	1974	1988
com	547 ac.	598 ac.
urb	+4821 ac.	+7432 ac.
	5364 ac.	8030 ac.

8030 - 5364 / 5364 = .497 x 100 = 49.7%

Percent change per year:

1988 - 1974 = 14 years

49.7% / 14 years = 3.55%

Projection of growth to 2010:

2010 - 1988 = 22 years

22 yrs X 3.55% = 78.10%

15,495 ac (urb and res Cedar Creek watershed 1988)

X .7810% = 12,102 ac + 15,495 ac = 27,597 ac.

Example Sediment Delivery Calculation:

Gross Sediment Yield = 34,110 tons/year

Total Acreage = 39,065

Acreage to Kilometer Conversion:

39,065 ac. X 0.4047 ha/ac = 15,810 ha

15,810 ha X 0.01 km/ha = 158.1 km

Sediment Delivery Ratio Calculation:

SD = 0.12 (from curve based on 158.1 km)

Annual Sediment Yield Calculation:

34,110 tons/year X 0.12 = 4093 tons/year

Sediment Yield Per Acre Calculation (lbs/year):

4093 tons/acre / 39,065 acres X 2000 lbs / 1 ton

= 210 lbs/acre/year