Assessing vegetation patterns and hydrologic characteristics of a semi-arid environment using a geographic information system and terrain based models
by Janelle Kay Jersey

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University
© Copyright by Janelle Kay Jersey (1993)

Abstract:
Geographic Information Systems (GISs) and simulation models are analytical tools available to researchers and natural resources managers; however, these technologies have limitations as welI as strengths when used in decision making. In this project:, a GIS and a terrain-based model were used to generate spatially varying attributes, affected by topography, for a watershed in southwest Montana. These attributes were compared to vegetation groups in the same catchment, to determine if they could be used to predict spatial variation in vegetation patterns.

A digital elevation model (DEM), created by digitizing contour lines, was used as the primary input to the Topographic Analysis Programs for Environmental Sciences (TAPES) model. This model generated two terrain attributes, a solar radiation index and a soil wetness index, which were used as indicators of soil water variation across the watershed.

A computer-based vegetation map for the area was created from six high resolution images produced by the Airborne Data Acquisition and Registration System. Red and near-infrared wavebands were ratioed, using the Normalized Difference Vegetation Index (NDVI), producing a new data layer. Using an unsupervised, sequential clustering method, a map with five vegetation groups was generated from the new NDVI data,band. The vegetation map was then registered to the data layers containing the solar radiation and soil wetness indices.

Comparisons between the computer-generated terrain indices and the vegetation groups were completed using correspondence analysis; Results showed that the solar radiation index values were closely associated with vegetation groups. The soil wetness index values had a more ambiguous relationship to vegetation groups.

The DEM used to create the terrain indices was also used as input to a distributed parameter hydrology model which is included in the TAPES programs. A single storm event was simulated using actual rainfall data. Large discrepancies between the simulated runoff and recorded runoff for that event were found when the two were compared.

The GIS and modeling technologies used in this project provide a method of data analysis that is both repeatable and transferable. Researchers, who are familiar with these tools, will find them useful in terrain analysis projects.

ASSESSING VEGETATION PATTERNS AND HYDROLOGIC CHARACTERISTICS OF A SEMI-ARID ENVIRONMENT USING A GEOGRAPHIC INFORMATION SYSTEM AND TERRAIN BASED MODELS

by

Janelle Kay Jersey

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Soils

MONTANA STATE UNIVERSITY
Bozeman, Montana

November 1993

© COPYRIGHT

by

Janelle Kay Jersey

1993

All Rights Reserved

N378
J4878

APPROVAL

of a thesis submitted by

Janelle Kay Jersey

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

11/24/93
Date

Co-Chairperson, Graduate Committee

11/24/93
Date

Co-Chairperson, Graduate Committee

Approved for the Major Department

12/6/93
Date

Head, Major Department

Approved for the College of Graduate Studies

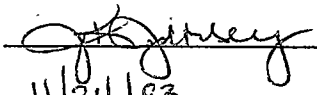
12/13/93
Date

Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature 

Date 11/24/93

ACKNOWLEDGMENTS

Several people deserve credit for the progress and completion of this thesis. Dr. Jeff Jacobsen and Dr. John Wilson, my committee co-chairpersons, contributed both individually and jointly to this project. Dr. Jacobsen provided direction and timely words of encouragement throughout the project; Dr. Wilson provided conceptual understanding of terrain analysis as well as access to the TAPES model. Together, they provided the funds necessary to complete the remote sensing portion of this project. Dr. Gerald Nielsen was responsible for my initial interest in both GIS and terrain analysis; he was also responsible for obtaining funding to support my research. Dr. Clayton Marlow, who had previously conducted studies in the Cottonwood Creek area, freely made his data available for my use. Also, Mr. Robert Snyder deserves recognition for his technical support of my programming endeavors. I extend my sincere thanks to these individuals for providing me with both the opportunity and the environment to pursue my study of terrain analysis.

TABLE OF CONTENTS

	Page
APPROVAL	ii
STATEMENT OF PERMISSION TO USE	iii
ACKNOWLEDGMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
ABSTRACT	xi
CHAPTER:	
1. INTRODUCTION	1
2. VEGETATION PATTERN PREDICTION USING A TERRAIN ANALYSIS MODEL	5
Introduction	5
Materials and Methods	10
Study Area	10
Creation of Digital Elevation Model	14
Generation of Terrain Attributes	16
PREPROC	17
ANUDEM	18
TAPES-G	20
SRAD	22
WET	23
Remote Sensing	25
Data Collection System	26
Image Processing	28
Geographic Information System	31
Data Analysis	31

TABLE OF CONTENTS--Continued

CHAPTER: Page

2. cont.

Results and Discussion..... 32
Digital Elevation Data..... 32
Terrain Attributes..... 34
Net Radiation Index..... 34
Soil Wetness Index..... 35
Vegetation Map..... 37
Analysis..... 40
Correspondence between the Net Radiation Index and Vegetation..... 41
Correspondence between the Soil Wetness Index and Vegetation..... 47
Conclusions..... 50

3. PREDICTING CATCHMENT RUNOFF USING A TERRAIN-BASED HYDROLOGY MODEL..... 56

Introduction..... 56
Materials and Methods..... 59
Hydrology Model..... 59
Additional Programming Requirements..... 61
Field Measurements..... 62
Results and Discussion..... 63
Conclusions..... 65

4. SUMMARY..... 67

REFERENCES CITED..... 69

APPENDICES..... 77

Appendix A--Vegetation Categories..... 78

Appendix B--Flowchart and Inputs to Programs..... 82

Appendix C--Conversion Programs..... 109

LIST OF TABLES

Table		Page
1.	Generalized characteristics of soil complexes found in the Cottonwood Creek study area, as described in 'Soil Survey of Madison County Area, Montana'.....	13
2.	Primary topographic attributes.....	21
3.	Characteristics of Thematic mapper compared to Airborne Data Acquisition and Registration (ADAR) System 5000.....	27
4.	Net radiation categories and percent of catchment included in each category.....	35
5.	Soil wetness index categories and percent of catchment included in each category.....	37
6.	Vegetation categories and percent of catchment included in each category.....	40
7.	Matrix of data showing the interaction between net radiation groups and vegetation categories.....	41
8.	Relative frequencies of vegetation categories within net radiation groups (i.e. row profiles) and the row masses.....	42
9.	Relative frequencies of net radiation groups within vegetation categories (i.e. column profiles) and the column masses.....	44
10.	Matrix of data showing the interaction between wetness index groups and vegetation categories.....	47
11.	Plant species found in each vegetation category, and locations where sampling was done.....	79

LIST OF FIGURES

Figure		Page
1.	Location of Cottonwood Creek study area. The inset contour map (30 m interval) shows the catchment boundary and stream network in bold.....	11
2.	Three distinct technologies, GIS, remote sensing, and computer modeling, are integrated in this project.....	16
3.	Program flowchart for deriving terrain indices.....	17
4.	Visual representation of the elevation data layer created by digitizing contour lines.....	33
5.	Visual representation of the net radiation data created by the TAPES model.....	36
6.	Visual representation of the wetness index data generated by the TAPES model.....	38
7.	Visual representation of the vegetation classes created by classifying digital images.....	39
8.	Correspondence analysis of the net radiation group profiles given in Table 8.....	43
9.	Correspondence analysis of the vegetation category profiles given in Table 9.....	45
10.	Correspondence analysis of the data in Table 7. This is the joint display of Figures 8 and 9.....	46

LIST OF FIGURES--Continued

Figure		Page
11.	Correspondence analysis of wetness index profiles of the data matrix in Table 10.....	48
12.	Correspondence analysis of vegetation profiles of the data matrix in Table 10.....	48
13.	Correspondence analysis of the data in Table 10. This is a joint display of Figures 11 and 12.....	49
14.	Observed discharge vs. predicted discharge....	64
15.	Comprehensive data flow for: (A) generating terrain attributes and (B) simulating hydrologic characteristics.....	83
16	Documentation for digitizing data in ARC/INFO and converting to TAPES compatible format.....	84
17.	PREPROC prompts and responses for grid-based programs.....	95
18.	ANUDEM prompts and responses.....	96
19.	TAPES-G prompts and responses.....	99
20.	Parameter file for SRAD.....	100
21.	SRAD prompts and responses.....	101
22.	WET prompts and responses.....	102
23.	PREPROC prompts and responses for contour-based programs.....	103
24.	TAPES-C prompts and responses.....	104
25.	THALCH prompts and responses.....	105
26.	THALES prompts and responses.....	106
27.	Parameter file for THALES.....	107
28.	Lookup table for THALES.....	107
29.	Precipitation data file for THALES.....	108

LIST OF FIGURES--Continued

Figure		Page
30.	Evaporation data file for THALES.....	108
31.	Radiation Data file for THALES.....	109
32.	AML which identifies features as contour, stream, high or saddle point on ARC/INFO data base.....	110
33.	Interactive AML allowing user to edit direction of vectors on ARC/INFO data base....	111
34.	AML which unloads ARC/INFO information to two ASCII files.....	128
35.	FORTRAN program merging two ASCII files into one file useable by the hydrology model.....	130

ABSTRACT

Geographic Information Systems (GISs) and simulation models are analytical tools available to researchers and natural resources managers; however, these technologies have limitations as well as strengths when used in decision making. In this project, a GIS and a terrain-based model were used to generate spatially varying attributes, affected by topography, for a watershed in southwest Montana. These attributes were compared to vegetation groups in the same catchment, to determine if they could be used to predict spatial variation in vegetation patterns.

A digital elevation model (DEM), created by digitizing contour lines, was used as the primary input to the Topographic Analysis Programs for Environmental Sciences (TAPES) model. This model generated two terrain attributes, a solar radiation index and a soil wetness index, which were used as indicators of soil water variation across the watershed.

A computer-based vegetation map for the area was created from six high resolution images produced by the Airborne Data Acquisition and Registration System. Red and near-infrared wavebands were ratioed, using the Normalized Difference Vegetation Index (NDVI), producing a new data layer. Using an unsupervised, sequential clustering method, a map with five vegetation groups was generated from the new NDVI data band. The vegetation map was then registered to the data layers containing the solar radiation and soil wetness indices.

Comparisons between the computer-generated terrain indices and the vegetation groups were completed using correspondence analysis. Results showed that the solar radiation index values were closely associated with vegetation groups. The soil wetness index values had a more ambiguous relationship to vegetation groups.

The DEM used to create the terrain indices was also used as input to a distributed parameter hydrology model which is included in the TAPES programs. A single storm event was simulated using actual rainfall data. Large discrepancies between the simulated runoff and recorded runoff for that event were found when the two were compared.

The GIS and modeling technologies used in this project provide a method of data analysis that is both repeatable and transferable. Researchers, who are familiar with these tools, will find them useful in terrain analysis projects.

CHAPTER 1

INTRODUCTION

The environment is a complex system of physical, chemical, biological, cultural and socio-economic resources; consequently, managers and researchers dealing with environmental issues must be able to understand information that spans several disciplines, ranging from basic social issues and values to highly technical research results (Coulsen et al., 1987; Devi et al., 1993; Jorgensen and Johnsen, 1981). Individually, a manager or researcher might have expertise in one or a few fields, but must rely on the expertise of others for a more complete understanding of other disciplines (Moffatt, 1990). Tools such as simulation models and Geographic Information Systems (GISs) provide mechanisms for acquiring and integrating knowledge of others into a useable format. Separately models and GISs represent technologies of significant analytical and management capabilities, however when integrated their effectiveness is compounded providing more powerful capabilities than when used alone (Heatwole et al., 1987; Montas and Madramootoo, 1992).

A GIS is a computerized mapping system for capture, storage, retrieval and analysis of spatial and descriptive data. GIS technology provides for the integration of data collected from different sources and in different formats, allowing two or more maps with the same spatial reference to be overlaid. This capability along with GIS analytical

capabilities, which include the evaluation of boolean and simple mathematical relationships between themes of data, is useful in assessing consequences of land management practices (Coulsen et al., 1987). The accuracy of the results of analysis using a GIS depends on the reliability of the spatial databases (ie. dependability of data sources and methods of data extraction) and the precision with which data layers can be registered together (Lo and Shipman, 1990).

While GISs are excellent tools for visualization of spatial data, they were not developed to support complex modeling of ecological and physical systems (Folse et al., 1990). They can, however, be used as sources of spatial data for detailed simulation models. Models which focus on spatio-temporal change of environmental systems can accept GIS data as input, manipulate it as needed, and write the resultant data back to the GIS to take advantage of that subsystem's data management capabilities (Heatwole et al., 1987; Folse et al., 1990). Unfortunately, integrating a GIS with a simulation model can be extremely difficult. The lack of standards defining data formats, data storage, and interface structures presents a "formidable challenge" to the development of GIS/model interfaces (Heatwole et al., 1987; Power, 1993).

A model which deals with environmental relationships is a representation of the knowledge of one or more researchers regarding certain processes which occur in a natural system. The portability of computer software makes this knowledge dynamic; by using a model, other researchers or resource managers can acquire the use of this knowledge to integrate into their own projects. However a model is only as good as the assumptions, relationships, and data embedded in it and a considerable level of technical

expertise may be needed to both use a model and to interpret its results (Morgan and McMichael, 1981).

Simple, easy to use models tend to be overused and the inaccuracies and limitations in the results they produce tend to be played down or ignored (Morgan and McMichael, 1981). On the other hand, detailed process-based models, which are better suited to describing causative relationships in natural systems, are not used as widely as they could be because they require that the user have expertise with computers, with simulation concepts, and with the specific model (Heatwole et al., 1987). Providing good estimates of parameter values is often a problem for an inexperienced user, and in the case of complex, dynamic models, small variations in parameters or initial conditions can send a model into a "chaotic trajectory" which may be difficult to control (Moffatt, 1990; Heatwole et al., 1987). Thus, while models may have the potential of contributing very useful information to a project, the process of extracting or interpreting that information is not necessarily easy. Unfortunately, this frequently results in more accurate, advanced models being unavailable for use outside the research laboratory where they were developed (Morgan and McMichael, 1981).

In this thesis, two projects involving the integration of a GIS and detailed, process-based models are described. In the first project (Chapter 2), elevation data for a small semi-arid catchment in southwestern Montana were obtained by digitizing contour lines using a GIS and were used as input to a model which generates spatially variable terrain based attributes (Moore et al., 1993a). Two of the attributes, a net radiation index and a soil wetness index, were loaded back to the GIS for comparison to a

vegetation map created by classifying digital images. Comparisons between vegetation patterns and spatial variation of the two indices were done using correspondence analysis.

In the second project (Chapter 3), elevation data for the same catchment were used as input to THALES, a distributed parameter hydrology model (Grayson et al., 1992a). Discharge for a single storm in July, 1990 was simulated using this model and the results were plotted as a hydrograph and compared to observed discharge for the same event.

CHAPTER 2

VEGETATION PATTERN PREDICTION USING A TERRAIN ANALYSIS MODEL

Introduction

Soil water conditions markedly affect plant growth by altering the soil nutrient supply (Vegh, 1991). Water affects the nutrient supply through its influence on mass flow (movement of nutrients through the soil to the roots in the convective flow of water) and on diffusion (movement caused by a concentration gradient) (Barber, 1984). Consequently, as available soil water varies across a landscape the nutrient supply also varies, influencing patterns of vegetation growth (Allen, 1991).

Studies conducted in many different ecosystems have demonstrated a correlation between soil water and plant productivity and diversity. For example, Puerto and Rico (1992) found that diversity in Mediterranean grasslands could be correlated with hillslope positions in the landscape, and postulated that both soil water availability and nutrient levels could be mechanisms causing the variation in species diversity. In forested areas, Gagnon and Bradfield (1987) found that several groups of vegetation on Vancouver Island varied spatially with edaphic conditions, particularly with soil moisture and soil nutrients. A moisture-nutrients gradient, in combination with a dynamics gradient based on tree size-class data, accounts for much of the variation observed in southern

Wisconsin forests (Peet and Loucks, 1977). Distribution patterns of subspecies of big sagebrush are associated with competition for soil water (Morris et al., 1976). In northeastern Nevada, Jensen (1990) found that the transition from black sagebrush to low sagebrush, basin big sagebrush, and mountain big sagebrush appeared to represent a gradient of increasing available soil water.

Interest in determining the spatial distribution of soil properties, such as soil water and nutrient content, has been an ongoing concern for pedologists since Milne (1935) introduced the term *catena* to describe a regular repetition of soils on the landscape. Across a catena, one of the primary agents affecting soil characteristics is water; as water moves over soils, it carries with it both dissolved and suspended materials. Hugget (1975) stressed that processes such as water movement are not merely surficial in nature, but that they operate in a three-dimensional continuum. He defined the boundaries of a soil landscape as the drainage divide, the surface of the land and the base of the soil profile. Within that soil landscape, water moves both on the surface and in the subsurface, and in the subsurface the movement can be lateral as well as vertical (Zaslavsky and Rogowski, 1969). Bear et al. (1968) showed that the vertical hydraulic conductivity through a soil profile is smaller than the hydraulic conductivity parallel to the soil layers. Therefore, once water enters the soil, a portion of it has a tendency to move laterally downslope transporting suspended and dissolved materials.

Hall (1983) described the process of water movement for the hillslope positions of summit, shoulder, backslope, and footslope, which were originally defined by Ruhe (1960, 1969). In a generalized account, Hall stated that the summit water movement in

soil is predominantly vertical except near the transition to the shoulder. In that transitional area, as well as in the shoulder and backslope positions, lateral flow, both on the surface and in the subsurface, occurs, causing transportation of material as well as water.

The contention that the concentration of nutrients, as well as their availability due to higher moisture content, increases in downslope positions is supported by Glazovskaya (1968) who made the point that soils that are adjacent, but at different elevations, are united by the lateral migration of chemical elements into a single geo-chemical landscape. He referred to this soil landscape as a "geo-chemical soil catena" and implied that as water moves down slope, both in the surface and subsurface regions, it carries nutrients as well as other chemicals with it, depositing them on lower parts of the slopes.

In a study on three semi-arid rangeland sites, Honeycutt et al. (1990a) proposed that differential depths to maximum clay and to maximum carbonate concentration, which were found along a slope gradient, might be attributed to hillslope erosional history and/or the effects of subsurface lateral flow. In a companion study, they also found that organic-C, total-N, and organic-P contents often increased in a downslope direction (for one site the increases from summit to footslope were as much as 23, 19, and 42%, respectively) (Honeycutt et al., 1990b). They attributed this chemical differential to a topographic effect. In a study conducted on steep slopes in the Appalachian Mountains, chemical properties of the upper 20 cm of soil varied distinctly based on slope position (Kalisz, 1986). Average OM, N, P, Ca, Mg, and pH concentrations increased in downslope positions compared to the middle portion of slope segments. The pattern

created by this gradient conforms to the distribution of soil properties that results from a gradual removal of solid and dissolved materials from linear slope segments, and the accumulation of the materials near breaks in the slope (Kalisz, 1986; Gerrard, 1981).

In as much as topography controls the direction and flow of water across the terrain, gradients of soil moisture and, perhaps to a lesser extent, soil nutrients should be reflected by position on the landscape. By association, patterns of vegetation should also be reflected by landscape position. Hypothetically, spatially distributed topographic attributes, generated by a model which accounts for water flow paths, should have some correlation to vegetation patterns that exist on the modelled terrain. Beven and Kirkby (1979) were among the first to employ a topographic index to predict patterns of soil saturation. The topographic index $\ln(a/\tan \beta)$, where a is the area drained per unit contour length and $\tan \beta$ is the slope of the ground surface at the location, was found by Beven and Kirkby to compare favorably with observed patterns of surface saturation. Moore et al. (1993a) have incorporated Beven and Kirkby's early work in a terrain based model know as the Topographic Analysis Programs for Environmental Sciences (TAPES). TAPES generates a spatially varying soil wetness index based on hydrologic flow paths. In this project, the capacity to predict vegetation patterns using the TAPES soil wetness index is evaluated.

In addition to controlling surface and subsurface hydrologic flow patterns, topography influences the spatial distribution of soil water by having an affect on evapotranspiration. Hutchins et al. (1976) found, in eastern Kentucky, that greater total radiation falling on a SW slope caused air temperature to be higher during the day, which

resulted in greater evaporative demands for that slope compared to a NE slope. Soil moisture readings, taken throughout 1971, consistently showed that there was more soil moisture by volume on the cooler NE slope compared with the corresponding SW slope. Franzmeier et al. (1969) also found south facing soil pedons to be drier than pedons in equivalent slope positions on a north facing slope.

Because solar radiation is affected both by the angle at which a slope is inclined and the direction it faces (Hutchins et al., 1976), net radiation amounts can vary rapidly over small distances. Where rainfall is inadequate to constantly recharge soil water, variation in net radiation will impact the distribution of soil water. The ability to predict the spatial variation of net radiation across a landscape could be a first step in predicting soil water variation due to evapotranspiration losses. Traditional evapotranspiration models (Thornthwaite, 1948; Jensen and Haise, 1963; Priestly and Taylor, 1975) are generally one-dimensional and are intended to describe the average behavior of a system rather than the variability within the system (Campbell and Harris, 1981). In contrast, the TAPES model generates a spatially varying net radiation index based, in part, on the variation of slopes and aspects across a terrain (Moore, 1993a). In this project the capacity to predict vegetation patterns using this index is evaluated.

The specific objectives of the project are: 1) to create digital elevation data for a study area by digitizing contour lines on topographic maps; 2) to use the TAPES model to generate two spatially distributed terrain attributes, a soil water index and a net radiation index, using the digital elevation data generated in the previous step as input to the model; 3) to create a vegetation map of the study area by classifying digital

images; and 4) to compare the spatial distribution of the computer generated terrain attributes with the distribution of vegetation groups across the study area.

Materials and Methods

Study Area

This study was conducted in southwestern Montana on a small tributary of the Madison River (45° 33' N, 111° 38' W). The area targeted for investigation is the watershed for the upper 1.7 km of the north fork of Cottonwood Creek, a stream with a total length of 4 km which is located on the Montana Agricultural Experiment Station's Red Bluff Research Ranch in Madison County (Figure 1). The 210 ha study area is characterized by moderate to steep slopes with elevations ranging from 1633 m (5360 ft) at the outlet of the watershed to 1975 m (6480 ft) at its highest point. Currently, the area is used as summer and fall pasture for cattle and sheep. Historically, the Red Bluff area has been mined for silver and gold, and several active mines still exist in the region.

The north branch of Cottonwood Creek is spring fed and runs year around. It is flanked by small, intermittent seeps which feed laterally into its channel. At the lower end of the study area, Pogacnik (1985) found the creek to have flow values ranging from 0.03 m^3/sec (30 l/sec) in June to 0.01 m^3/sec (10 l/sec) in September. In addition to the perennial flow from the headwater spring, two ephemeral tributaries exist and several small seeps dot the landscape with surface water, which is quickly reabsorbed into the coarse textured soil and fractured bedrock.

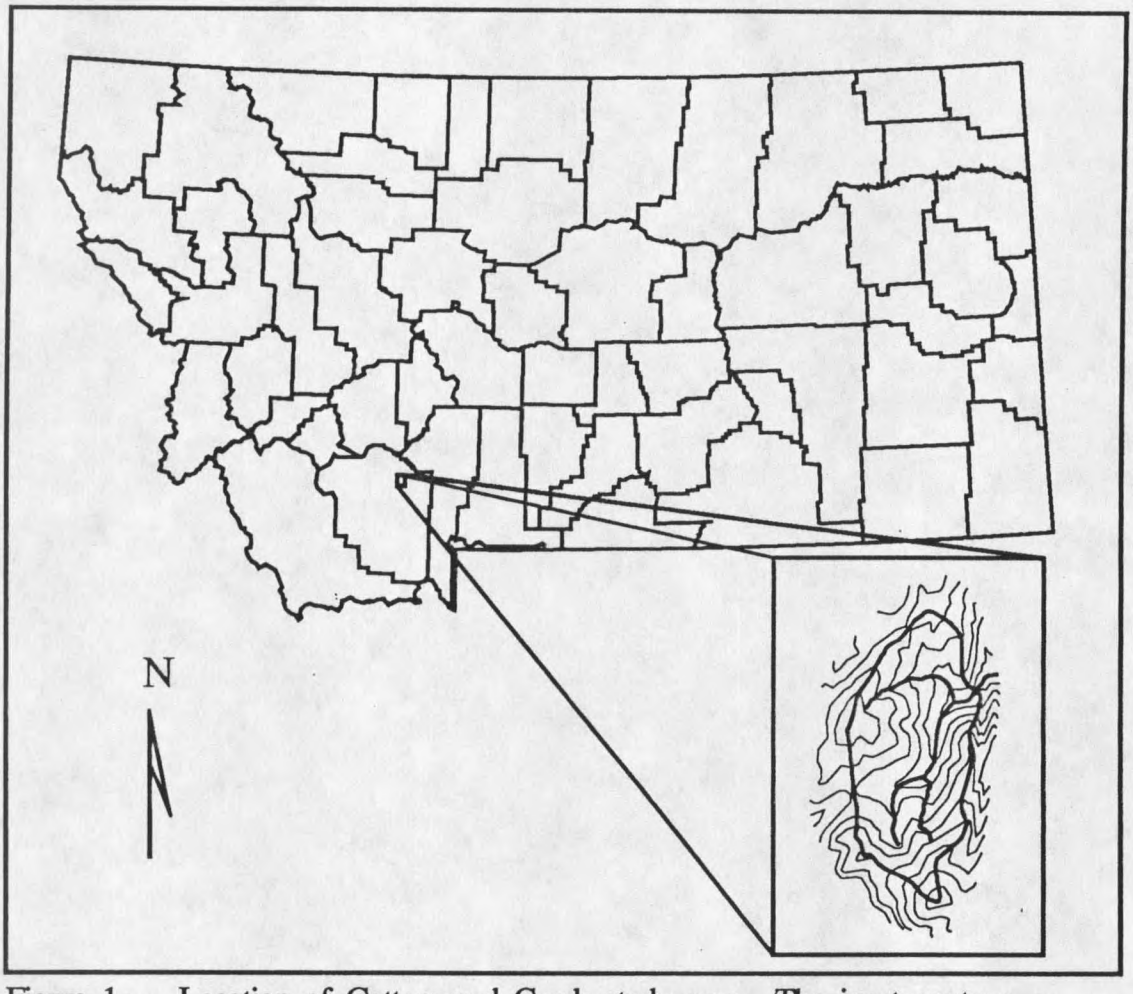


Figure 1. Location of Cottonwood Creek study area. The inset contour map (30 m interval) shows the catchment boundary and stream network in bold.

Bedrock in the region consists primarily of highly metamorphosed rocks of Precambrian age. The predominant material is Archean quarto-feldspathic gneiss which is inter-layered with amphibolite and hornblende gneiss (Chadwick, 1984). The unweathered bedrock is quite homogeneous with low permeability; however, where weathering has occurred on rock outcrops the result is grussified (coarse-grained) material that is very permeable. Joint and fracture zones in the bedrock, in combination

with the grussified metamorphic outcrops, probably cause less runoff during a rainstorm than would normally be expected in an area with metamorphic bedrock (Aspie, 1989; Fetter, 1980). The water table in the study area is very deep, except in small areas close to the streambank where groundwater seepage occurs (Aspie, 1989). Saturated overland flow from these seepage areas and direct precipitation into the stream channel are the major sources of storm runoff in this catchment (Aspie, 1989).

The soils in this area are mapped as either Oro Fino-Poin complexes or as Shurley-Rock outcrop complexes (SCS and MAES, 1989). Approximately two-thirds of the catchment, the northern third and the southern third, is mapped as Oro Fino-Poin units, while the middle portion of the catchment is mapped as a Shurley-Rock outcrop unit. Soils in both complexes are formed in colluvium and alluvium derived from gneiss; surface layers of these soils are primarily sandy or gravelly loams. Table 1 describes several generalized characteristics, particularly those associated with moisture, of the soil series identified with these complexes.

During a previous study in this area (Pogacnik, 1985), the following three soil families were identified: loamy-skeletal, mixed Typic Cryorthents on north facing slopes; loamy-skeletal, mixed Typic Cryoborolls on south facing slopes; and fine-loamy, mixed Argic Cryoborolls in the alluvial riparian zone. These three soil families are consistent with what would be expected in a region having both an Oro Fino-Poin complex and a Shurley-Rock outcrop complex.