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

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.

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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.

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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.

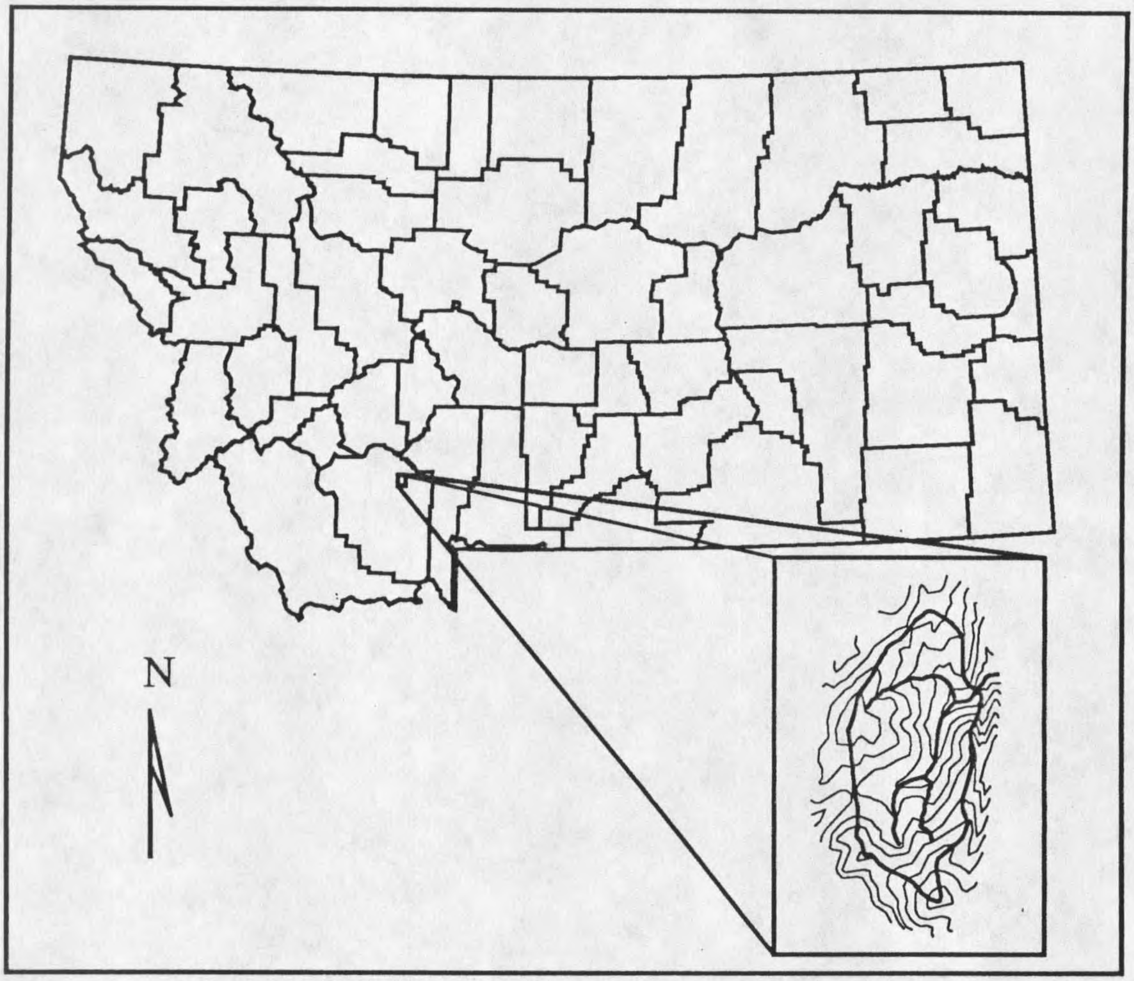

Figure 1. Location of Cottonwood Creek study area. The inset contour map (30 m interval) shows the catchment boundary and stream network in bold.

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.

Table 1. Generalized characteristics of soil complexes found in the Cottonwood Creek study area, as described in 'Soil Survey of Madison County Area, Montana' (SCS and Montana Agricultural Experiment Station, 1989).

COMPLEX/ SERIES	TAXONOMIC CLASSIFICATION	%*	TOPOGRAPHIC LOCATION	DEPTH/ DRAINAGE	AWC** (cm)	RUNOFF/ PERM***	EROSION HAZARD
Oro Fino-Poin Complex							
Oro Fino Series	fine-loamy, mixed Argic Cryoborolls	50	hillsides and footslopes	deep well drained	15.2	rapid moderate	high
Poin Series	loamy-skeletal, mixed Lithic Cryoborolls	30	hilltops and ridges	shallow well drained	2.5	rapid mod. rapid	high
Adel Series	fine-loamy, mixed Pachic Cryoborolls	20	depressional areas on north facing slopes	deep well drained	22.9	medium moderate	moderate
Shurley-Rock Outcrop Complex							
Shurley Series	sandy-skeletal, mixed Borollic Camborthids	40	on rough broken slopes	deep well drained	5.1	rapid mod. rapid	high
Rock outcrop	(exposures of gneiss, schist, or granite)	40	occur as ledges				
One or more of:		20					
(a) Rentsac Series	loamy-skeletal, mixed (calcareous), frigid Lithic Ustic Torriorthents		adjacent to areas of rock outcrop	shallow well drained	2.5	rapid mod. rapid	high
(b) Yetull Series	mixed, frigid Ustic Torripsamments		small fans and footslopes	deep well drained	10.2	medium rapid	moderate
(c) Nuley Series	fine-loamy, mixed Aridic Argiborolls		ridges and hillsides	deep well drained	10.2	rapid moderate	high

* Percent of a "representative" complex made up by each series.
** Available water holding capacity.
*** Permeability. (top line is read as runoff; bottom line is read as permeability).

Vegetation in this catchment is highly variable, with some southern exposures having very sparse populations of grass species, while north facing depressions and the lower stream bottom have dense stands of riparian vegetation. For the purposes of this study, five categories of vegetation were derived based on a two-day field study conducted in August, 1991 by R. Wallander (M.S. candidate, Reclamation Unit Dept. of Animal and Range Sci., MSU). The category designations are as follows: Grassland, Sagebrush, Conifers, Upland Riparian, and Bottom Riparian (stream). Species found in each category, as well as locations sampled are listed in Table 11 in Appendix A.

Climate data from the weather station at Montana Power's Madison Power House, which is approximately 6 km south of and 300 m lower than the study area, show 1991 temperature extremes of -23°C in January and 36°C in August. Average annual air temperature for the 84 years of accumulated data at this station is 8°C, and average annual precipitation is 39 cm (NOAA, 1991). Precipitation between the months of November and March comes primarily in the form of snow (Marlow et al., 1987).

Creation of Digital Elevation Model

Spatially distributed landscape attributes such as slope, aspect, and specific catchment area can be derived directly from elevation data. These, in turn, can be used to derive indices of other, more complex, topographic characteristics such as soil water content and net solar radiation (Moore et al., 1991). Computer-based terrain models provide a means of deriving estimates for these attributes over large spatial areas in relatively short amounts of time. One of the primary requirements for using a terrain model is that the input elevation data be in a digital format.

Three formats for storing elevation data digitally are common: linear models (e.g. contour lines), regular point models which take the form of altitude matrices (square or rectangular grids), and irregular point models which are known as Triangulated Irregular Networks (TINs) and are defined by irregularly spaced points forming triangular facets across a landscape (Burrough, 1986). Frequently, digital data can be obtained in one of these formats from an agency such as the U.S. Geological Survey (USGS). However, because medium-scale digital data did not pre-exist for this area, a contour-based Digital Elevation Model (DEM) was produced by line digitizing 6 m (20 ft) contours from 1:24,000 scale USGS topographic maps.

Topographic representation of the area overlaps two quad sheets, the Norris, MT and Bear Trap Canyon, MT quads (1989). Two contour coverages, one for the area covered on each quad sheet, were digitized using ARC/INFO software; each was referenced to the Universal Transverse Mercator Projection (UTM) coordinate system. In addition to needing elevation data, the terrain model used in this project produces better results when information about stream information is included (Hutchinson, 1989) and the hydrology model discussed in Chapter 3 requires data about local high points and saddle points in the catchment. Therefore, the stream network (including ephemeral tributaries) and elevations of hill tops and of saddle points were also digitized for each coverage. Subsequently, the individual coverages were merged to form a single data layer containing elevation information for the study area.

Elevation data from this contour coverage is used as input to the terrain model (Figure 2 shows the interaction of the major components of this project), as well as to

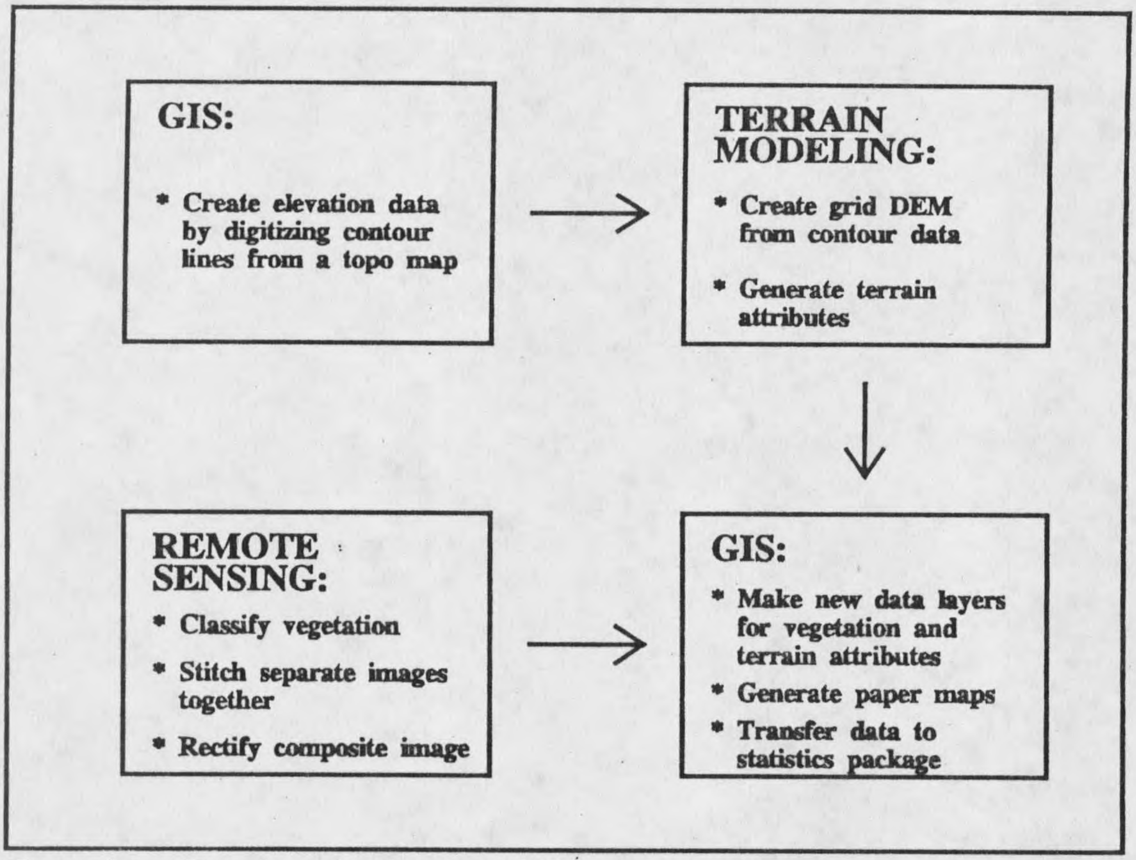

Figure 2. Flowchart showing how GIS, remote sensing, and computerized terrain modeling were integrated in this project.

the hydrology model (Figure 15, Appendix B). Because the data structure in ARC/INFO is incompatible with the data structure required by the first program of the terrain model, it was necessary to write a series of programs to convert the data to the appropriate format. This conversion process (Figure 16, Appendix B) is discussed in Chapter 3, because while it is essential to the hydrology model, it could have been bypassed for the terrain model.

Generation of Terrain Attributes

The terrain method used to estimate topographic attributes for the Cottonwood Creek area is known as the Topographic Analysis Programs for Environmental Sciences (TAPES) (Moore et al., 1991; Moore et al., 1993a). TAPES is made up of several programs written in C and FORTRAN, of which four are used in this project. These four are: PREPROC (Moore et al., 1988), TAPES-G, SRAD, and WET (Moore et al., 1991; Moore et al., 1993a). In addition, one other program known as ANUDEM (Hutchinson, 1989) is necessary for the generation of terrain attributes from contour elevation data. These programs are discussed briefly in this section; the order in which they are run is shown in Figure 3.

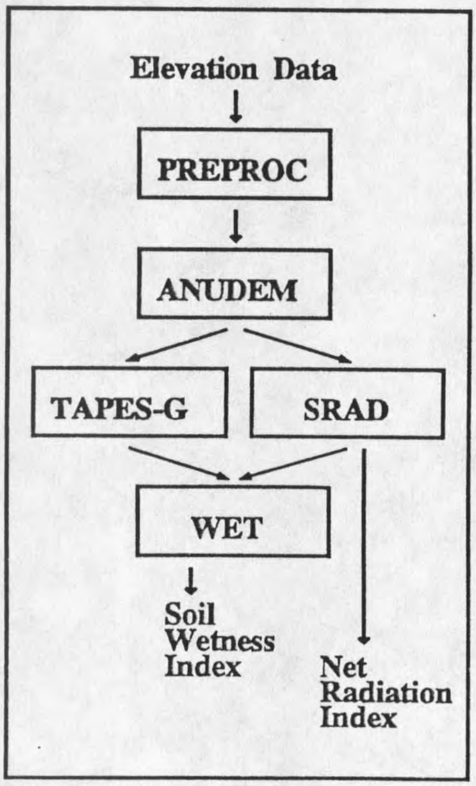

Figure 3. Program flowchart for deriving terrain indices for vegetation project.

PREPROC. Elevation data generated by digitizing contour lines from topographic maps are used for both the hydrology model and the terrain model; however, data requirements are slightly different for each of these models. PREPROC is a program which pre-processes contour data for both models. One of the functions this program performs is to interpolate regularly spaced *x,y* coordinates along each contour. Manually digitized contours often have *x,y* coordinates located at irregular distances from one another; this process creates coordinates along a contour that are the same distance apart. Another function of PREPROC is to format output data that is compatible either with the terrain model or with the hydrology model depending on options chosen by the user. If the terrain model is to be run, contour data and stream network data are output. If the hydrology model is to be run, contour data and elevation data for hill tops and for saddle points are output.

For this project, PREPROC was run to obtain contour and stream network data in a format usable by ANUDEM. A copy of the interactive prompts generated by this program and the responses used for this project are shown in Figure 17 (Appendix B).

It should be noted that it is not necessary to run PREPROC if generation of terrain attributes is all that is required for an area (i.e. hydrologic modeling is not desired). The next program (ANUDEM) used in generating terrain attributes will accept data in a variety of formats. For this project, the contour elevation data could have been converted to either a lattice or a TIN structure using ARC/INFO algorithms and that data could have been input to ANUDEM as x,y,z point data. The advantage to this option is that, in addition to bypassing the PREPROC program, the series of conversion programs mentioned at the end of the previous section could also be bypassed.

ANUDEM. Terrain attributes can be derived from any of the three previously discussed DEM structures; however, the grid format is computationally more efficient to use than is either the TIN or the contour construct (Moore et al., 1991). The next program in the TAPES model (TAPES-G) requires elevation data in grid format in order to take advantage of these computational efficiencies. Therefore, contour-based elevation data needs to be converted to a grid format before the rest of the TAPES model can be run.

The program ANUDEM was used for this conversion (Figure 18, Appendix B). This program calculates regularly spaced grid DEMs, with the distance between grid points defined by the user, from either irregularly spaced *x,y,z* point data or from contour data (Hutchinson, 1989). Interpolation of contour data or of irregular point data to a grid structure is a frequently used technique, but it has a weakness in that it often introduces sinks or pits in the grid data structure. With the exception of recently glaciated or karst topography, pits and sinks are not common across a landscape because fluvial erosion processes will not normally produce such features, therefore when sinks or pits occur in an interpolated data structure they are generally errors created during the interpolation process (Band, 1986). Furthermore, these closed depressions may cause serious errors for any algorithm that depends on mapping hydrologically connected regions. This is of concern in this project because for any given point on the catchment the soil wetness index is derived, in part, from the size of the area above that point which drains to or through that point.

The interpolation technique used in ANUDEM differs from other interpolation techniques in that it includes a drainage enforcement algorithm which automatically removes such artifacts as spurious sinks or pits, based on user defined tolerances (Hutchinson, 1989). In addition to the drainage enforcement algorithm which needs only elevation data in order to process, hydrologic fidelity can be further enhanced by including information about the stream network. The perennial stream and ephemeral tributaries of Cottonwood Creek were digitized and used in ANUDEM to take advantage of this option.

ANUDEM outputs a grid DEM which maintains hydrologic fidelity to the actual landscape. The DEM produced for this project was subsequently used as input to both the TAPES-G program and the SRAD program.

TAPES-G. Terrain attributes that can be derived from elevation data fall into two categories: primary attributes and secondary attributes. Primary attributes are those that can be calculated directly from elevation data. Table 2 presents some primary topographic attributes which have hydrologic significance (Moore et al., 1991 adapted from Speight 1974, 1980). The attributes identified with asterisks in this table can only be appraised for points along the stream network, while the others are properties which can be derived for any point across the landscape. Secondary attributes are those that are derived from combinations of primary attributes. The soil wetness and net radiation indices, which will be discussed later, are examples of secondary attributes.

TAPES-G is a hydrologically-based method of terrain analysis that includes Jenson and Domingue's (1988) method of developing depressionless DEMS. It was used (Figure 19, Appendix B) to calculate the primary topographic attributes of elevation, slope, aspect, profile curvature, plan curvature, specific catchment area, and maximum flow path length. These attributes change continuously over a landscape; TAPES-G emulates this variability by calculating each attribute separately for every node in the digital elevation model, and subsequently stores that data along with the corresponding *x,y* coordinate in an output file.

Table 2. Primary topographic attributes (Moore et al., 1991).

Attribute	Definition	Hydrologic significance
Altitude	Elevation	Climate, vegetation type, potential energy
Upslope height	Mean height of upslope area	Potential energy
Aspect	Slope azimuth	Solar irradiation
Slope	Gradient	Overland and subsurface flow, velocity and runoff rate
Upslope slope	Mean slope of upslope area	Runoff velocity
Dispersal slope	Mean slope of dispersal area	Rate of soil drainage
Catchment slope*	Average slope over the catchment	Time of concentration
Upslope area	Catchment area above a short length of contour	Runoff volume, steady-state runoff rate
Dispersal area	Area downslope from a short length of contour	Soil drainage rate
Catchment area*	Area draining to catchment outlet	Runoff volume
Specific catchment area	Upslope area per unit width of contour	Runoff volume, steady-state runoff rate
Flow path length	Maximum distance of water flow to a point in the catchment	Flow acceleration, erosion rates
Dispersal length	Distance from a point in the catchment to the outlet	Impedance of soil drainage
Catchment length*	Distance from highest point to outlet	Overland flow attenuation
Profile curvature	Slope profile curvature	Flow acceleration, erosion/deposition rate
Plan curvature	Contour curvature	Converging/diverging flow, soil water content

* All attributes except these are defined at points within the catchment.

The primary attribute data which TAPES-G generates is used as input to the WET program, which is run after the SRAD program. While SRAD uses primary attribute data, it receives its input from ANUDEM and calculates its own slope and aspect information using the same algorithms that are used in TAPES-G.

SRAD. Net radiation is a measure of the energy available at the ground surface and is important because it is the fundamental quantity of energy available to drive the processes of evaporation, air and soil heating, as well as other, smaller energy-consuming processes such as photosynthesis (and therefore transpiration) (Rosenberg et al., 1983).

Moore et al. (1993a) note that net radiative flux density, R_n, received by an inclined surface can be expressed as:

$$R_n = (1 - \alpha)(R_{dir} + R_{dif} + R_{ref}) + \epsilon_s L_{in} - L_{out} = (1 - \alpha) R_t + L_n$$

where α is the surface albedo; R_{dir}, R_{dif}, and R_{ref} are the direct, diffuse and reflected shortwave irradiance, respectively; ϵ_s is the surface emissivity; L_{in} is the incoming or atmospheric longwave irradiance and L_{out} is the outgoing or surface longwave irradiance. R_t, the global shortwave irradiance, is equal to $R_{dir}+ R_{dif}+ R_{ref}$; and L_n, the net longwave irradiance, is equal to $\epsilon_s L_{in} - L_{out}$.

Both L_n and R_t are affected by topography. L_n is affected by the slope angle of the terrain and R_t is affected by slope and aspect as well as by time of year (which controls solar declination). In the northern hemisphere, steep south-facing aspects receive more radiation for longer time periods than north-facing aspects, because the sun has a southerly declination and steep slopes receive radiation perpendicularly (Coughlan and Running, 1989).

The program SRAD calculates slope and aspect for each *x,y* node in the DEM and incorporates that information into a calculation of net radiation for those nodes, producing estimates of spatially variable net radiation over a landscape. Besides the

DEM data which comes from ANUDEM, an additional input file is required in order to run this program. This parameter file (Figure 20, Appendix B) includes information about latitude as well as temporally variable data (i.e. different values are possible on a month by month basis) for albedo, cloudiness factor, sunshine factor, maximum and minimum temperatures, and leaf area index. Based on start and finish dates and time steps specified by the user, SRAD can integrate the radiation equation over any time period ranging from one day to one year to estimate seasonal (or annual) radiation values.

For the Cottonwood Creek project, net radiation values were generated using SRAD (Figure 21, Appendix B). The resulting information was loaded to a GIS (ARC/INFO) to form a new data layer for the area.

WET. Soil water is a driving force in many processes such as movement of nutrients to plant roots, plant transpiration, and leaching of chemicals to groundwater. Over a spatially diverse area, variation in soil water may be due in part to changes in topography. Moore et al. (1993a) use the following general expression, which accounts for the effects of topography as well as soil properties, deep seepage, rainfall, and evapotranspiration, to describe a soil water index, X_i :

$$X_i = \ln\left[\frac{1}{b\tan\beta}\int \mu P \, dA\right]_i + [\ln(T_e) - \ln(T_i)]$$

where b_i is the outflow width (m), β_i is the slope angle (degrees) in the ith element, μ_i is an area weighting coefficient which represents the fraction of precipitation that is converted to runoff in each element, P_i is the precipitation rate (mm d^{-1}), and dA_i is the element area (m^2). T_i is the transmissivity of the soil ($m^2\ d^{-1}$) in the i^{th} element, and $\ln(T_e)$ is the areal average value of $\ln(T_i)$. These last two terms cancel one another when uniform soil properties are assumed (i.e. when transmissivity is assumed to be constant throughout the landscape and equal to unity).

The area weighting coefficient μ, where $0 \leq \mu_j \leq 1$, is dependent on the evapotranspiration (i.e., solar radiation, vegetation characteristics), deep drainage losses and precipitation in each element. It can be written as:

$$\mu = 1 - \left(\frac{E + D}{P}\right)$$

where E is the actual evapotranspiration (mm d^{-1}), P is the precipitation (mm d^{-1}), and D is the deep drainage loss (mm d^{-1}) on a monthly, seasonal or annual basis.

Topographic influence in wetness index expression is found in the terms μPdA and β_i. The integral term in conjunction with the μPdA term represents the amount of runoff (during a rainstorm) from upslope areas (specific catchment area) which reaches a particular element in a landscape. β_i is the slope of that element. The slope angle will influence what portion of precipitation and runoff reaching an element will infiltrate into the soil and what portion will become runoff into a lower, adjoining element. The program WET estimates spatially variable soil wetness indices based on the above expression. It uses primary attributes generated in TAPES-G as input. Also, it uses solar radiation data from the SRAD program as one of the parameters used to calculate the area weighting coefficient, μ_i. While processing, the program prompts the user for additional information such as mean air temperature, elevation, and daily precipitation.

As with the net radiation index, after SRAD (Figure 22, Appendix B) was run for Cottonwood Creek, the spatially variable soil wetness indices which were generated were loaded to a new GIS data layer.

Remote Sensing

A computer-based vegetation map was needed for the comparison of terrain attributes generated by the TAPES model to the spatial variation of plant groups in the study area. Since no vegetation map, computer-based or otherwise, existed for this area, field mapping was initiated in late summer 1991. To aid in the mapping effort a hand-held GPS (Global Positioning System) receiver (Magellan Systems Corp., 1991) was used to obtain latitude/longitude coordinates along boundary lines between plant communities. This proved to be extremely time consuming for a variety of reasons: 1) in some areas vegetation varies rapidly forming many small map units with a corresponding number of boundaries to be accounted for; 2) depending on satellite positions the process of obtaining a set of coordinates could take from 2 minutes to 15 minutes (using the option which averages multiple readings); and 3) GPS readings could not be taken in the middle of the afternoon because satellites were out of position.

A new remote sensing system which produces high resolution images became available at this time, and the decision was made to incorporate a map produced from this technology in this project. Field mapping was discontinued and the data already collected, was kept as reference material to be used during the image classification process.

Data Collection System. The Airborne Data Acquisition and Registration (ADAR) System 5000, created by Positive Systems, Inc., in Kalispell, MT (Benkelman et al., 1990), was used to collect digital images of Cottonwood Creek. In many respects ADAR's product is similar to images produced by satellite technology; however, the two systems have significant differences also. Both systems collect information based on electro-magnetic (EM) energy that is either reflected or emitted from the earth's surface. In a satellite, EM energy is detected using a scanning radiometer (Harris, 1987), which is built to divide incoming energy into several different wavebands (e.g. Landsat's Thematic Mapper (TM) collects data in 7 bands).

In comparison, the ADAR system is capable of gathering data in several wavebands, but does simultaneous data collection in only four of those bands. This is because the system uses separate sensors for each waveband and only four sensors are included in the hardware. Depending on the application of the data, any combination of four wavebands can be used in the ADAR system. Table 3 compares the wavebands available from TM to the wavebands available for the ADAR system in September, 1991 (additional bands have been added since that time).

The primary differences between satellite images and ADAR's images result from the fact that the platform for the ADAR system is a small aircraft. Spatial resolution (i.e. pixel size) is controlled by flying height of the aircraft and can range from 0.5 m to 3.0 m per pixel (compared to TM's 30 m pixel). This is advantageous for projects where a high level of detail is required. Another advantage of having an aircraft as host

Table 3. Characteristics of Thematic Mapper compared to Airborne Data Acquisition and Registration (ADAR) System 5000 (adapted from Lillesand and Kiefer, 1987; Behrendt, personal communication, 1991; and Harris, 1987).

THEMATIC MAPPER SPECTRAL BANDS				ADAR BANDS
Band	Wavelength (nm)	Spectral location	Principal Application	Wavelength (nm)
1	450 - 520	Blue	Useful for coastal water mapping, soil/vegetation discrimination, and forest type mapping	410 - 490*
2	520 - 600	Green	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment.	510 - 590
3	630 - 690	Red	Designed to sense in a chlorophyll absorption region aiding in plant species differentiation	610 - 690*
		Red/ Near-infrared		684 - 696 680 - 720
4	760 - 900	Near-infrared	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination	730 - 770* 810 - 890* 700 - 1000
5	1550 - 1750	Mid-infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds.	
6	10400 - 12500	Thermal infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.	
7	2080 - 2350	Mid-infrared	Useful for discrimination of mineral and rock types. Also sensitive to vegetation moisture content.	

* Bands chosen for Cottonwood Creek project.

for the sensors is that flights can be scheduled to avoid cloudy or stormy weather that might affect EM measurements and to select time of day to avoid morning and evening shadows.

<u>Image Processing</u>. Positive Systems, the company which created the ADAR 5000 system, was contracted to collect digital image data for Cottonwood Creek. On September 4, 1991 several images of 2 m pixel resolution were taken of the catchment between 1:00 and 2:00 p.m. Positive Systems processed the raw data and delivered 15 images on separate diskettes (approximately 1.5 MB each) which were in a format compatible with ERDAS, the software system used to process the images. Each image was comprised of four bands of data (Table 3) and covered an area of 1.4 km^2 (359,000 pixels).

At this time in 1991, the ADAR system was still in the early stages of being tested and not all factors had been accounted for with regard to covering an area larger than could be represented by one image. For example, the random flight pattern that was used to collect the data caused problems later. From the 15 images received, six were identified which, when combined, would provide complete coverage of the area. However, two of these images were oriented west, two north, one northeast, and one southwest. The first consideration, therefore, was to reorient the images so that north was consistently represented at the top of each image.

The rectification process used to reorient images involves resampling data file values and can cause some loss of spectral integrity in the data. ERDAS (1991) recommends classifying an image before rectifying, because the classification will be more accurate using the original, unaltered data. Following their advice, each of the images was classified separately.

Background soil can cause significant spectral distortions in areas like the Cottonwood Creek catchment where large areas are sparsely vegetated (McDaniel and Haas, 1982; Frank, 1984; Huete et al., 1985). To help minimize the influence of background soil on the classification process, a ratioing technique known as the Normalized Difference Vegetation Index (NDVI) was used (Tucker, 1979). Two bands of data, the Near Infrared (NIR) and the Red are used to calculate the NDVI which is expressed as:

$$NDVI = \frac{NIR - Red}{NIR + Red} .$$

Ratioing creates a new band of data with the value of each new pixel being equal to the ratioed values of the Red and NIR pixels at the same *x,y* location. It is this new band that is processed during classification. The second NIR band (801 - 890 nm) which was collected at the study area (Table 3) was used along with the Red band (610 - 690 nm) in this calculation.

Vegetation groups were classified from the new NDVI band using an unsupervised sequential clustering method which begins processing with the top, left hand pixel in an image and sequentially compares one pixel to the other pixels, grouping them into clusters (classes) based on their spectral values. Eight classes were created by the clustering process for each image. These classes were regrouped, based on information collected during field mapping, to form the five classes which were already identified for this area: Grassland, Sagebrush, Conifer, Upper Riparian, Bottom Riparian (creek).

After all the images were classified, the four which were not oriented with north at the top were rectified to do so. This was done by matching pixels on the image to *x,y* coordinates (UTM) taken from the contour coverage which had already been digitized in ARC/INFO. The rectification ("rubbersheeting") was done on each image using a second order transformation with a minimum of seven ground control points for each.

In order to form a composite map of the area, the six classified images were stitched to each other one at a time. However, even though each image was rectified, their edges did not align perfectly. The process of stitching the images together caused some distortion as edges in one image were "stretched" to fit edges of the next image. As each additional image was added to the growing composite the distortion was compounded. The final product was again rectified against the contour coverage. The Root Mean Square Error for this process was 32 m (i.e. the pixels on the vegetation map might be displaced from their true position by as much as 32 m). While this error seems large, Bolstad (1992) suggests that errors of this magnitude should be expected when using 2-dimensional transformation techniques (i.e. those available in both ERDAS and ARC/INFO) to rectify large scale areal photographs (or images) taken in moderate to steep terrain.

As with the attributes created by the TAPES model, the newly created vegetation map was loaded as a data layer to the GIS.

Geographic Information System

The spatially varying topographic attributes generated by the TAPES model and the vegetation map created in the ERDAS system were put into a GIS (ARC/INFO) to take advantage of both its data management capacity and its display capabilities. Since the data in the terrain attribute layers and in the vegetation layer had previously been registered to the UTM coordinate system, only minor adjustments were needed to align these layers. Because the cell size of the terrain attributes was 20 m (specified by the user in the TAPES-G program) and the cell size in the vegetation layer was 2 m, the vegetation layer was resampled to produce 20 m cells. Data from the three layers were unloaded to 3 separate ASCII files, which were then combined, using a FORTRAN program written for that purpose, to produce 2 new files. One of the new files contained net radiation and vegetation data for each *x,y* coordinate in the study area; the other file contained wetness index and vegetation data. These files were used as input to a statistics package for analysis purposes.

Data Analysis

Data were ordinated using correspondence analysis (CA). Ordination is a technique of data exploration that reduces large matrices of data to graphs or charts showing one or more axes of variation (Shumar and Anderson, 1986). The methodology used in CA is described by Greenacre (1984). Very briefly, it is a geometric method of quantitative analysis where data are transcribed algebraically to points in multidimensional space. Results are generally displayed in 2-D space to facilitate ease of interpretation.

Results and Discussion

Four objectives were defined for this project: 1) the creation of a digital elevation coverage of the Cottonwood Creek catchment, 2) computation of terrain attributes from that elevation data, 3) creation of a computer-based vegetation map of the area, and 4) quantification of the relationship (if any) between the spatially varying terrain attributes and the location of vegetation groups found in the catchment. The results of these endeavors are discussed in this section.

Digital Elevation Data

A GIS data layer for elevation data was created by digitizing contour lines from USGS topographic maps (Figure 4). The lowest contour elevation, in the northeast portion of the catchment, is 5360 ft (1633 m) while the highest contour, on the southernmost hilltop, is 6480 ft (1975 m). In addition to contour information, the *x,y* coordinates of local high points and local saddle points were identified because this information is needed in the hydrology model. For that model, the elevation of each high point needs to be slightly higher than the elevation of the nearest contour and the elevation of each saddle point must be exactly the same as the elevation of the next higher contour (even though in reality it is lower than that elevation).

Stream data, which can be used in the ANUDEM program to help with drainage enforcement, is included with the digital elevation data. The stream network is represented by numbering the different tributaries in the manner shown in Figure 4.

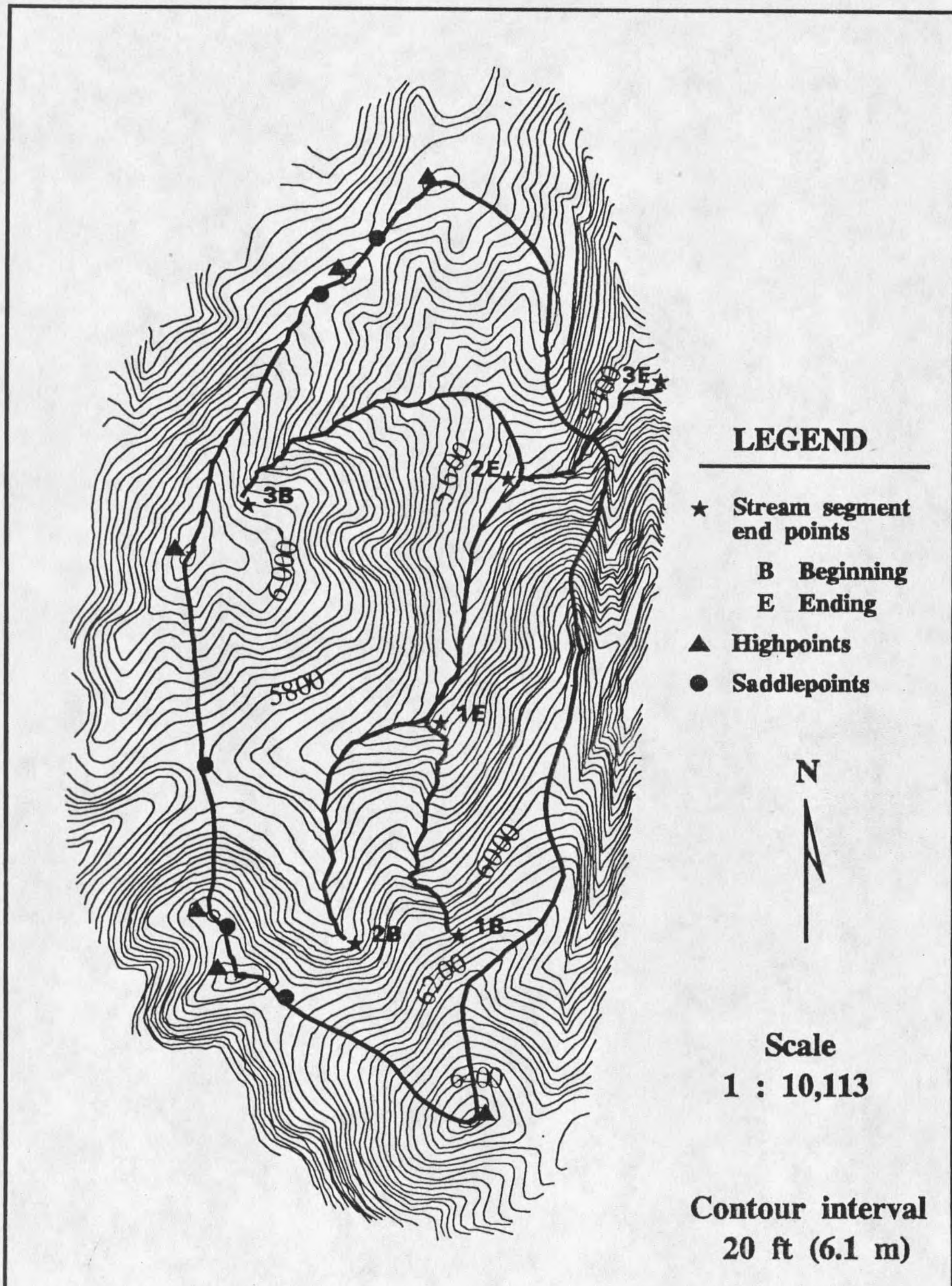

Figure 4. Visual representation of the elevation data layer created by digitizing contour lines.

Terrain Attributes

The terrain attributes were generated by the TAPES programs. These programs are computationally complex and require a number of input parameters to be entered by the user. Because the documentation describing parameter requirements for these programs was minimal, an unexpectedly large amount of time had to be allocated to determining appropriate input values.

The TAPES model generates several terrain attributes such as elevation, slope, aspect, and plan and profile curvature in the TAPES-G program; values for longwave and shortwave radiation and temperature estimates in the SRAD program; and soil water content, potential evapotranspiration, and estimated actual evapotranspiration in the WET program. The number of attributes included in this project was limited to two: the net radiation index and the soil wetness index. Both of these attributes should have an impact on how water is distributed across a landscape, and in as much as available water influences the type and quantity of plant growth in an area, the spatial variation of these indices should correlate to some degree with the spatial variation of the vegetation.

Net Radiation Index. Net radiation indices, based in part on the slope and aspect of a particular point on the landscape, were generated by the SRAD program. Positive net radiation values indicate that there is more incoming than outgoing radiation at the ground surface. The values for the Cottonwood Creek catchment, which were calculated for an integrated period of one year, range from +3 to +105 W m^{-2} (Table 4). A watt is the basic metric unit of power and is the equivalent of one joule per second (Berry, 1991).

Table 4. Net radiation categories and percent of catchment included in each category.

NET RADIATION INDEX			
Category name	Range of values (W / m^2)	Number of cells in each category	Percent of total area
NR 1	< 20.00	172	9.1
NR 2	20.00 - 39.99	440	23.2
NR 3	40.00 - 59.99	482	25.4
NR 4	60.00 - 79.99	398	21.0
NR 5	> 79.99	403	21.3
TOTALS		1895	100.0

Spatial variation of the net radiation index values is shown in Figure 5. When a comparison is made between the distribution of the radiation categories and the inset contour map, it can be seen that the steeper, north-facing slopes have the lowest net radiation values indicating the probability of locally cooler temperatures and less evapotranspiration. The more gently sloping, south-facing terrain has two to three times higher net radiation values indicating the probability of warmer overall temperatures and higher evapotranspiration.

Soil Wetness Index. Values for the soil wetness index, which is unitless, were generated by the WET program. For the Cottonwood Creek area these values ranged from -1 to +10 and were divided into classes as shown in Table 5. Spatial distribution of those categories is shown in Figure 6. The cells with the highest index values form a linear pattern which to some extent follows the stream network (see inset). This particular result was expected and conforms to the fact that the calculation for this index

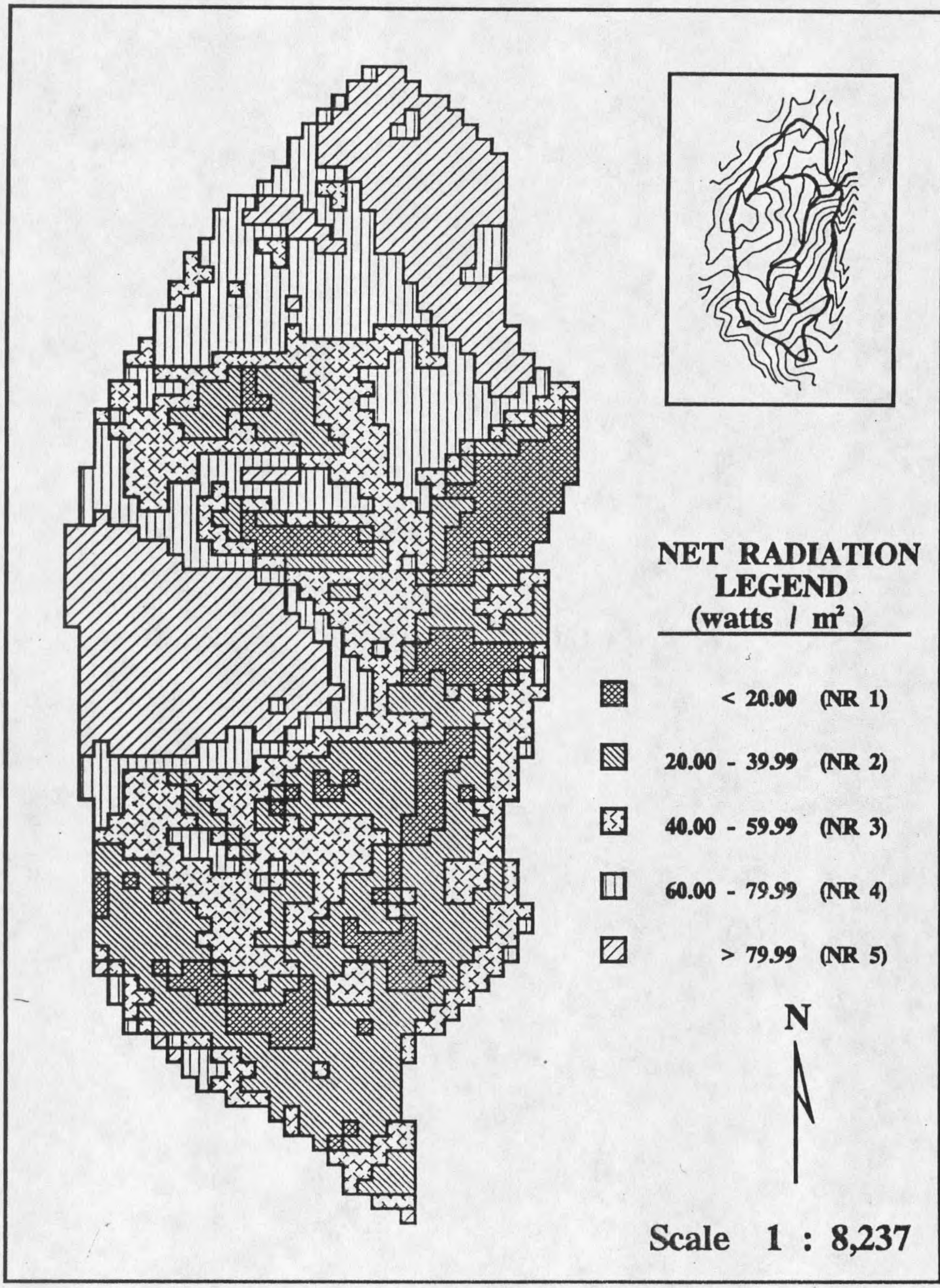

Figure 5. Visual representation of the net radiation data created by the TAPES model.

Table 5. Soil wetness index categories and percent of catchment included in each category.

SOIL WETNESS INDEX			
Category name	Range of values (unitless)	Number of cells in each category	Percent of total area
WET 1 (dry)	< 2.00	10	0.5
WET 2	2.00 - 3.99	564	29.8
WET 3	4.00 - 5.99	933	49.2
WET 4	6.00 - 7.99	295	15.6
WET 5 (wet)	> 7.99	93	4.9
TOTALS		1895	100.0

incorporates basic catchment hydrology theory. However, the pattern does not maintain complete fidelity to the stream network, probably due to the inclusion of an area weighting coefficient in the calculation which takes into account evapotranspiration on upslope areas.

Vegetation Map

The composite vegetation map that was classified from ADAR 5000 images is reproduced in Figure 7. Resolution of the original images was 2 m, however the classified image was resampled (using nearest-neighbor assignment) to produce cells that are 20 m by 20 m, which can be matched to the cells produced for terrain attributes. One consequence of resampling is that detail is lost when several smaller cells are combined to form a larger one.

Also, as explained in the methodology section, the composite image was rectified to the base contour map with a resulting RMSE of 32 m. This means that spatially, some cells may be shifted the distance of one or two cells from where they should be.

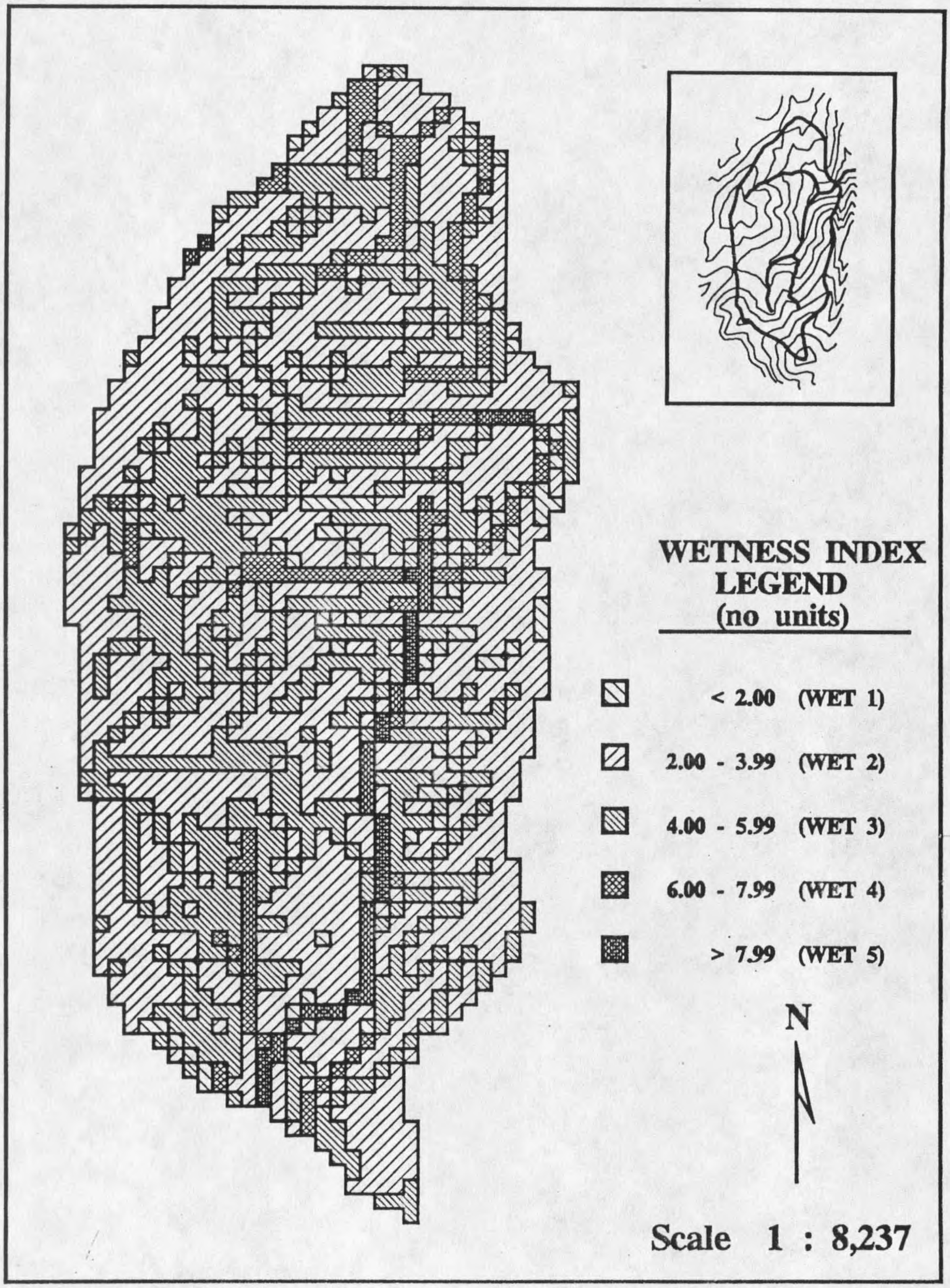

Figure 6. Visual representation of the wetness index data generated by the TAPES model.

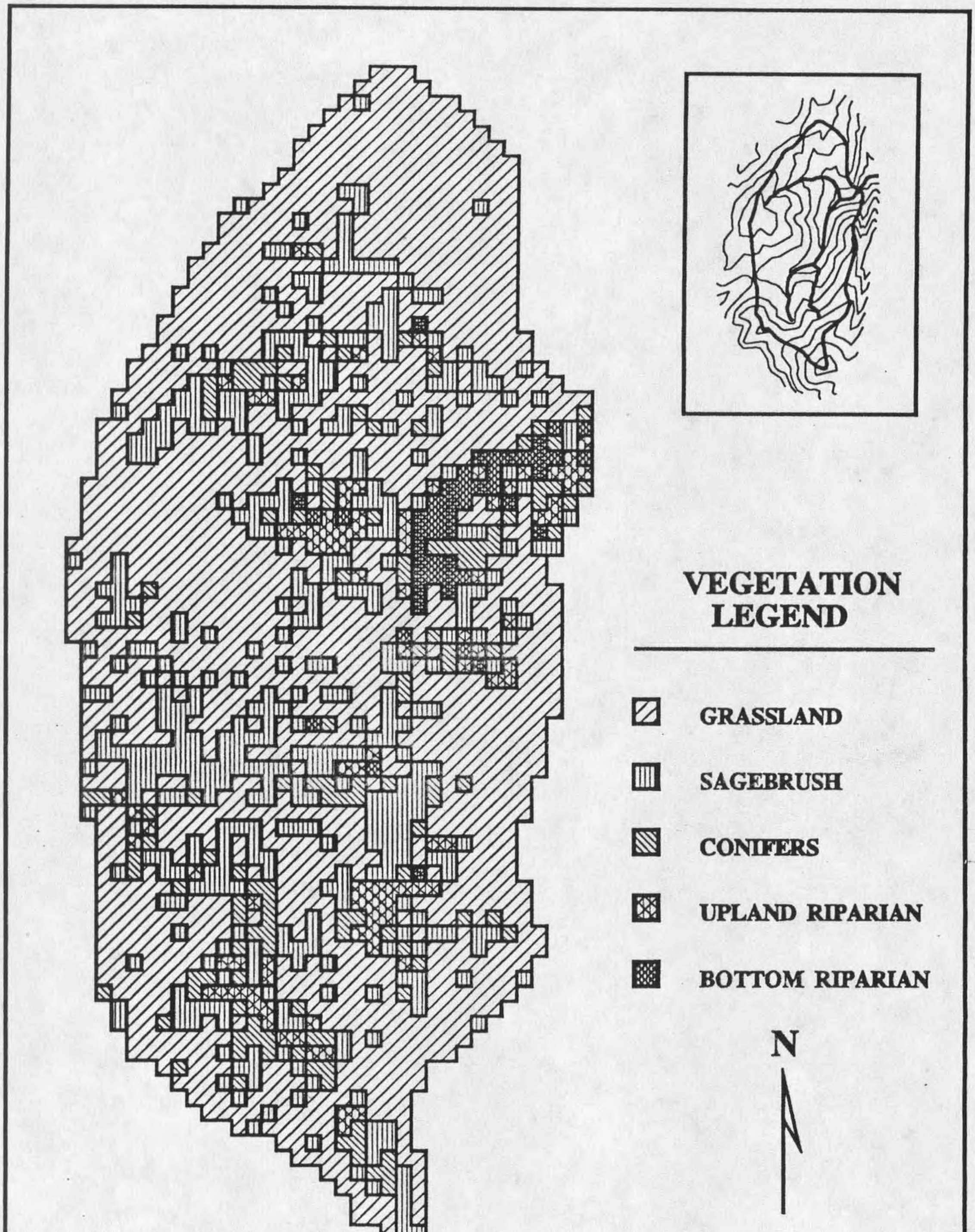

Figure 7. Visual representation of the vegetation classes created by classifying digital images.

Therefore, when the vegetation layer in the GIS is overlain on the terrain attribute layers, there may be some mismatch. The impact of this may be more significant with the soil wetness data layer than with the net radiation layer, because the pattern for the wetness index is fairly linear. If it is out of adjustment with the vegetation layer by even one cell then whole, rather than just parts of, categories could be misaligned.

The vegetation patterns shown in Figure 7 follow the topography (see inset) fairly closely. Riparian areas can be seen on the lower creek bottom and in north facing depressional areas. Sagebrush similarly follows the drainage pattern in the higher elevations. Grassland covers much of the upper slopes and hilltops. Table 6 shows what percent of the study area is covered by each category.

Table 6. Vegetation categories and percent of catchment included in each category.

VEGETATION CATEGORIES		
Category	Number of cells in each category	Percent of total area
Grassland	1212	65.0
Sagebrush	410	21.6
Conifers	129	6.8
Upland Riparian	95	5.0
Bottom Riparian	49	2.6
TOTALS	1895	100.0

Analysis

Correspondence analysis (CA) is a technique for displaying the rows and columns of a data matrix as points in dual low-dimensional vector spaces (Greenacre, 1984). Two CAs were performed for this project using the NCSS software (Hintze, 1990). The first CA shows the relationship between net radiation indices and vegetation groups; the second shows the relationship between soil wetness indices and vegetation groups.

Correspondence between the Net Radiation Index and Vegetation. Data obtained by combining the information in the net radiation data layer and in the vegetation data layer are shown in Table 7. For instance, of the 172 cells identified as being in the lowest net radiation group (NR 1), 66 had vegetation classified as grassland, 33 as sagebrush, 30 as conifers, 30 as upland riparian, and 13 as bottom riparian.

Table 7. Matrix of data showing the interaction between net radiation groups and vegetation categories.

		VEGETATION CATEGORIES					
		Grass land	Sage brush	Conifers	Upland Riparian	Bottom Riparian	TOTALS
NET RADIATION	NR 1 (low)	66	33	30	30	13	172
	NR 2	265	95	39	28	13	440
	NR 3	276	120	43	28	15	482
	NR 4	284	85	13	9	7	398
	NR 5 (high)	321	77	4	0	1	403
TOTALS		1212	410	129	95	49	1895

Relative frequencies of vegetation categories within each net radiation group are given in Table 8, allowing for easier comparison between groups. Each row of relative frequencies is the row of original frequencies divided by its total (e.g. NR 1/Grassland value of 66 (Table 7) is divided by row total of 172 to produce a relative frequency of 0.384). In correspondence analysis a set of relative frequencies (which add up to 1) is called a "profile" (Greenacre, 1984). Therefore, the row profile for the NR 1 group consists of the values 0.384, 0.192, 0.174, 0.174, and 0.076.

Table 8. Relative frequencies of vegetation categories within net radiation groups (i.e. row profiles) and the row masses.

	Grassland	Sagebrush	Conifers	Upland Riparian	Bottom Riparian	Masses
NR 1 (low)	0.384	0.192	0.174	0.174	0.076	0.091
NR 2	0.602	0.216	0.089	0.064	0.029	0.232
NR 3	0.573	0.249	0.089	0.058	0.031	0.254
NR 4	0.714	0.214	0.033	0.023	0.018	0.210
NR 5 (high)	0.797	0.191	0.101	0.000	0.002	0.213

Multiplying a relative frequency by 100 allows the value to be expressed as a percentage. For the NR 1 group (lowest net radiation), it can be seen that 38.4% of the area was classified as grassland and 25.0% as riparian (combining the two Riparian categories). In contrast, the NR 5 group (highest net radiation) had 79.7% of its area classified as grassland and only 0.2% classified as riparian.

Geometrically, CA defines each profile as a point in multi-dimensional space. Therefore, each net radiation group profile given in Table 8 defines a point in 5-dimensional space (i.e. each value in the profile is associated with a separate axis). Each point is weighted by a mass (Table 8) which is calculated by dividing row totals (Table 7) by the matrix total (eg. the mass allocated to the point defining the NR 1 profile is $172 \div 1895 = 0.091$) (Greenacre, 1984).

Because multi-dimensional space is difficult to visualize, the display of a correspondence analysis is typically 2-dimensional. Figure 8 is the display obtained from the correspondence analysis of the net radiation profiles shown in Table 8. When converting from 5-dimensional space to a 2-dimensional subspace a certain amount of inter-profile information is lost; the measure of the completeness of the summary

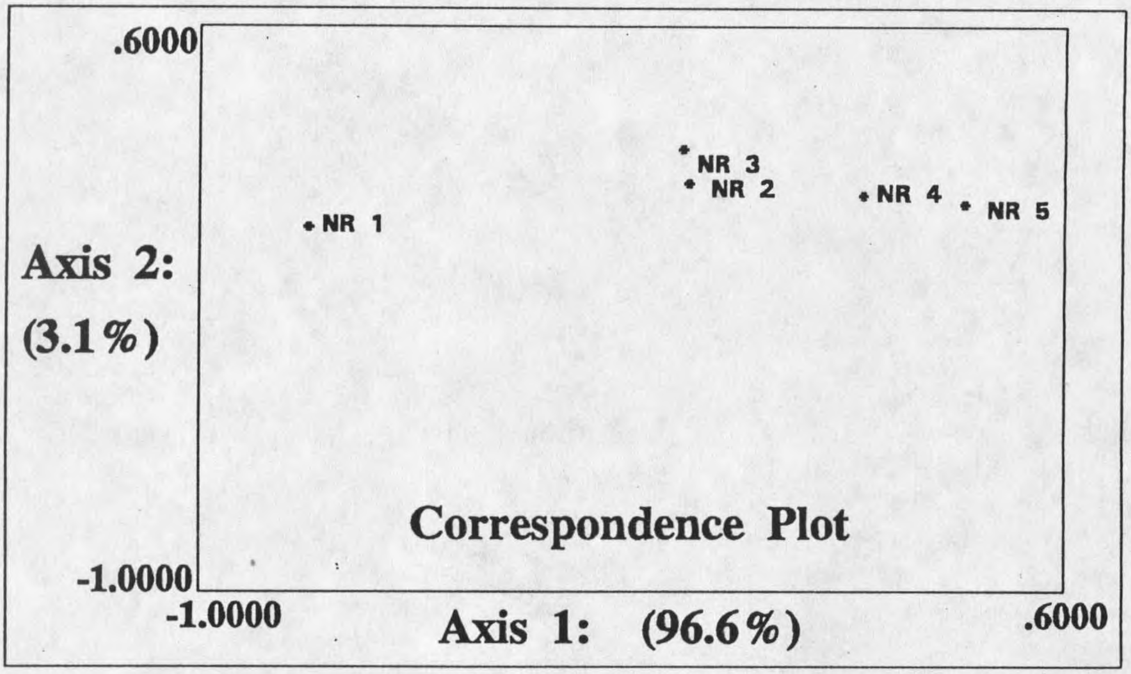

Figure 8. Correspondence analysis of the net radiation profiles given in Table 8.

provided by the display is given by adding the percentages on the two axes: 96.6% + 3.1% = 99.7% (Greenacre, 1984). The values -1.00 and .6000 are automatically generated scale values which create the best visual dispersion for interpretation (Hintze, 1990).

The distance between the points shown in Figure 8 is a measure of the similarity between the profiles of the net radiation groups. In other words, the display shows the relationships among net radiation groups in terms of the relative frequencies of their associated vegetation categories. From the display, it can be seen that the frequency distribution of the vegetation categories in the lowest net radiation group (NR 1) profile is distinctly different from the profiles of the other net radiation groups. Groups NR 2 and NR 3 are quite similar in terms of the frequency distribution of their associated vegetation categories; and groups NR 4 and NR 5 also share some similarities. Referring back to Table 8, this can be seen to be true when comparing the NR 2 and NR 3 profiles, and when comparing the NR 4 and NR 5 profiles.

A correspondence analysis for the vegetation category profiles is performed in the same basic manner. Table 9 gives the relative frequencies of net radiation groups within vegetation categories. The profile for the Grassland vegetation category shows that 5.4% of the area in that category is associated with the lowest net radiation group (NR 1) and that 26.5% is associated with the highest group (NR 5). The Bottom Riparian column profile shows that over 50% of the area it covers is associated with the two lowest radiation groups (NR 1 and NR 2), while only 2.1% of its area is associated with the highest group (NR 5).

Table 9. Relative frequencies of net radiation groups within vegetation categories (i.e. column profiles) and the column masses.

	Grassland	Sagebrush	Conifers	Upland Riparian	Bottom Riparian
NR 1 (low)	0.054	0.080	0.233	0.316	0.265
NR 2	0.219	0.232	0.302	0.295	0.265
NR 3	0.228	0.293	0.333	0.295	0.306
NR 4	0.234	0.207	0.101	0.094	0.143
NR 5 (high)	0.265	0.188	0.031	0.000	0.021
Masses	0.640	0.216	0.068	0.050	0.026

Figure 9 is the display obtained from the correspondence analysis of the vegetation category profiles shown in Table 9. It is shown graphically that the categories Upland Riparian, Bottom Riparian, and Conifers are roughly similar to each other in terms of the frequency distributions of their associated net radiation groups. The points

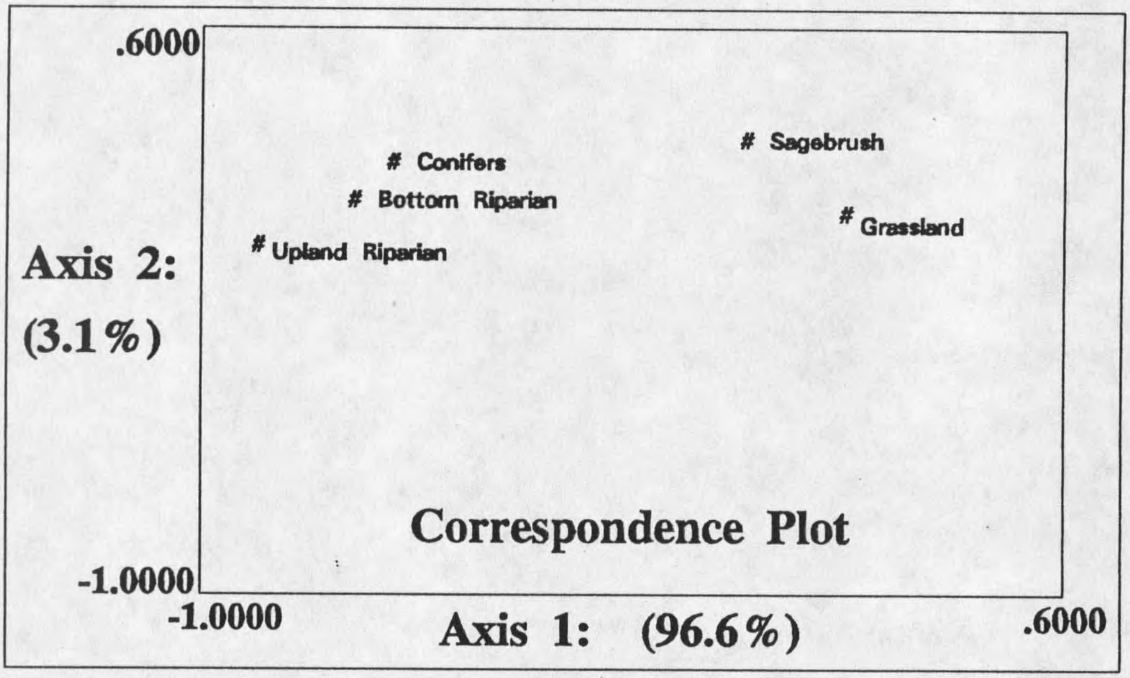

Figure 9. Correspondence analysis of the vegetation profiles given in Table 9.

for Sagebrush and Grassland lie relatively far from those groups, but appear to have some similarity to each other.

The geometry of the net radiation profiles (Figure 8) is directly related to the geometry of the vegetation profiles (Figure 9), so the displays may be merged into one joint display (Figure 10). The points in an individual display are considered to be a "cloud" of points, and the distances between points within an individual cloud can be used as a measurement of similarities between groups or categories. Distances between points contained in two different clouds (in a joint display) cannot be interpreted as explicitly. However, because there is a geometric relationship between the two individual displays there is a "correspondence" between the two clouds of points (Greenacre, 1984). Generally, each vegetation group will lie "more or less" in the

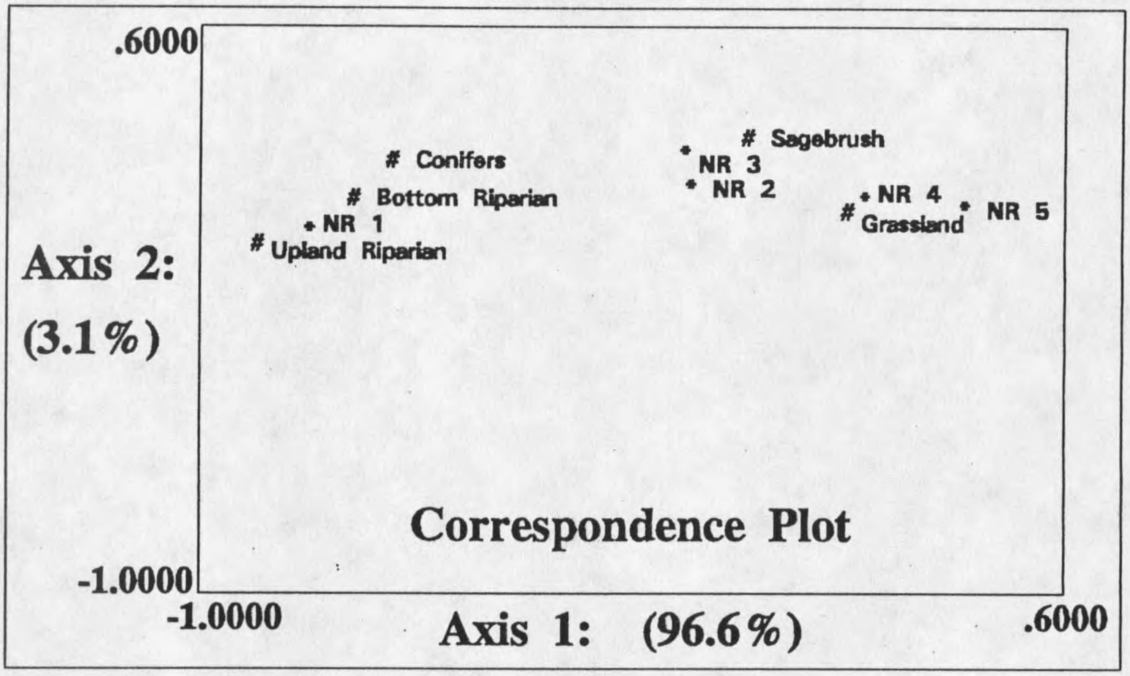

Figure 10. Correspondence analysis of the data in Table 7. This is the the joint display of Figures 8 and 9.

direction of the net radiation group in which that vegetation's profile is prominent. For example, looking at the Sagebrush category in Table 9, the order of prominence of the net radiation groups in the profile is NR 3 (0.293), NR 2 (0.207), NR 4 (0.207), NR 5 (0.188), and NR 1 (0.080). In the joint display (Figure 10), the point for Sagebrush lies closest to the points for NR 3 and NR 2, showing correspondence to those two groups. Looking at the NR 4 group in Table 8, the order of prominence of the vegetation categories in the profile is Grassland (0.714), Sagebrush (0.214), Conifers (0.033), Upland Riparian (0.023), and Bottom Riparian (0.018). In Figure 10, the point for NR 4 lies closer to the point for Grassland than to the points for other vegetation groups, indicating a strong correspondence.

Generally, in Figure 10 it can be seen that the vegetation categories of Upland Riparian, Bottom Riparian, and Conifers are grouped around NR 1, Sagebrush is near the NR 2 and NR 3 categories, and Grassland is near the NR 4 and NR 5 categories. While a one to one correspondence between net radiation values and vegetation groups does not exist, it appears that a strong association does occur between the computer generated index and vegetation.

Correspondence between the Soil Wetness Index and Vegetation. Data obtained by combining the information in the soil wetness data layer and the vegetation data layer are shown in Table 10. Correspondence analyses for the wetness index profiles, the vegetation profiles, and the merged profiles are displayed in Figures 11, 12, and 13, respectively. It should be noted that approximately 90% (17.4% + 72.5% = 89.9%) of the variation in the matrix table is accounted for in these plots.

In Figure 11, it can be seen that, in terms of associated vegetation categories, WET 5 (highest moisture) and WET 1 (lowest moisture) are extremely dissimilar, both

Table 10. Matrix of data showing the interaction between wetness index groups and vegetation groups.

		VEGETATION CATEGORIES					
		Grass land	Sage brush	Conifers	Upper Riparian	Bottom Riparian	TOTALS
WETNESS INDEX	WET 1 (low)	9	0	1	0	0	10
	WET 2	367	107	39	34	17	564
	WET 3	601	218	63	36	15	933
	WET 4	188	66	15	16	10	295
	WET 5 (high)	47	19	11	9	7	93
TOTALS		1212	410	129	95	49	1895

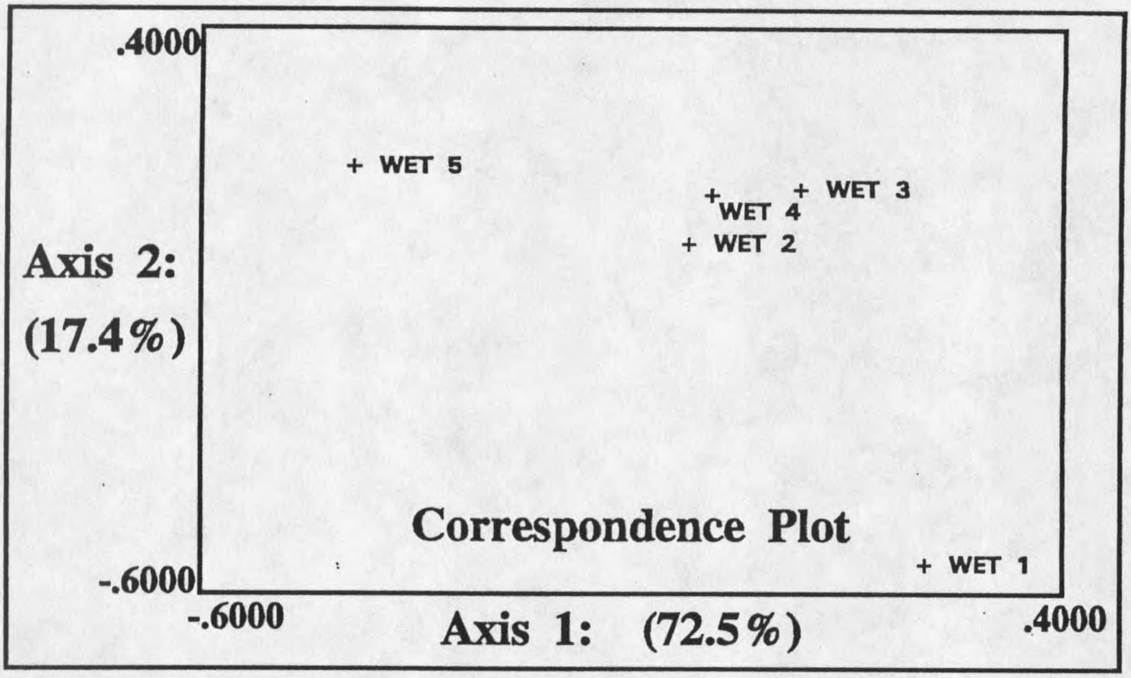

Figure 11. Correspondence analysis of wetness index profiles of the data matrix in Table 10.

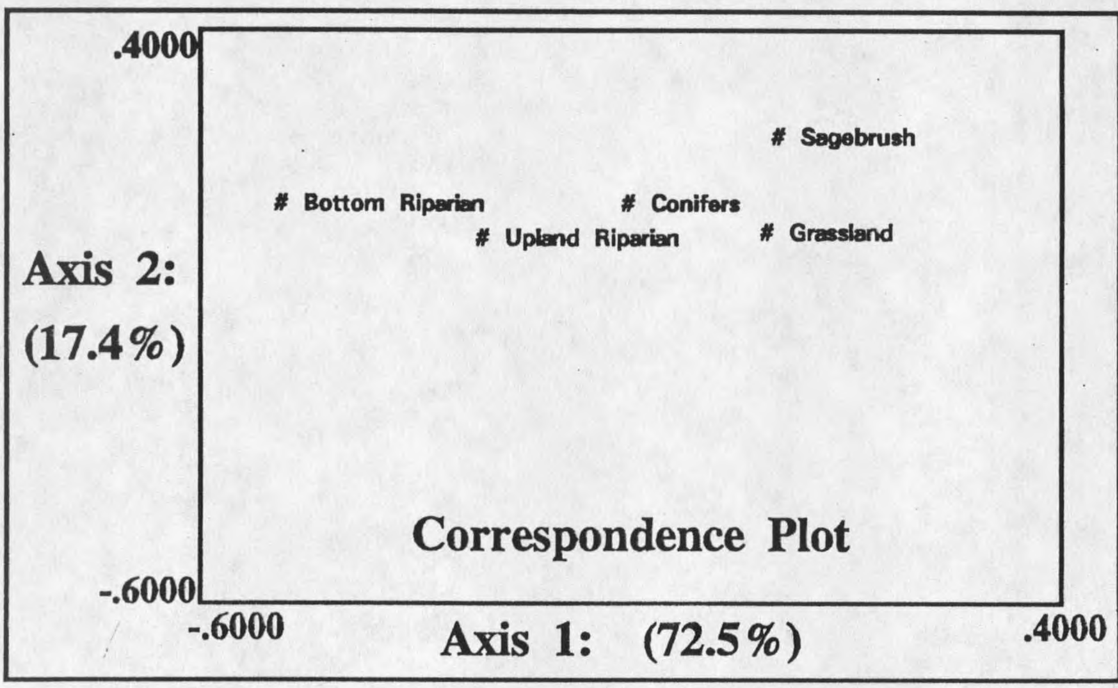

Figure 12. Correspondence analysis of vegetation profiles of the data matrix in Table 10.

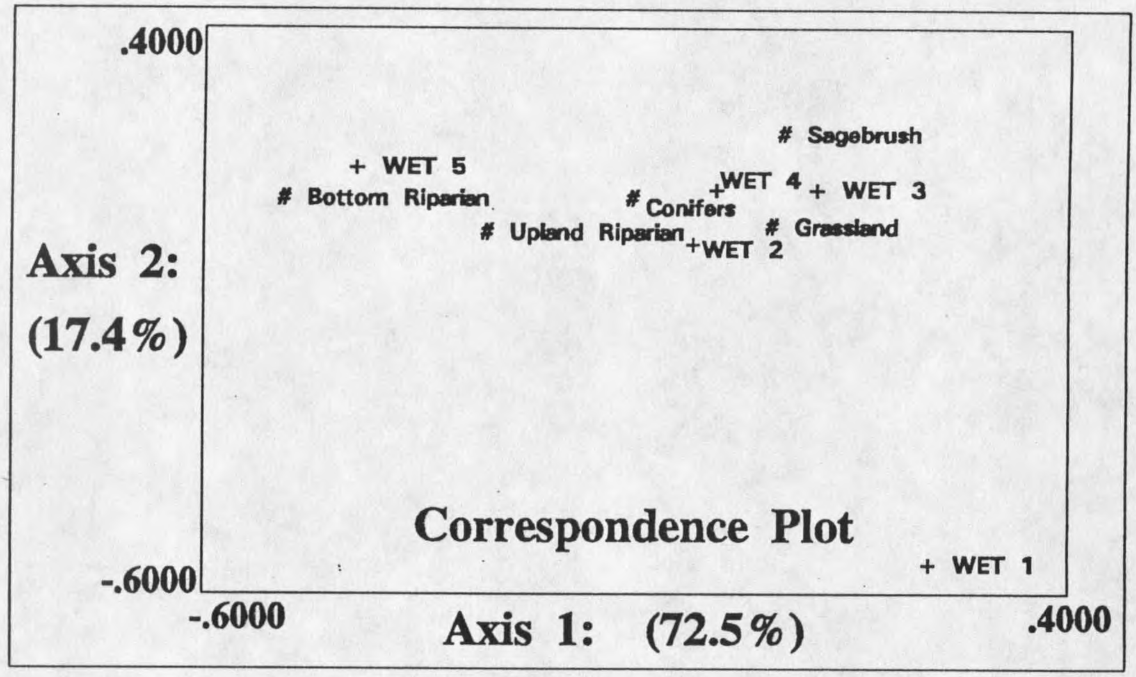

Figure 13. Correspondence analysis of the data in Table 10. This is a joint display of Figures 11 and 12.

to each other and to WET 2, WET 3, and WET 4 which appear to have some similarities among themselves. It should be noted that WET 2, WET 3, and WET 4 do not fall in a linear pattern along AXIS 1 as might be expected for categories that define a gradient. A possible explanation is that the misalignment of the wetness data layer with the vegetation data layer, which was discussed earlier, might affect the placement of these points.

In Figure 12, it appears that the vegetation categories are fairly distinct in terms of their associated wetness groups. When Figures 11 and 12 are combined into Figure 13, the relationships between the wetness index and vegetation appear to be more ambiguous than the association observed between vegetation and the net radiation index (Figure 10). The Bottom Riparian vegetation group corresponds strongly to WET 5.

However, Upland Riparian appears to be associated with WET 5, WET 4, and WET 2 (when it seems more likely that it would be associated with WET 3 than with WET 2). Conifers are associated with WET 4 and WET 2; Sagebrush with WET 3 and WET 4; and Grassland with WET 2 and WET 3. No vegetation group appears to be strongly associated with WET 1, probably because it occupied so few cells (Table 10).

Conclusions

The primary purpose of this project was to test whether spatially distributed topographic attributes, which are generated by the TAPES model, could be associated with vegetation patterns found on the upper Cottonwood Creek catchment. It was shown (using correspondence analysis) that categories of the net radiation values generated by this model are associated in a quasi-linear manner (along AXIS 1) with the distribution of vegetation groups in this area. The relationship between categories of soil wetness indices and vegetation groups is more ambiguous. There is a strong association between the category representing the wettest areas of the catchment and the Bottom Riparian vegetation group, but the relationship among the other wetness categories and vegetation groups is neither one to one nor linear in nature.

While there are several attributes that can be generated by the TAPES model, only two were used directly in this project. It is possible that other attributes (e.g. slope, aspect, or elevation) could have a stronger correspondence with vegetation patterns than is exhibited by the wetness index. In a study of soil attribute prediction using the TAPES model, it was found that the terrain attributes of slope and wetness index were most highly correlated with soil attributes (A horizon depth, organic matter, extractable P and pH) in a field in Colorado (Moore et al., 1993b). This suggests that vegetation that varies on a nutrient gradient might correlate well to a simple slope index.

To evaluate several different data layers or themes in a GIS requires that all layers be geodetically referenced to each other. While a GIS provides for relatively easy data integration among different thematic layers and cuts down on the time consuming process of synthesizing tremendous amounts of information it is only a tool and cannot compensate for data layers that might contain spatial or positional inaccuracies. This is relevant to a discussion of this project because there were several steps, in the creation of both the terrain attribute layers and the classified vegetation layer, during which spatial error was introduced. The terrain attributes contain considerable spatial error because they were derived from U.S.G.S. topographic map contour lines. The accuracy of topographic contour lines is regulated by the National Map Accuracy Standards (NMAS) which state "At least 90 percent of all elevations determined from solid-line contours shall be (vertically) accurate within one-half the contour interval and the remaining 10 percent shall be accurate within one contour interval" (U.S. Geological Survey, 1987). In terms of Cottonwood Creek, this translates to an error of $\pm$ 10 ft (3 m) on the source document. In addition, error was added during the digitizing process (human error) and during the interpolation process which translates contour lines to regularly space grid point data (Walsh et al., 1987). Therefore, while the thematic layers for the terrain attributes reflect the relative change across the landscape for each of the topographic indices, they are not perfectly correct in the geodetic sense. This is not a problem if the data layers are viewed individually for qualitative purposes; however it is a problem if they are layered with other thematic layers, which may or may not be out of adjustment themselves, and quantitative analysis is performed on the resultant combined layer.

In terms of the spatial integrity of remotely sensed data, some of the problems encountered have already been discussed. The rectification process, which uses a least squares solution of polynomial rectification equations that account for space in the x and y directions but not in the z direction, resulted in an RMSE of 32 m which is within the range that Bolstad (1992) found could be expected when rectifying air photos taken in moderate to steep terrain using two-dimensional transformation techniques. Welch et al. (1985) found similar error (28 m) when rectifying LANDSAT images with relief of 400 to 1000 m, so the error appears to be platform independent. They (Welch et al., 1985) noted that for average terrain conditions, this type of rectification will produce a product that will conform to NMAS standards for 1:50,000 to 1:100,000 scale maps, but not for scales to 1:24,000 (where acceptable error is $\pm$ 12.2 m (U.S. Geological Survey, 1987)). Therefore, if absolute precision is required in a classified image, geometric correction should be done by a technique which takes into consideration elevation changes across the terrain. These techniques exist, however they require expensive software and knowledgeable operators. The advantage of the 2-D transformation technique used in this project is that it is relatively easy to use and is included as a module in several software packages such as ARC/INFO or ERDAS.

While processing the ADAR images, spatial error was compounded when stitching several images together. An exact match between the sides of the images did not exist, therefore the edges of some images were "stretched" to match the others. This is an unavoidable problem when working with several images; ideally an entire study area needs to be captured on one image to avoid this problem. The ADAR imagery is relatively new and was chosen for this project because it was available at a reasonable cost. Its primary strength is that, with its high resolution, it produces images that contain a high degree of detail. Also, the spectral data values provide good contrast and are easy to use for classification. The drawback to the images produced by this system is that they provide coverage for areas that are relatively small (pixel matrix of 486 rows by 739 columns). Therefore, multiple images need to be mosaiced together, if coverage of a large area is desired. In retrospect, given that the cell size for the terrain attributes can be varied based on user requirements, it may have been more appropriate for this project to use satellite data which are based on a pixel size of 30 m. The terrain attributes could have been generated in a 30 m grid pattern. This approach would have allowed for the generation of overlays among the layers without any need for resampling the image data and would have had the additional advantage of providing full coverage of the area on one image.

Soil/landscape/vegetation interactions are sufficiently complex that it is probably overly simplistic to expect any one index to account wholly for patterns of vegetation over a landscape. It is more feasible to expect that several factors, in combination, would better reflect landscape conditions and therefore be more predictive of vegetation patterns. However, because of the complexity of the relations among environmental factors, one predictor, such as net radiation, might be dominant on one section of the landscape while other predictors such as elevation or slope might be dominant in another area. Therefore, even if data layers existed for several themes, it would be virtually impossible to derive one scheme of combining those themes which would be representative for every position on the landscape. One approach to this problem, which has been under investigation for the past several years (Coughlan and Running, 1989; Twery et al., 1991), is to use an expert system which allows thematic values to be weighted so that dominance might be shifted from factor to factor depending on how those factors interact across a landscape. This approach, which is still in its infancy, tries to emulate the reasoning of environmental experts, by using a series of decision rules, to determine how the interactions of several spatially varying factors change over a landscape. The challenge of creating an expert system, which could predict vegetation patterns based on landscape parameters, would be in figuring out how to reduce the knowledge of an environmental expert to a series of logical rules that could be coded to use with data layers in a GIS.

In spite of the spatial errors contained in the thematic layers, there was enough correspondence between the net radiation attributes and the vegetation groups to determine that additional research using computer generated terrain attributes is warranted in environmental studies. It will require significantly more testing to determine which of the attributes generated by the TAPES programs provide the best predictive information and what the optimal grid size is for a given research objective and study area. However, comprehensive documentation (which did not exist for this project) describing the data inputs and computational options for TAPES is needed before other researchers can integrate the use of these programs into their own projects.

CHAPTER 3

PREDICTING CATCHMENT RUNOFF USING A TERRAIN-BASED HYDROLOGY MODEL

Introduction

Erosion is a natural process which occurs on soils of all landscapes, regardless of the type of vegetation present. In undisturbed areas the rate of erosion may be faster or slower than the rate of soil formation, but generally the net accumulation or loss of soil will be so slow that it is measurable only in hundreds or thousands of years. In contrast, in disturbed areas (e.g. areas which have been altered by grazing, cultivation, logging, fire, or construction) the rate of erosion can be many times greater than in similar undisturbed areas and can sometimes be measured in single years or decades.

Soil which is displaced during the process of water erosion manifests itself in two ways: on-site effects and off-site effects. On-site effects are frequently associated with changes in plant productivity. As soil is displaced, attributes important to plant life are changed or lost. Losses of organic matter and fine soil particles, which are selectively removed by water (Pimentel, 1993), decrease the water holding capacity of a soil, a critical component in plant growth. Once lost, water holding capacity cannot be replaced and this, along with restricted rooting depth due to thinning topsoil, is erosion's most harmful effect on productivity (Pimentel, 1993; Larson et al., 1985). Additionally, erosion removes soil nutrients, the loss of which can become a limiting factor in plant productivity. Nutrients can be replaced through fertilization; however, the cost of replacement may be prohibitive to the land manager/owner and the resulting plant productivity may not be as high as in the original soil matrix (Tanaka and Aase, 1989).

While the immediate on-site impacts of erosion are felt primarily by the landowner, the problems associated with the off-site effects of erosion are experienced by multiple water users downstream from an erosion site. Damages attributable to suspended sediments in water-ways are diverse. Aquatic life forms may be harmed or killed as sediment smothers small organisms and decreases the light penetration of water needed for plant photosynthesis. Sediments accumulate in reservoirs and stream channels causing increased risks of flooding and in some areas requiring dredging. Increased turbidity results in more wear and tear on water treatment systems and consequently, in higher costs associated with municipal water use (Patrick et al., 1992). The recreational value of water is reduced because the cloudiness associated with suspended sediments is unattractive to swimmers, fishermen, and boaters (Crosson, 1985; Dinius, 1981). Finally, many pollutants that are transported by suspended sediments, such as nutrients and pesticides, can be harmful to plant and animal populations (Razavian, 1990).

The problems attributable to erosion are numerous and have long-range effects which are costly and sometimes hazardous to deal with. Consequently, the need to develop reasonable methods for controlling soil erosion at its source has long been recognized. While a great deal of research has been focused on dealing with erosion as a uniform occurrence across a given basin, Campbell (1985) points out that, because the hydrologic response of a basin varies spatially, such a technique has no value other than simplicity. He discusses the need to understand sediment source areas in terms of the partial area runoff (or variable source area) concept. This concept recognizes that the portion of a watershed which produces runoff can shrink and expand depending on rainfall amount and antecedent wetness of the soil. Based on these criteria, runoff in almost all cases will be generated from an area much smaller than the total basin area (Black, 1991). Campbell concludes that sediment, like the runoff that produces it, is derived principally from spatially limited portions of a basin.

Therefore, the development of effective management practices, focused on limiting erosion at its source, will depend in part on understanding how hydrology responds to a spatially varying landscape. One approach to furthering this understanding is to develop and test models which reflect current knowledge of naturally occurring hydrologic processes. The degree to which simulated hydrologic responses correspond to real events is an indicator of the validity of the assumptions regarding hydrologic relationships and processes which are incorporated in a model. During the process of discovering the strengths and weaknesses of these assumptions, the understanding of hydrologic processes is advanced. The objective of this project is to test one such process based hydrologic model using as input the Cottonwood Creek contour data which were digitized for the terrain modeling project described in Chapter 2.

Materials and Methods

Hydrology Model

The THALES hydrology model (Grayson et al., 1992a) was used for this project. THALES is a distributed-parameter model in that: 1) data can be input to reflect variations in the landscape, and 2) the model will incorporate these spatially changing characteristics in its calculation of hydrologic processes. To accommodate this distributed parameter approach, the map area for which the model is run needs to be partitioned into small elements which are structured to realistically reflect catchment processes (ie., so that water can be expected to flow from one element to another). Therefore, as a prerequisite to running THALES, a terrain analysis program know as TAPES-C, Topographic Analysis Programs for the Environmental Sciences-Contour (Moore et al., 1988; Moore and Grayson, 1991), is run.

TAPES-C is a contour-based model designed to subdivide a catchment into elements based on the way water flows over the surface of a landscape. It uses a "stream tube" approach to partition a watershed, such that contour lines are treated as equipotential lines and orthogonal trajectories to those contour lines, spaced at a user specified distance, are used to define hydrologic streamlines. The intersection of the contour lines and the orthogonal trajectories to those lines define irregularly shaped elements. Each element is bounded on its upper and lower edge by a contour line and on each side by a trajectory. Elements are "stacked" one on top of another from stream bottom to ridge top forming "stream tubes" through which runoff can realistically be routed.

As TAPES-C subdivides a catchment into elements it also calculates a variety of terrain attributes. For each element, the following topographic characteristics are computed: element area; total upslope contributing area; connectivity of upslope and downslope elements; x,y,z coordinates of the element centroid; x,y,z coordinates of the midpoint on the downslope contour bounding the element; the average slope of the element orthogonal to the contour; the widths of the element on the upslope and downslope contour lines bounding the element; the flow distance across the element; and aspect or azimuth of the element.

THALES uses the network of elements generated by TAPES-C in its calculations of hydrologic processes. In this model, the calculation of surface runoff incorporates three concepts: 1) Hortonian overland flow (runoff which occurs when rainfall intensity exceeds the infiltration capacity of the soil), 2) variable source runoff (runoff from saturated areas), and 3) exfiltration of subsurface flow (runoff which occurs when the rate of subsurface flow exceeds the capacity of the soil profile to transmit water, causing part of the subsurface flow to return to the surface).

Mechanically, THALES calculates surface flow, subsurface flow, infiltration rate, exfiltration rate, and rainfall excess for every element at time intervals designated by the user. Computations start with the uppermost element, progress across the elements associated with the highest contour, and then continue with elements associated with successively lower contours. After the last element is reached, the process is begun again for the next time step. Surface and subsurface flow are routed from upslope elements to downslope elements. Subsurface flow enters and exits an element via the saturated zone. If the saturated zone reaches the surface, saturated source area runoff occurs and exfiltration of subsurface flow is possible. Surface runoff may continue after rainfall ceases and this surface runoff can infiltrate in a downslope element if the soil profile of the downslope element is not saturated.

Flow data generated for the lowest elements in a catchment can be imported to a graphics package, where hydrographs can be produced for simulated events. Comparisons to data collected from real events can be made visually using this format. Data inputs and files used for this project are shown in Figures 23 through 31 of Appendix B.

Additional Programming Requirements

Elevation data required as input to the TAPES-C program were digitized using ARC/INFO software as explained in Chapter 2. The data storage format in ARC/INFO is quite different from the data format required by TAPES-C; therefore, it was necessary to design and code a series of programs to convert and transfer the data in ARC/INFO to TAPES-C.

The contour based terrain model, TAPES-C expects the vectors representing contour lines to be ordered from lowest elevation to highest elevation and to all point in a consistent direction (Moore et al., 1988). In contrast, in ARC/INFO one contour line may be represented by several small vectors, and these vectors can be stored in a mixed order and with mixed directions. A process which allows a user to view the vector data and to interactively update the order and direction of vectors on the ARC/INFO database was designed and programmed. The core programs for this process and for the transferral of data to TAPES-C are shown in Figures 32 through 35 of Appendix C.

In addition to the need to write code for a conversion process, programming efforts were also needed to determine how to run TAPES-C and THALES. These programs are complex, requiring a number of variables as input. Because the programs are unaccompanied by instructions, it is difficult to know how the variables are defined and therefore is difficult to know what values to assign them as input. This is a problem because, to obtain the best results from a modelling effort, it is necessary to fully understand how the variables are used and how they interact. Lacking documentation, the only way to understand how the programs work is to walk through the code to see what calculations are made and how they are done. Given the complexity of these programs, full understanding of the calculations would require an intensive study. For this project, a cursory (relatively speaking) effort was made to understand how the programs function internally, and a "best guess" approach was used to determine input values which would not cause the programs to end abnormally.

Field Measurements

Precipitation and stream discharge data were obtained from Dr. C. Marlow (College of Agriculture, Montana State University) who began monitoring the Cottonwood Creek Catchment in 1981 with the intent of determining the relationship between various cattle-grazing management practices and riparian degradation (Marlow et al., 1987). Rainfall in the watershed was measured with two rain gauges, a tipping-bucket, recording rain gauge and a non-recording gauge. Both gauges, which were located next to each other near the lower end of the watershed, measure precipitation to

±0.01 mm (Aspie, 1989). As rainfall was measured at only one point in the watershed, the amount of rain received at this point is assumed to have fallen over the entire watershed (Marlow et al., 1987; Aspie, 1989).

Stream discharge was measured with a Parshall flume which was placed at the downstream boundary of the study area. The flume had a 6 in (15.24 cm) throat (58 l/s capacity). Stage height within the flume was monitored continuously using a Stevens Type F model 68 flow recorder which was mounted on the flume. Measurement precision of the recorder is ±0.01 ft (0.30 cm) (Marlow et al., 1987; Aspie, 1989). Stage-discharge relations for the Parshall flumes in English units are as follows:

$$6 \text{ in}: \quad Q \text{ (cfs)} = 2.06\, H^{1.58}$$

where Q is discharge (ft^3/sec) and H (ft) is stage height recorded on the upstream end of the flume (Aspie, 1989). Discharge calculated using this formula was subsequently converted to liters per second.

Results and Discussion

A rainfall event was simulated using precipitation data gathered on July 25 and 26, 1990. For the simulation, it was assumed that soil was saturated across the entire Cottonwood Creek catchment. Discharge predicted from this simulated event is compared to observed discharge for the same period in Figure 14. The Y axis on the left side of the chart is for discharge in l/sec, while the Y axis on the right is for precipitation measured in mm. Based on observed data for the week prior to this event, it was presumed that base flow in the channel was 1.4 l/sec.

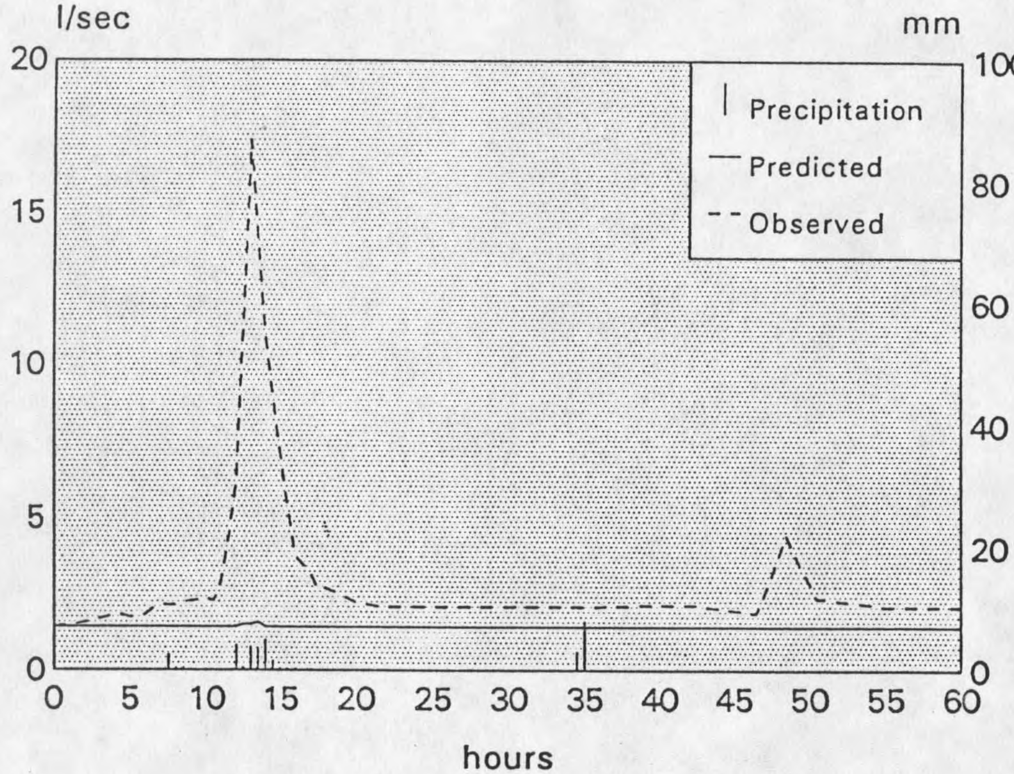

Figure 14. Observed discharge vs. predicted discharge.

The most striking observation is that variation in the predicted discharge is almost non-existent. At hour 13.5, simulated discharge peaks at 1.56 l/sec, a rise of only 0.16 l/sec above the assumed base flow. In contrast the observed discharge peaked at 17.40 l/sec at hour 13. This is at least an order of magnitude higher than the predicted peak. The discrepancy is more likely due to improper use of input values (ie. insufficient understanding of how to run the model) than to an inaccuracy in the model itself.

Another, much smaller simulated peak occurs at hour 34.5. It is so small (1.41 l/sec) that it does not show on the hydrograph, but is notable because it occurs in the same time period as a recorded precipitation event. The observed increase in discharge that can most closely be associated with this additional precipitation occurs more than ten hours later, peaking at hour 48. Such a discrepancy between the timing of observed precipitation and observed discharge might occur as the result of miscalibrated equipment.

An additional simulation was attempted using the same precipitation data, but changing input values to reflect soil conditions where infinite infiltration would occur across the catchment. Predicted discharge in this simulation did not increase above the 1.4 l/sec assumed base flow.

Conclusions

Hydrologic events simulated in this project compare very poorly to observed events, however as previously stated this is probably due to lack of information about how to run the programs to produce the best simulation. In addition to the file passed to THALES from TAPES-C which contains data for 9 attributes, there are 5 other input files to the THALES program which contain more than 30 other variables. Also, there are several interactive questions (the number varies depending on the options chosen, but there are typically more than 10) that the user needs to answer during program run-time. Uninformed choices in selecting values for the input parameters or in answering interactive questions have an adverse effect on output results.

While the simulations attempted in this project cannot be viewed as successful, a positive result of the experience is that a process now exists for converting data from an ARC/INFO format to a format compatible with TAPES-C. Future projects can take advantage of this, which will allow more time and energy to be devoted to understanding the mechanics of TAPES-C and THALES. This should result in more realistic simulations in the future. Until that time, it would be inappropriate to draw any conclusions about the efficacy of the model itself.

Two purposes exist for developing a model: 1) to provide a tool for hypothesis testing and 2) to provide a predictive tool (Beven, 1989; Grayson et al., 1992b). It should be noted that the THALES model is not intended for the purpose of prediction but rather for the purpose of assisting in the interpretation of data and in testing of hypotheses. Grayson et al. (1992b, p. 2665) remark that,

> for management purposes, simpler, less pretentious models in which data requirements are low, assumptions are clearly stated and results are generally qualitative may be a more realistic approach and more in balance with the available level of information....The development of the simpler "management" techniques will draw on the knowledge gained from the development of the more complex models, but these techniques are a fundamentally different tool to be developed in a different context.

They (Grayson et al., 1992b) also state that the data requirements for testing the complex models cannot be met by data originally collected for a different purpose. In this context, the approach taken for this project (i.e. the need for precise model instructions and the use of previously collected data) seems more appropriate for testing a simpler "management" type of model than for a complex model such as THALES.

CHAPTER 4

SUMMARY

GIS technology was used to collect elevation data for a small catchment in southwestern Montana. The GIS was then used as the source of elevation data for two terrain-based models which generate spatially distributed output. Two topographic attributes generated by the first model, a net radiation index and a soil wetness index, were written back to the GIS as separate data layers. A third data layer, containing vegetation information for the catchment, was created by classifying six digital images taken from a small aircraft.

Partially as a result of the methodology used to collect the image data and partially due to the steepness of the terrain, it is possible that serious spatial error, which could not be eliminated with available rectification methods, was introduced to the vegetation data layer. Nonetheless, comparisons between the net radiation data and the vegetation data showed that Upland Riparian, Bottom Riparian, and Conifer vegetation categories were strongly associated with the lowest net radiation index value generated by the terrain model; Sagebrush was associated with the two middle index values; and Grassland with the two highest values. The results of a comparison between the vegetation data and the soil wetness index data was more ambiguous; no definite pattern of association between vegetation categories and index values appeared. It is possible that the ambiguity encountered in this comparison is partially due to the spatial error occurring in the vegetation data and/or the way in which the cells were allocated to five variable-sized wetness categories.

The format of the elevation data in the GIS was sufficiently different from the data format required by the second model, a terrain-based hydrology model, that it was necessary to write an interface between the two systems. After that was completed, preliminary runoff simulations were conducted using the reformatted elevation data; however, the results of these simulations were not very encouraging and further work is required to generate more appropriate model inputs.

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APPENDICES

APPENDIX A

VEGETATION CATEGORIES

Table 11. Plant species found in each vegetation category and locations where sampling was done.

CATEGORY	COMMON NAME	SCIENTIFIC NAME
GRASSLAND		
a) Higher areas of the drainage		
	idaho fescue	Festuca idahoensis*
	bluebunch wheatgrass	Agropyron spicatum*
	fringed sage	Artemisia frigida
	cudweed sagewort	Artemisia ludoviciana
	western yarrow	Arcillea millefolium
	needle and thread	Stipa comata
	prairie junegrass	Koleria pyramidata
	salsify	Trapopogon dubius
	pussytoes	Antennaria sp
	cheatgrass	Bromus tectorum
	hairy goldaster	Chrysopsis viscidiflorus
b) In meadows close to the stream		
	bluebunch wheatgrass	Agropyron spicatum*
	western wheatgrass	Agropyron smithii*
	green needlegrass	Stipa viridula*
	fringed sage	Artemisia frigida
	green rabbitbrush	Chyrsothamnus viscidiflorus
	cheatgrass	Bromus tectorum
	sedge	Carex rostrata
	bearded wheatgrass	Agropyron caninum
	canada thistle	Cirsium arvense
	common mullein	Verbascum thapsus
	hounds tongue	Cynoglossum officinal
SAGEBRUSH		
a) area adjoining grassland meadow		
	big sagebrush	Artemisia tridentata*
	cheatgrass	Bromus tectorum*
	bluebunch wheatgrass	Agropyron spicatum*
	cudweed sagewort	Artemisia ludoviciana
	green rabbitbrush	Chyrsothmanus viscidiflorus
	basin wildrye	Elymus cinereus

* Dominant species.

CATEGORY	COMMON NAME	SCIENTIFIC NAME
CONIFERS		
a) South side of creek		
	limber pine	Pinus flexilis*
	juniper	Juniperus scopulorum*
	big sagebrush	Artemisia tridentata*
	idaho fescue	Festuca idahoensis
	bluebunch wheatgrass	Agropyron spicatum
	prairie junegrass	Koeleria pyramidata
	wild buckwheat	Eriogrium sp
UPLAND RIPARIAN		
a) Depressional areas on north facing slopes		
	wild rose	Rosa sp
	Rocky Mountain maple	Acer glabrum*
	chokecherry	Prunus virginiana
	snowberry	Symphoricarpos sp*
	serviceberry	Amerlanchier alnifolia
	ninebark	Physocarpus malvaceous*
	currant	Ribes setosum
	bergamot	Monarda fistulosa
	fleabane	Erigerort speciosus
	giant hyssop	Agastache urticifolia
	yarrow	Achillea millefolium
	false sunflower	Helianthella uniflora
	baneberry	Actaea rubra
	tall larkspur	Delphinium occidentale
	groundsel	Senecio serra
	Kentucky bluegrass	Poa pratensis
	green needlegrass	Stipa viridula
	timothy	Phleum pratense
	redtop	Agrostis stolonifera
	basin wildrye	Elymus cinereus*
	hawkweed	Hieracium cynoglossoides
	mountain brome	Bromus carinatus
	big sage	Artemisia tridentata
	green rabbitbrush	Chrysothamnus viscidiflorus
	nettle	Urtica dioica
	bluebunch wheatgrass	Agropyron spicatum
	sticky geranium	Geranium viscossismum
	iris	Iris sp

* Dominant species.

CATEGORY	COMMON NAME	SCIENTIFIC NAME
UPLAND RIPARIAN		
b) Ephemeral drainage on north side of catchment		
	willow trees	Salix bebbiana
	beaked sedge	Carex rostrata
	Kentucky bluegrass	Poa pratensis
	redtop	Agrostis stolonifera
	timothy	Phleum pratense
	catnip	Nepeta cataria
	juniper	Juniperus coopulorum
	currant	Ribes sp
	twisted stalk	Streptopus amplexifolius
	false solomens seal	Smilacina racemosa
BOTTOM RIPARIAN		
a) along lower end of stream		
	aspen	Populus tremuloides
	willow trees	Salix bebbiana
	beaked sedge	Carex rostrata
	timothy	Phleum pratense
	Kentucky bluegrass	Poa pratensis
	cheatgrass	Bromus tectorum
	currant	Ribes sp
	wild rose	Rosa sp
	redtop	Agrositis stolonifera

APPENDIX B

FLOWCHART AND INPUTS TO PROGRAMS

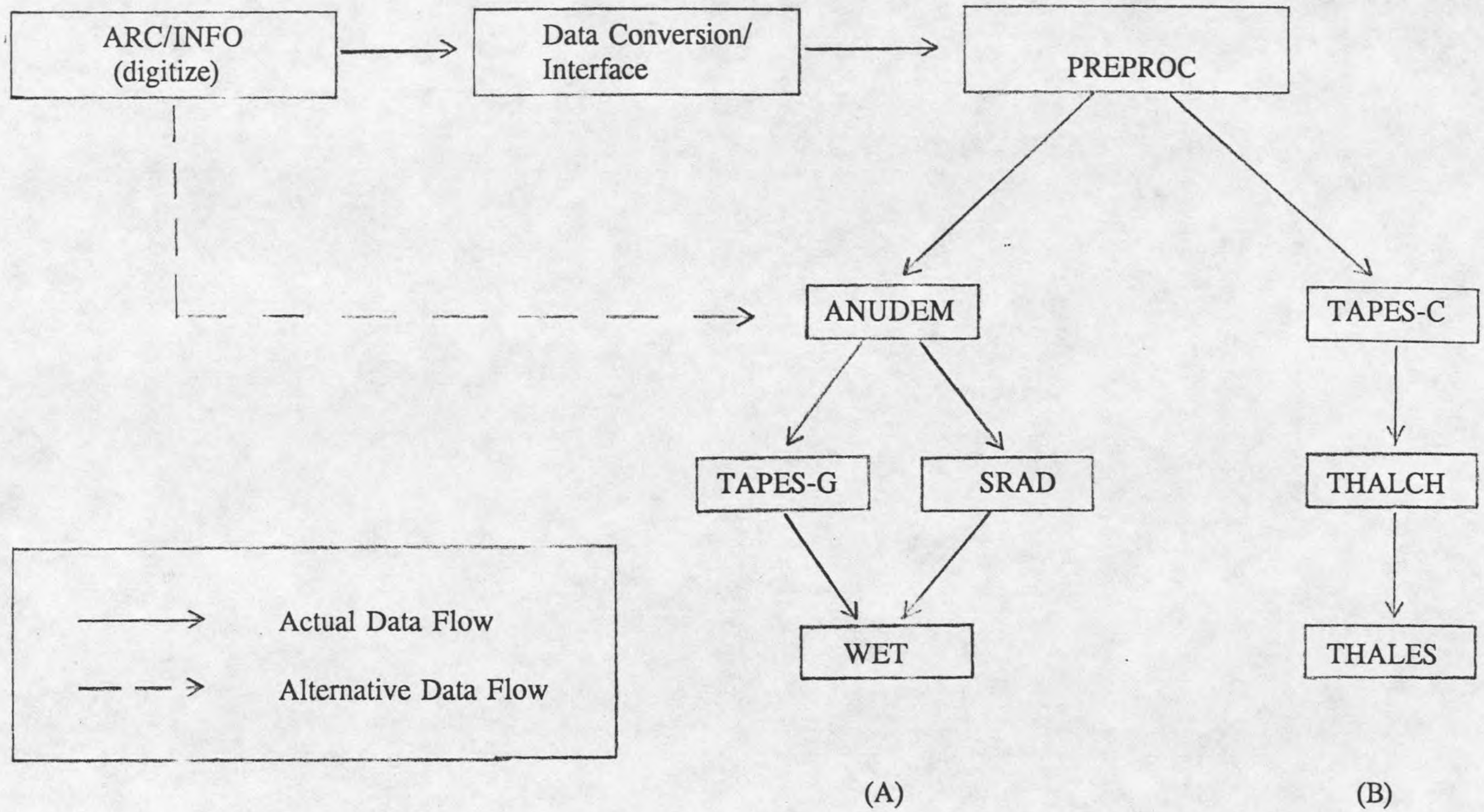

Figure 15. Comprehensive data flow for: (A) generating terrain attributes and (B) simulating hydrologic characteristics.

```
******************************************************************************
* Documentation:   Digitizing contour lines as input to TAPES model; conversion  *
*                  of data from ARC/INFO format to PREPROC format.               *
*                                                                                *
* Author:          JK Jersey, Department of Plant and Soil Science,              *
*                  Montana State University, Bozeman, MT                         *
*                                                                                *
* Date:            Summer, 1992                                                  *
*                                                                                *
* Assumption:      Coverage will be digitized using UTM projection.              *
******************************************************************************
```

1. Digitize the coverage. Do not allow the user-id to increment automatically; you want to enter the user-id manually.

   A. Contours: The elevation for each contour should be entered as the user-id. It is a good idea to digitize beyond the boundary of your study area (a half inch or more); the wider the border around your area, the better the predictive capability of the TAPES programs.

   B. Other features (ie. highpoints, saddlepoints, streamlines, two points defining a West/East line, boundary):

   Before digitizing any of these features, you need to add the item 'FEATURE' to your AAT (arc attribute table). However, at this point the AAT may not have been generated yet. If you don't have an AAT for your coverage, generate one by using the CLEAN command (see ARC/INFO User's Guide Vol. 2 for format); if you are on a PC you will probably need to do a BUILD also.

   Now, to add the item 'FEATURE' use the following command:

   ARC: ADDITEM 'COVERAGE'.AAT 'COVERAGE'.AAT FEATURE 1 1 C

   where 'COVERAGE' is the the name of your coverage. See the 'additem' command in the ARC/INFO Users Guide (vol. 2) for more information.

   Each of these features needs to be identified. This can be done either during the digitizing process (which is more efficient) or afterward in an edit process. To identify a feature during the digitizing process, use the NEW command from arcedit. For example if you are adding highpoints to the coverage, issue the following commands to move 'H' to the 'feature' item (see section on 'Adding features with attributes' in Chapter 7 of the ARCEDIT Users Guide for more information):

   Arcedit: NEW
   Arcedit: MOVEITEM 'H' FEATURE
   /

Figure 16. Documentation for digitizing data in ARC/INFO and converting to TAPES compatible format.

** WARNING: you must move a capital 'H' into the item; if you move small 'h' later SELECT commands will not find it

then, you can begin digitizing again by getting into ADD;

Arcedit: ADD

I. HIGHPOINTS: In ARCINFO point data and line data cannot be combined in one coverage. Rather than digitizing a separate coverage for the highpoints and saddlepoints, it is easier to digitize them as extremely short arcs. Do this by digitizing the first node exactly where the highpoint is; the end node can be digitized anywhere, but will look better if digitized right next to the beginning node. Later on, a fortran program will strip off the coordinates for the first node and that is what will be used as input to the 'preproc' program.

The elevation of the highpoint should be entered as the user-id. The elevation used for the highpoint should be the actual elevation of that point. ALL local highpoints in the coverage need to be entered.

'H' should be moved to the 'feature' item.

II. SADDLEPOINTS: As with highpoints, digitize these as very short arcs.
The elevation of the saddlepoint should be entered as the user-id. It is VERY IMPORTANT that the elevation of the saddlepoint be entered as the same elevation given to the next highest contour. TAPES-C needs these elevations to be the same in order to link the saddlepoint to the appropriate contour.

'D' should be moved to the 'feature' item.

e.g. Arcedit: NEW
Arcedit: MOVEITEM 'D' FEATURE
Arcedit: ADD

III. STREAMLINES: Stream networks should be digitized from the highest branch to the lowest branch. The highest branch should be digitized starting at the top and ending where it intersects with the next lowest branch. The second branch should be digitized starting at its highest point and ending where the stream intersects with the third branch, and so on.

The user-ids for the stream network should start with '1' and should increment by one. Therefore, '1' will be the user-id for the first (highest) branch, '2' will be the user-id for the second branch, etc.

'S' should be moved to the 'feature' item.

IV. TWO POINTS DEFINING A WEST/EAST LINE: The 'preproc' program uses a line digitized from West to East to adjust the coordinates to true north and true east. Therefore, a straight West/East line (just two end points) needs to be digitized.

The distance between the two endpoints should be entered as the user-id (this distance is used in 'preproc' as a scaling factor. If the elevations of the contours have been entered as feet (1.A.) then this distance should be in feet, likewise if the elevations have been entered as meters, this distance should be in meters.

'T' should be moved to the 'feature' item.

**** NOTE **** Digitize this line from the Southwest corner of your coverage to the Southeast corner: this will set the origin of the coordinate system in the Southwest corner which is one of the options acceptable to the TAPES_GRD program. Also, make sure this line is below the rest of the coverage (ie. it must not intersect any contour lines).

V. BOUNDARY: Digitizing a boundary is optional. If in doubt, consider that it is easier to delete a boundary later than to edit one in. The boundary should define exactly the catchment you are working with (ie. it should start at your desired endpoint on the stream network and follow the ridgelines around the entire catchment).

'B' should be moved to the 'feature' item.

****** WARNING ********
If you decide to use a boundary, the highpoints and saddlepoints must lie on that boundary. (Make sure the arcs defining the highpoints and saddlepoints cross the boundary; at least one side of a highpoint (saddlepoint) arc must be long enough that it will not be deleted during a clean--the other side needs to be deleted either during a clean or edited out after a clean.) In the final coverage the from-node of the arc defining a high or saddle point must lie on the boundary.

---

2. If you have intersecting arcs (e.g. two ends of a donut shape crossing each other, or branches of a stream network crossing each other) you need to clean the coverage. Cleaning will create nodes at the intersections: if you choose good dangle_length and fuzzy_tolerance values then dangling arcs will automatically be deleted. If you don't want to be bothered with figuring the optimal dangle_length and fuzzy_tolerance, then just take the defaults and delete any remaining dangling arcs manually in ARCEDIT (using the SELECT and DELETE commands).
   See the CLEAN command in ARC/INFO Users Guide Vol. 2 for more information.

---

3. The next step will irretrievably change the items in your coverage, therefore you should make a backup at this point. Use the 'COPY' command in ARC (see ARC Command References manual).

---

4. The AML 'swapid.aml' creates a new item called 'feature-id'. Values from the user-id are moved into the 'feature-id' item (ie. elevation data for contour, highpoint, and saddlepoint features are moved to this field; distance data are moved to this field for the W-E line; and values indicating the sequence of the stream branches (1,2,3 etc.) are moved to this field for the streamline).

   This program then calculates unique userids which are required to run the 'FLIPARC.AML' and 'MERGE.FOR' programs later on.

   The command to run this aml is (you need to be in the subdirectory where your coverage resides):

   ARC: &r /usr/user1/uesg04/execode/swapid

   When the popup menu appears, choose the coverage you wish to be processed.

4a. You can still edit the coverage after this point. However, if you add any new lines, let the user-id increment automatically and update the 'feature-id' item in the AAT manually (with the SELECT and CALCULATE commands in ARCEDIT).

   Also, and this is IMPORTANT, if for any reason you need to clean the coverage after this point then you may be generating user-id's that are not unique. This is particulary true if you have added a line which crosses previously existing arcs (e.g. a stream line crossing contour lines). The previously existing arcs will be split into smaller arcs during a CLEAN, but they will all retain the same user-id. If this occurs, you will need to generate new user-id's. Do this by running the UNIKID aml:

   ARC: &r /usr/user1/uesg04/execode/unikid.aml

5. The 'preproc' and TAPES programs expect input data to be in a specific sequence. Depending on the order features are digitized and on what ARC commands have been used on the coverage, the order of the data on the INFO database can become scrambled. Therefore, an edit process is necessary to order the data in an acceptable sequence. The 'fliparc.aml' program provides an interactive means to editing the database.

   Arcs for three different features (contour lines, stream lines, and the W-E line) need to be in a certain order. The 'fliparc' program was originally written with the intent of editing only contour lines, therefore the prompts are more taylored to that feature; however, stream lines and the W-E line can also be edited in this program. (If you digitized a boundary, then the arcs defining the high and saddle points also need to point in a certain direction---see 5.D.).

   The command to run this AML is:

   ARC: &r /usr/user1/uesg04/execode/fliparc

   A. STREAMLINES: If you have streamlines on your coverage and you assigned '1' to the userid for the highest branch when you were digitizing, the program will inform you that '1' is the 'min-feature-id'; therefore '1' is the value you want to enter for the feature-id prompt. The next prompt asks for the feature-id interval. If you incremented your userid value by one each time you digitized a new stream branch, then enter 1 for this prompt. If you incremented by some other amount, then enter the value of that amount for this prompt.

      The program will highlight the highest stream branch at this point and prompt you to point to the arc you want to process. If the stream branch crosses several contours and the coverage has been cleaned then the branch will be represented by multiple arcs. You want to choose the arc with the highest elevation. If the highest arc is not highlighted in green then respond with a 'n' when asked if this is the arc to be processed; an adjacent arc will then be highlighted.

      When the highest arc is highligted in green, enter 'y' when asked if this is the arc to be processed. Then you will be asked if the new segment number is correct. Respond with a 'y'. The segment number for all the stream branches will be '1' (the processing done with this information is really only pertinant for the contour data so we don't need to be concerned about it at this point).

      The zoom prompt just allows you to enlarge the display of a select area on the coverage if you need to. The highlighted arcs should have arrows on one end of them (the arrows point to the to-nodes). If you cannot see the arrows because the arcs are very short, use the zoom option.

You want all the arcs for the stream to be pointed downhill, therefore if the arrow on the highlighted arc is pointed downhill answer 'y' to the prompt asking if the direction is correct, otherwise answer 'n' and the arc will be flipped for you.

Process the rest of the branches on the stream network in the same manner. After you have processed the last of the stream branches, quit out of the program by answering 'n' when asked if you wish to process segments for the next feature-id. Save all edit changes.

B. W-E LINE: If you don't remember the distance you entered for the userid when you digitized this line, SELECT this line in ARCEDIT and do a LIST to find that value (it is now under the FEATURE-ID column, because it was moved there by the 'swapid' program).

Run the 'fliparc' program again, however when prompted for the FEATURE-ID instead of using the min-feature-id which is displayed on your screen enter the distance value for that line. Enter a '1' for the interval between feature-ids (actually you can enter any value here and it won't matter).

Select the highlighted line. Answer 'y' to the prompt about whether it is the arc to be processed, and 'y' to whether the segment number is correct.

The arrow should be pointing toward the East node. If this is true then answer 'y' to the question about whether the direction is correct; otherwise answer 'n'.

Now quit out of the program by answering 'n' when asked if you wish to process segments for the next feature-id. Save the edit changes.

C. CONTOUR LINES: There may be several contour lines of the same elevation on a complex coverage. Also, a single contour line may consist of several arcs which may or may not be going in the same direction. If there are multiple lines of the same elevation (hereafter refered to as segments), there needs to be a way to put them in an order acceptable to the 'preproc' and 'TAPES' programs. If there are multiple arcs within a segment, they must all point in the same direction. In fact, all the arcs on the contour lines must run in the same direction. So there are two things that you need to accomplish: 1) Put the contour segments in an appropriate order and 2) make sure the arcs all go in the same direction.

I. DISCUSSION:

a. How do you put contour segments in an appropriate order? If there is only one contour segment for a given elevation then there is no problem; then the segment number is always '1'. However, when more than one segment exists for an elevation, they need to be given segment numbers so they can be processed in a consistent order. To do this, you will always use the bottom of the catchment as a starting point. You need to choose to go either clockwise or counter clockwise from that point, and remember you are concerned about segments of only one elevation at a time. From the bottom of the catchment you proceed clockwise (or counterclockwise) and the first segment (of your current elevation) which you encounter should be assigned a segment number of '1', the second segment gets a segment number of '2' etc. When you have given numbers to all the segments of one elevation, continue to the next elevation and do the same for it (beginning again with a segment number of '1' for the first segment encountered). Remember, once you decide to proceed in either a clockwise or counter-clockwise direction from the bottom of the catchment you need to do that consistently for all the elevations represented in the coverage.

b. How do you make sure the arcs all go in the same direction? The issue here is not to make all the arcs go from left to right or from east to west because this is clearly not possible on coverages that have have donut shapes or contour lines that double back on themselves. In this case, the direction of an arc is determined by whether the space to the left (or right) of it is uphill or downhill in terms of the terrain represented. The answer to this is dependent on which node you are facing when you decide what is the left (or right) side of the arc. THE ASSUMPTION IS THAT YOU WILL ALWAYS BE FACING THE TO-NODE (WHICH WILL BE DISPLAYED WITH AN ARROW POINTING TOWARD IT) WHEN YOU DETERMINE WHERE THE LEFT (OR RIGHT) SIDE OF THE ARC IS.

The rule of thumb is that if, in the last step, you chose to number segments in a clockwise fashion, then the space to the left of the arc must always be uphill in terms of the terrain represented. If you chose to number segments in a counter-clockwise fashion, then the space to the left of the arc must always be downhill.

Lets assume that you have chosen to number segments in a clockwise fashion. The space to the left of the arc (when you are facing the to-node, which will have an arrow pointing to it) must be uphill from the arc. If this is not the case, then a correction must be made. To do this you change the direction of the arc, ie. you interchange the to-node and the from-node. Now the arrow is pointing in the direction opposite to its original position, and now when you face the to-node the space to the left of the arc is uphill in terms of the terrain represented.

The direction of every arc in the coverage needs to be checked. Any arc which is not going in the correct direction needs to have its direction flipped by interchanging its to-node with its from-node.

II. RUNNING FLIPARC FOR CONTOUR FEATURES

The 'fliparc' program allows you to view contour lines one elevation at a time. You will be able to assign segment numbers and change the direction of arcs at the same time.

a. Start the program with the command:

ARC: &r /usr/user1/uesg04/execode/fliparc

b. When prompted for the feature-id to begin processing with, enter the lowest contour elevation on your coverage (if you have already processed the streamline and W-E line data, this should be displayed on your screen as min-feature-id). At the feature-id interval prompt, enter the contour interval you used when digitizing.

c. The next prompt asks you to point at the arc you wish to process. Probably there is only one segment highlighted because you are low on your coverage (you will get multiple segments highlighted when you get to higher elevations). However, that segment may contain more than one arc; in any case you need to decide at this point whether you are going to proceed in a clockwise or counter-clockwise fashion around this coverage (see DISCUSSION #1). Lets assume you choose to proceed in a clockwise fashion: if the contour segment is comprised of only one arc then you select that arc; however, if there are multiple arcs in that segment you want to select the arc that you encounter as you go clockwise around the edge of the coverage (ie. one node is on the edge of the coverage, the other node is shared with another arc).

d. If your chosen arc lights up in green, input 'y' to the prompt about whether this is the arc to be processed.

e. The next prompt assigns the number of '1' to this segment. This is correct. When you get to elevations which have multiple segments, the program will automatically increment this number for you. So if you select the segments in the correct order (ie. in a clockwise/counter-clockwise sequence), the correct segment number will automatically be assigned. However, if you make a mistake in the order you select your segments, you can manually override the number by answering this prompt with a 'n' and entering your own number at the next prompt. If you interrupt the automatic incrementation of segment numbers you will be forced to continue entering the segment numbers manually until processing is done for that particular elevation.

f. After the zoom prompt, you are asked if the direction of the arc is correct. Again, assuming you are processing in a clockwise direction, you want the area to the left of the arc to be uphill in terms of the terrain represented (See DISCUSSION #2). If the direction of the arc is correct input 'y'; otherwise input 'n'. If there are multiple arcs in the segment, the program will automatically check the remaining arcs for direction and will correct those that are not going the right way.

   If there is only one segment for this elevation you will now be asked if you want to process the next highest elevation. However, if there are multiple segments for this elevation you will be asked to point at the next arc you wish to process (the arc you choose should be the next one encountered when going clockwise (counter-clockwise) around the coverage).

III. OTHER RELEVENT STUFF

a. This program isn't fool proof. If it hangs up you can get out of it using 'Ctrl C'. If you have to do this, be aware that any changes that were made will be saved to the database. This means that something strange probably got saved for the very last elevation you were working on. This is easy to fix. The next time you run the program start with the elevation you got hung up on, your new input will override anything that got put out before.

b. If you think you made a mistake on an elevation, just enter that elevation to be processed again (you can do this either as you enter the program, or after declining to process the next elevation you are asked if you want to process a different elevation: enter the elevation you think you made a mistake on at that point). You cannot choose to redo just one arc but will need to process all the arcs for that elevation again.

c. You don't need to process the whole coverage at one sitting. The next time you run the program it will check to see what the next elevation is that you have not yet processed. You can choose to start processing with that elevation or go back and make corrections if you need to.

D. HIGH POINTS / SADDLE POINTS: If a boundary has been digitized, the high points and saddle points must lie on that boundary. Therefore, the from-node of the arc which represents a high or saddle point should be the node which lies on the boundary. Because the arcs representing the high and saddle points are so small it is easier to edit these features manually than to do so with the FLIPARC program.
In ARCEDIT, use the drawenvironment of DRAWE ARC ARROWS. Zoom in on the high or saddle point in question. If the orientation of the arc is not correct, you can change the direction by using the FLIP command (see ARCEDIT Command References Manual).

---

6. It isn't possible to generate a single file containing both coordinate data and attribute data. Therefore, these data are dumped to two separte ASCII files and merged in the next step. To unload these data use the UNLOAD.AML program. This program outputs two permanent files ' ----.srt and ---.pts ' and a temporary coverage called 'tempsort'. Before running this program, check your workspace to make sure that neither these files nor the coverage exists. If they do, delete them from your workspace (use 'rm' to delete the files; use 'kill' from the ARC prompt to remove the coverage--see ARC Command References Manual).

The command to run this aml is:

ARC: &r /usr/user1/uesg04/execode/unload

When the popup menu appears, choose the coverage from which you wish to unload data. The program creates two new files: 'cover'.srt (contains attribute info) and 'cover.pts' (contains coordinate info). It takes two to three minutes to run; when finished it returns to the GIACX prompt.

---

7. PATIENCE!! THIS PROGRAM CAN TAKE 20 OR MORE MINUTES TO RUN

The 'merge.for' program merges data from the coordinate file and the sorted attribute file and reformats those data to the format needed by the 'preproc' program. Check your workspace for the files '---.cns' and '----.utm'; if they exist from a previous run of the program, delete them.

If you want to reproduce UTM coordinates when you put data back on ARCINFO, you need to save the coordinates of the western node of the W-E line (this becomes the origin of the grid used in the TAPES programs). This program gives you the option to save those coordinates to a file that will be used as input to the SPLIT.FOR program in step 12.

The command to run this program is:

GIACX: /usr/user1/uesg04/execode/merge.exe

The program contains the following prompts:

ENTER NAME OF SORTED FILE (---.srt):	name of attribute file generated during step 6
ENTER NAME OF UNGEN FILE (---.pts):	name of coordinate file generated during step 6
ENTER NAME OF OUTPUT FILE (---.cns):	name of output file; this will be used as input to step 8 when TGRD will be used
DO YOU WANT UTM INFO SAVED (Y/N)?	'y' if you want coordinates of origin saved
ENTER NAME OF UTM FILE (---.utm):	name of file containing utm coordinates of the origin; used as input to step 12

7a. (NOTE: THIS STEP IS RUN ONLY WHEN USING HYDROLOGY PGMS) The current version of PREPROC does not reformat a file with stream data to meet the requirements of TCON. Therefore, if TCON is going to be used, the '----.cns' data needs to be run through the RMCREEK.FOR program. If elevations were digitized in feet and you want to convert to meters, do so in this program (PREPROC converts for contours but not for saddle points). Check your workspace for the file '---.ele'; if it exists from a previous run of the program, delete it.

The command to run this program is:

GIACX: /usr/user1/uesg04/execode/rmcreek.exe

The program has three prompts:

ENTER NAME OF INPUT FILE (---.cns):	name of file generated during step 7
ENTER NAME OF OUTPUT FILE (---.rmc):	name of output file; this will be used as input to step 8 when TCON will be used
CONVERT FEET TO METERS (Y/N)?	'y' if you want conversion

8 - 12. These steps deal with putting data generated by TAPES-G back on ARC/INFO. Documentation for them can be found in GIAC account: uesg04/mydata/document.

```
********************************************************************************
*                               PREPROC                                        *
********************************************************************************
```

giacxx> ~/moore792/preproc

Standard input/output (Y/N): y

INTERPOLATING INTERVAL (m or ft): 5

OUTPUT for grid-based analysis (Y/N): y

ENTER INPUT FILE NAME (----.cns): cotton.cns

OUTPUT CONTOUR FILE NAME
(----.con): cotton.con

OUTPUT STREAMLINE FILE NAME
(----.stl): cotton.stl

OUTPUT HIGHPOINT FILE NAME
(----.hpt): cotton.hpt

DO YOU WANT UNIT CONVERSION?
  No unit conversion (1)
  English to metric (2)
  Metric to english (3): 2

Interpolation limits
 AINT1 (20), AINT2 (50): 20,50

ENTER BOUND. FILE NAME (----.BDY): cotton.bdy

Mesh size for overlay grid (m or
  number of nodes): 20

Figure 17. PREPROC prompts and responses for grid-based programs.

```
*****************************************************************************
*                         ANUDEM                                            *
*****************************************************************************

giacxx> ~/execode/anudem

 DRAINAGE OPTION (0,1,2  OR 3):
   0 NO DRAINAGE ENFORCEMENT
   1 DRAINAGE ENFORCEMENT
   2 DRAINAGE ENFORCEMENT WITH SINK DIAGNOSTICS
   3 DRAINAGE ENFORCEMENT WITH FULL DIAGNOSTICS
     3

 BCONTOUR DATA OPTION (0 OR 1):
  0 - ELEVATION DATA CONSISTS MAINLY OF SPOT HEIGHTS
  1 - ELEVATION DATA CONSISTS MAINLY OF CONTOURS
     1

 MAXIMUM RIDGE LENGTH (AT LEAST 0.0):
     0.00

 ROOT MEAN SQUARE RESIDUAL (AT LEAST 0.0):
  NORMALLY 0.0 FOR POINT DATA
  NORMALLY 1% CONTOUR INTERVAL FOR CONTOUR DATA
     0.05000

 MAXIMUM OPTION (0 OR 1):
  0 - MAXIMA NOT CONSTRAINED TO LIE AT DATA POINTS
  1 - MAXIMA CONSTRAINED TO LIE AT DATA POINTS
     0

 ROUGHNESS PENALTY TRADE-OFF (AT LEAST 0.0):
  0.0 - MINIMUM CURVATURE - FOR CONTOUR DATA
  0.5 - RECOMMENDED FOR POINT DATA
  1.0 - APPROACHING MINIMUM POTENTIAL (NOT RECOMMENDED)
     0.00000

 THREE NON-NEGATIVE ELEVATION TOLERANCES:
 (1ST TOLERANCE MUST BE AT LEAST FOUR TIMES RMS)
 (2ND TOLERANCE MUST BE AT LEAST TWICE 1ST TOLERANCE)
 (3RD TOLERANCE MUST BE AT LEAST TWICE 2ND TOLERANCE)
     2.50     10.00     50.00

 MAXIMUM NO. OF ITERATIONS (NORMALLY 20-30):
     30

 HEIGHT LIMITS:
     1610.0000  1990.0000
```

Figure 18. ANUDEM prompts and responses.

RESIDUAL FILE NAME (BLANK IF NOT REQUIRED):
cotton.res

MINIMUM RESIDUAL (NON-NEGATIVE REAL):
0.3000

X (LONGITUDE) LIMITS:
20.0000 1060.0000

Y (LATITUDE) LIMITS:
20.0000 2020.0000

GRID SPACING:
20.000000

NUMBER OF DATA FILES (MAX =150):
TYPE 1 = DATA POINT FILE
TYPE 2 = SINK POINT FILE
TYPE 3 = STREAMLINE FILE
TYPE 4 = POLYGON FILE
TYPE 5 = CONTOUR FILE
2

DATA FILE 1:
cotton.con

DATA FILE TYPE (1,2,3,4 OR 5):
5

DATA FILE HEADER FORMAT:
(2X,I4,F10.2)

DATA FILE LINE STRING FORMAT:
(2F9.2)

DATA FILE 2:
cotton.stl

DATA FILE TYPE (1,2,3,4 OR 5):
3

DATA FILE HEADER FORMAT:
(2X,I4,F8.2,F8.2)

DATA FILE LINE STRING FORMAT:
(2F9.2)

OUTPUT GRID FILE NAME:
cotton.anu
/

MODE OF OUTPUT GRID (0,1 OR 2):
0 - GRID VALUES BY ROWS
1 - X,Y,Z FORMAT
2 - STANDARD USGS (ARC/INFO) DEM FORMAT
1

OUTPUT GRID X,Y,Z FORMAT (BLANK FOR UNFORMATTED):
(3(1X,F9.2))

OUTPUT SINK FILE NAME (BLANK IF NOT REQUIRED):
cotton.snk

OUTPUT STREAM FILE NAME (BLANK IF NOT REQUIRED):
cotton.str

```
*****************************************************************************
*                              TAPES GRID                                   *
*****************************************************************************
```

giacxx> ~/moore792/tapesg

Standard input/output (Y/N): y

Grid cell size (m): 20

ENTER: Original DEM filename: cotton.anu

ENTER: Output file name: cotton.grd

Analysis is set up for origin in north-
west and x-axis pointing east and y-
axis pointing south. If origin is in
south-west with x-axis pointing east &
y-axis pointing north TYPE Y: y

Is the DEM input as a direct access file
of integer values (1), as an unformatted
file of real x,y,z values (2), as an
unformatted file of real z values (3), or
as an unformatted file of integer z
values (4) ordered in rows: 2

X-Y data entered as nodal increments (1)
or as absolute length units (2): 2

DO YOU WANT TO RESTRICT CALCULATIONS TO
WITHIN A CATCHMENT BOUNDARY (Y/N): n

Input critical number of cells for
defining stream network: 40

Do you want drainage directions
calculated using D8 (1) or Rho8
algorithm (2): 2

Do you want multiple drainage
direction algorithm (Y/N): y

Maximum cross grading area
(number of cells): 40

Global area weight (0.0-1.0): 1

Figure 19. TAPES-G prompts and responses.

```
************************************************************************
*                    COTTON.PARM                                       *
************************************************************************

45.54
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.21 0.21 0.21 0.21 0.21 0.21 0.21 0.21 0.21 0.21 0.21 0.21
0.600 0.700 0.700 0.800 0.625 0.750 0.850 0.850 0.700 0.650 0.600 0.600
 1.7 10.1  7.9 11.6 16.6 22.9 32.1 32.4 23.9 15.6 4.4  5.2
-8.5 -1.2 -2.8  0.3  4.3  8.3 12.3 13.4  8.4 1.9 -3.5 -3.6
-3.4  4.4  2.6  6.0 10.4 15.6 22.2 22.9 16.2 8.7  0.4  0.8
6.50 6.50 6.50 6.50 6.50 6.50 6.50 6.50 6.50 6.50 6.50 6.50
7.30 7.30 7.30 7.30 7.30 7.30 7.30 7.30 7.30 7.30 7.30 7.30
6.00 6.00 6.00 6.00 6.00 6.00 6.00 6.00 6.00 6.00 6.00 6.00
1.00
1.75 1.75 1.75 1.75 1.75 1.75 1.75 1.75 1.75 1.75 1.75 1.75
10.0 0.96 0.00008 1447.6
0.71 0.70 0.69 0.68 0.66 0.65 0.65 0.66 0.67 0.68 0.69 0.70
```

Figure 20. Parameter file for SRAD.

```
******************************************************************************
*                    SRAD                                                    *
******************************************************************************
```

giacxx: ~/moore792/srad

ENTER: Original DEM file name: cotton.anu

Grid cell size (m): 20

Is the DEM input as:
  (1) direct access file of integer values
  (2) file of real x,y,z values
  (3) file of real z values ordered by rows
  (4) integer z values ordered in rows
    SELECT (1-4): 2

  Is the file a binary file (Y/N): n

X-Y data entered as nodal increments (1)
   or as absolute length units (2): 2

Number of circle divisions for horizon
   calculations (typically use a value
   of 16): 16

SOLAR CONSTANT: 1.9 cal/cm2/min (1);
  119.4 Ly/h (2); 4.871 MJ/m2/h (3); or
  1354 W/m2 (4): 4

Do you wish to use a lumped transmittance
  approach (1) or a component calculation
  approach (2): 1

Radiation parameter file name: cotton.parm

Output file name: cotton.rad

  Output file in binary format (Y/N): n
  Output summary temperatures (Y/N): y

Start month & day, finish month & day, time
  step (days) - MS, IDS, MF, IDF, IDD: 1,1,12,31,30

Figure 21: SRAD prompts and responses.

```
***************************************************************************
*                              WET                                        *
***************************************************************************

giacxx: ~/moore792/wet

Soil water factoring (Y/N): y

Value of critical wetness index (corresponding to
   field capacity soil water content) in the function
   THET = wetnessindex/critical wetnessindex: 11

Mean air temperature (oC) & Mean elevation
   above MSL: 9 1852

Precipitation (mm/d) & Storage deficit (mm/d): 4 0

Max drainage rate (mm/d) & BETA (2b+3=10-15): 1 12

Bowen ratio equivalent: 0.1497

Change value of Bo (Y/N): y
     Bo = 2

Exponent, C, in soil water index relationship
   T**(C/Ep) (approx. 12 mm/d): 12

Grid cell size (m): 20

ENTER: Original DEM attribute file name: cotton.grd
   Is it a binary file (Y/N): n

ENTER: Original radiation file: cotton.rad
   Does file include temperature data (Y/N): y
   Is it a binary file (Y/N): n

Radiation in w/m2 (1) or MJ/m2/d (2): 1

ENTER: Output file name: cotton.wet
   Is it a binary file (Y/N): n

X-Y data entered as nodal increments (1) or as
   absolute length units (2): 2

Summary statistics output file name: cotton.stats
```

Figure 22. WET prompts and responses.

```
*************************************************************************
*          PREPROC    (for contour based programs)                      *
*************************************************************************

giac5> ~/moore792/preproc

Standard input/output (Y/N): y

 INTERPOLATING INTERVAL (m or ft): 5

 OUTPUT for grid-based analysis (Y/N): n

 ENTER INPUT FILE NAME (----.cns): cot3.rmc

 OUTPUT FILE NAME (----.ppp): cot3.ppp

 DO YOU WANT UNIT CONVERSION?
     No unit conversion (1)
     English to metric (2)
     Metric to english (3): 1

 Interpolation limits
  AINT1 (20), AINT2 (50): 20,50

 ENTER BOUND. FILE NAME (----.BDY): cot3.bdy

 Mesh size for overlay grid (m or number of nodes): 100
```

Figure 23. PREPROC prompts and responses for contour-based programs.

```
*****************************************************************************
*                      TAPES-C                                              *
*****************************************************************************
giacxx: ~/moore792/tapesc

 Standard input/output (Y/N): y

 Approx. distance between trajectory start points (m): 50

 Maximum search radius for locating
    uphill trajectory - DISTES (m): 150

 Critical plan curvature at which
    the ortogonal criteria for determining
    trajectories is used in preference to
    minimum distance criteria (approx.
    0.01 rad/m): 1.5

 Threshold plan curvature for
    determining location of channel on
    downhill side of element (approx.
    0.15 rad/m): 23

 Terminate trajectories when distance
    between trajectories is less than
    a minimum (Y/N) - normally
    answer N: n

 Imposed boundaries (Y/N) - normally answer N: n

 Uphill contour is always on the LEFT
    (L) or RIGHT (R) of a contour line
    as it is being drawn: l

 ENTER INPUT FILE NAME (_____.ppp): cot.ppp

 ENTER OUTPUT FILE NAME (_____.asd): cot.asd

 mesh size for overlay grid (number of m): 100
```

Figure 24. TAPES-C prompts and responses.

```
*****************************************************************************
*        THALCH     reformats .asd record from TAPESC to                    *
*                             .atr record for THALES                        *
*****************************************************************************
```

giacxx: ~/moore792/thalch3

Enter input file name
(______.ASD): hydro2.asd

Enter output file name
(______.ATR): hydro3.atr

Figure 25. THALCH prompts and responses.

```
******************************************************************************
*                    THALES3    (for saturated catchment)                    *
******************************************************************************

giacxx> ~/moore792/thales3

Name of file with model parameter values
  (---.par): hydro.par

Name of file with lookup table values of
  roughness & soil types, & initial soil water
   content values (---.lok): hydro2a.lok

Name of terrain attribute file
  (---.atr): hydro3.atr

Enter ouptput file name: hyd3sat.out

Standard analysis (Y/N): n

MODEL OPTIONS:
  Model infiltration
       (1) Hortonian infiltration,
       (2) Zeros infiltration (impervious surface)
       (3) Infinite infiltration capacity
           SELECT (1,2,3): 2
  Model canopy interception (Y/N): n

Weighting coefficient for numerical solution
  (typically 0.7-0.8): .7

Output specified element results (Y/N): y
  Numbers of elements for which output
   data is required (max 10): 6
  Enter element numbers: 2780 2781 2782 2783 2784 2785

Enter threshold area for channelized flow (ha)
  e.g. 0.5-10 ha: 2

Rainfall file name (___.pre): hydro2.pre725
Evaporation file name (___.evap): hydro.evap
Radiation ratio file name (___.rad): hydro.rad

Minimum and maximum time steps (minutes): 30 2880
Start time (month,day,hour,minute): 7 25 18 0
Finish time (month,day,hour,minute): 7 27 17 30
```

Figure 26. THALES prompts and responses.

```
******************************************************************************
*                HYDRO.PAR                                                   *
******************************************************************************
1
1 0.25 0.23 0.11 0.04 0.25 4.0 9.0 100.0
1
1 0.02
1
1 0.95 0.2 0.2 0.5 0.4 2.3
6 00 19 0
0.5 0.5 2.0 0.0
```

Figure 27. Parameter file for THALES.

```
******************************************************************************
*                HYDRO2A.LOK                                                 *
******************************************************************************
     1       1       1       1   1.500000     0.3500000
     2       1       1       1   1.500000     0.3500000
     3       1       1       1   1.500000     0.3500000
     4       1       1       1   1.500000     0.3500000
     5       1       1       1   1.500000     0.3500000
     6       1       1       1   1.500000     0.3500000
     7       1       1       1   1.500000     0.3500000
     8       1       1       1   1.500000     0.3500000
     9       1       1       1   1.500000     0.3500000
    10       1       1       1   1.500000     0.3500000
    11       1       1       1   1.500000     0.3500000
    12       1       1       1   1.500000     0.3500000
    13       1       1       1   1.500000     0.3500000
    14       1       1       1   1.500000     0.3500000
    15       1       1       1   1.500000     0.3500000
          (continues for all elements in watershed)
```

Figure 28. Lookup table for THALES.

```
*****************************************************************************
*            HYDRO2.PRE725                                                  *
*****************************************************************************
0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7
 1  1 11  0  0.0
 1  1 12  0  0.0
 1  1 13  0  50.0
 1  1 19  5  50.0
 1  1 19 35  75.0
 1 10 12  0  75.0
```

Figure 29. Precipitation data file for THALES.

```
*****************************************************************************
*                HYDRO.EVAP                                                 *
*****************************************************************************
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0 1.0
```

Figure 30. Evaporation data file for THALES.

```
*****************************************************************************
*                HYDRO.RAD                                                  *
*****************************************************************************
0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4
0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4
0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4  0.4 0.4
```

Figure 31. Radiation data file for THALES.

APPENDIX C

CONVERSION PROGRAMS

```
/*****************************************************************************
/* AML:        swapid.aml                                                    *
/* Author:     JK Jersey, Department of Plant and Soil Science,              *
/*             Montana State University, Bozeman, MT                         *
/* Date:       June, 1992                                                    *
/* Description: Creates the item 'feature-id' in the AAT file. Updates the   *
/*             'feature-id' field with the data that was entered             *
/*             in the user-id field during digitizing process. Creates       *
/*             user-id's which are necessary in the 'merge.for' program.     *
/*****************************************************************************
  &term 9999
/*
  &s COV          = [GETCOVER]                  /* prompts for coverage
/*
  &s PATH         = [DIR [PATHNAME %cov%]]      /* obtains pathname
/*
  &s FILENAME     = [ENTRYNAME %cov%]           /* obtains filename
/*
  &s feature-id   = ~
    [ITEMINFO %path%/info!arc!%filename%.aat -INFO feature-id -EXISTS]
/*
  &if %feature-id%  = .FALSE. &then &do
        &type \ ADDING ITEM CALLED 'feature-id' \
        ADDITEM %path%/info!arc!%filename%.aat %filename%.aat FEATURE-ID 4 8 F 2
/* creates item 'feature-id'
/*
        TABLES
        SELECT %filename%.aat
        CALCULATE FEATURE-ID       = %filename%-ID    /* copies cov-id entries
                                                      /* into item feature-id
        CALCULATE %filename%-ID    = %filename%#      /* copies unique internal
                                                      /* ids into cov-id
        QUIT
        QUIT
        IDEDIT %cov% LINE
/*
  &type \   THE ITEM 'FEATURE-ID' HAS BEEN ADDED TO THE AAT FILE. \ ~
   IT HAS BEEN UPDATED WITH THE ELEVATION DATA ENTERED  \ ~
   IN THE USER-ID. NEW USER-ID'S HAVE BEEN GENERATED  \ ~
   WHICH ARE UNIQUE. \
/*
  &end
  &else &do
        &type \ THE ITEM 'FEATURE-ID' ALREADY EXISTS FOR THIS COVERAGE. \
  &end
/*
  &s text         = '    HIT RETURN TO TERMINATE PROGRAM'
  &pause %text%
  &return
```

Figure 32. AML which identifies features as contour, stream, high or saddle point on ARC/INFO data base.

```
/*******************************************************************************************************
/* AML:        fliparc.aml                                                                              *
/* AUTHOR:     J.K. Jersey, Department of Plant and Soil Science, Montana State University,             *
/*             Bozeman, MT                                                                              *
/* DATE:       February, 1992                                                                           *
/*                                                                                                      *
/* DESCRIPTION:  This program is interactive and allows the user to change the direction of arcs on contour   *
/*             coverages, updating the FNODE# and TNODE# items in the AAT.  It also updates the SEGMENT item;  *
/*             each contour segment for an elevation is given a number; numbering begins with 1 for each new  *
/*             elevation.                                                                               *
/*                                                                                                      *
/*             The macro first verifys that the requested elevation is contained in the coverage.  The user is   *
/*             prompted to choose which arc to begin processing with.  A segment number for that contour segment  *
/*             is assigned.  The direction of the arc is shown by the arrow which points toward the TNODE#.  The  *
/*             user is prompted to change the direction of the arc if necessary.  A                      *
/*             'do loop' processes all other arcs contained in that segment, flipping them if necessary and  *
/*             assigning them the appropriate segment number.  If more than one segment exists for an elevation,  *
/*             the user will be prompted to identify the order in which the segments should be processed.  *
/*             When all segments for a particular elevation have been  processed, the next highest elevation is  *
/*             chosen for processing; the user is allowed to continue or to quit the program at this point.  *
/*                                                                                                      *
/*             This program may be used to make corrections to previously processed segments.           *
/*                                                                                                      *
/* INPUTS:  AAT for the coverage being used.  The AAT must have included the items 'FEATURE-ID', 'SEGMENT', and  *
/*             'ARC_CHEK'.  The aml ADDITEM.AML will add these items if they are not currently included in the AAT.  *
/*             The item 'ARC_CHEK' is needed only for the duration of processing and may be deleted when done.  *
/*******************************************************************************************************
/*
/*  &messages &off &all
/*  &echo &on
  &term 9999
/*
```

Figure 33. Interactive AML allowing user to edit order and direction of vectors on ARC/INFO data base.

```
  &s red                =   2
  &s green              =   3
  &s blue               =   4
  &s aqua               =   5
  &s violet             =   6
  &s yellow                   =   7
  &s brown                    =   8
/*
  &s counter-for-save         =   0
  &s bailout                  =   .false.
/*
  &s cov                      =   [getcov]
  &s path                     =   [DIR [PATHNAME %cov%]]
  &s filename                 =   [ENTRYNAME %cov%]
/*
  &s segment                  =   ~
    [ITEMINFO %path%/info!arc!%filename%.aat -INFO segment -EXISTS]
  &if %segment% = .false.  &then &do
       &type \ ADDING ITEM CALLED 'SEGMENT'\
       ADDITEM %path%/info!arc!%filename%.aat %filename%.aat SEGMENT 4 5 B
       &type \ ADDING ITEM CALLED 'ARC_CHEK'\
       ADDITEM %path%/info!arc!%filename%.aat %filename%.aat ARC_CHEK 4 5 B
       &type \ ADDING ITEM CALLED 'SORTFEAT'\
       ADDITEM %path%/info!arc!%filename%.aat %filename%.aat SORTFEAT 4 5 B
  &end
/*
  &s current-editdist         =   20
  &call check-editdistance                                   /**   call routine check-editdistance
/*
  arcedit
  editdistance %current-editdist%
  editcoverage %cov%
  editfeature arc
/*
```

```
  &s feature-exists          =  .true.
  select feature             eq  'T'
  &severity &error &routine feature-does-not-exist
  &s dummy5                  =  [show select 1]
  &severity &error &fail
  &if %feature-exists%       =  .true. &then &do
     calculate sortfeat      =  10
  &end
/*
  &s feature-exists          =  .true.
  select feature             eq  'D'
  &severity &error &routine feature-does-not-exist
  &s dummy5                  =  [show select 1]
  &severity &error &fail
  &if %feature-exists%       =  .true. &then &do
     calculate segment       =  15
     calculate arc_chek      =  15
     calculate sortfeat      =  20
  &end
/*
  &s feature-exists          =  .true.
  select feature             eq  'H'
  &severity &error &routine feature-does-not-exist
  &s dummy5                  =  [show select 1]
  &severity &error &fail
  &if %feature-exists%       =  .true. &then &do
    calculate segment        =  1
    calculate sortfeat       =  30
  &end
/*
  &s feature-exists          =  .true.
  select feature             eq  'S'
  &severity &error &routine feature-does-not-exist
  &s dummy5                  =  [show select 1]
  &severity &error &fail
  &if %feature-exists%       =  .true. &then &do
    calculate sortfeat       =  40
```

```
  &end
/*
  &s feature-exists              =   .true.
  select feature                eq   ' '
  &severity &error &routine feature-does-not-exist
  &s dummy5                      =   [show select 1]
  &severity &error &fail
  &if %feature-exists%           =   .true. &then &do
      calculate sortfeat             =   100
  &end
/*
  &s feature-exists                  =   .true.
  select feature                    eq   'B'
  &severity &error &routine feature-does-not-exist
  &s dummy5                          =   [show select 1]
  &severity &error &fail
  &if %feature-exists%               =   .true. &then &do
     calculate sortfeat              =   200
  &end
/*
  &s unprocessed-arcs-still-occur    =   .true.
  select segment                     =   0
/*
  &severity &error &routine entire-coverage-already-processed
  &s dummy4                          =   [show select 1]
  &severity &error &fail
/*
  &if %unprocessed-arcs-still-occur% =   .true. &then &do
    &type \ THE LOWEST FEATURE-ID WHICH HAS NOT YET BEEN PROCESSED IS:
    statistics
    minimum feature-id
    end
/*
    &call prompt-for-elevation                          /** call routine prompt-for-elevation
    &call prompt-for-contour-interval                   /** call routine prompt-for-contour-interval
  &end
```

```
  &else &do
    &if %update%                    = .true.  &then &do
      &call prompt-for-elevation
      &call prompt-for-contour-interval
    &end
    &else &do
      &s bailout                    = .true.
    &end
  &end
/*
  display 9999 2
/*
  &do &until %bailout%              = .true.
/*
   drawenvironment arc arrow
   draw
   select feature-id                = %elev%
/*
   &s elev-exists-on-db             = .true.
   &severity &error &routine no-arcs-found-for-this-elev        /** call routine no-arcs-found-for-this-elev
   &s dummy1                        = [show select 1]
   &severity &error &fail
/*
   &if %elev-exists-on-db%          = .true. &then &do
/*
      &if %counter-for-save%        ge 5  &then &do
         &call perform-save                                     /** call routine perform-save
      &end
/*
      &s counter-for-save           = %counter-for-save% + 1
      calculate arc_chek            = 0
      &s segment-number             = 0
      &s input-seg-num-manually     = .false.
/*
```

```
        reselect segment            = 0
        &severity &error &routine updating-segments-already-processed   /** call routine updating-segments-already-
        &s dummy2                   = [show select 1]                    /** processed
        &severity &error &fail
/*
        drawenvironment arc arrow
        setdrawsymbol %red%
        drawselect
/*
        reselect segment ne 0
        setdrawsymbol %violet%
        drawselect
/*
        &s done-with-current-elev             = .false.
        &do &until %done-with-current-elev%   = .true.
/*
         select feature-id                    = %elev%
         &type \ POINT AT THE ARC YOU WANT TO PROCESS
         reselect one
         setdrawsymbol %green%
         drawselect
/*
         &s desired-edge-arc                  = .false.
         &do &until %desired-edge-arc%        = .true.
           &type
           &s desired-edge-arc                = [query ' IS THIS ARC TO BE PROCESSED (y/n)' .TRUE.]
/*
           &if %desired-edge-arc%             = .true.   &then  &do
/*
             &call determine-seg-num                               /** call routine determine-seg-num
/*
             &type
             &s enlarge-feature               = [query ' DO YOU WISH TO USE THE "ZOOM" FEATURE (y/n)' .FALSE.]
             &if %enlarge-feature%            = .true.   &then &do
               &type   \ DEFINE AREA TO BE ENLARGED
               mape *
               draw
```

```
          drawselect
          &type
          &s correct-direction          =  [query ' IS THE DIRECTION OF THIS ARC CORRECT (y/n)' .TRUE.]
          mape default
          draw
          drawselect
        &end
        &else &do
          &type
          &s correct-direction          =  [query ' IS THE DIRECTION OF THIS ARC CORRECT (y/n)' .TRUE.]
        &end
/*
        &if %correct-direction%         =  .false.  &then   &do
          flip
        &end
/*
        &call process-rest-of-arcs-in-seg                  /**  call routine process-rest-of-arcs-
      &end                                                 /**  in-seg
      &else &do
        setdrawsymbol %red%
        drawselect
/*
        next
        setdrawsymbol %green%
        drawselect
      &end
    &end
/*
    select feature-id                   =  %elev%
    setdrawsymbol  %violet%
    drawselect
/*
    reselect for segment                =  0
    setdrawsymbol  %red%
    drawselect
/*
```

```
        &severity &error &routine all-segs-processed-for-this-elev      /** call routine all-segs-processed-
        &s dummy3                                   = [show select 1]    /**  for-this-elev
        &severity &error &fail
/*
        &end
      &end
    &end
/*
    &messages &on
    &type
    &s TEXT                                     =    ' HIT RETURN WHEN DONE VIEWING'
    &pause %text%
    quit
    &return
/*
/*****************************************************************************************************
/*        ROUTINE ENTIRE-COVERAGE-ALREADY-PROCESSED                                                   *
/*   User is queried whether to update an already processed coverage or not.                         *
/*****************************************************************************************************
/*
    &routine entire-coverage-already-processed
      &s unprocessed-arcs-still-occur          =  .false.
      &type  \ PROCESSING FOR THIS COVERAGE HAS ALREADY BEEN COMPLETED
      &s update                                =  [query ' DO YOU WISH TO UPDATE THIS COVERAGE (y/n)' .FALSE.]
    &return
/*
/*****************************************************************************************************
/*        ROUTINE NO-ARCS-FOUND-FOR-THIS-ELEV                                                         *
/*                                                                                                    *
/*   If an arc does not exist for the elevation requested, the user is notified and asked to select   *
/*   another elevation.                                                                               *
/*****************************************************************************************************
/*
    &routine no-arcs-found-for-this-elev
      &s elev-exists-on-db                     =  .false.
/*
```

```
    &type \ NO ARCS EXIST FOR ELEVATION OF:   %elev%
    &s alternative-elev                 = .false.
    &s alternative-elev                 = [query ' DO YOU WISH TO PROCESS A DIFFERENT ELEVATION (y/n)' ~
                                              .FALSE.]
/*
    &if %alternative-elev%              = .true. &then &do
      &call prompt-for-elevation                          /** call routine prompt-for-elevation
    &end
/*
    &else &do
      &s  bailout                       = .true.
    &end
/*
  &return
/*
/*****************************************************************************************************
/*      ROUTINE PERFORM-SAVE                                                                        *
/*                                                                                                  *
/*  User is prompted whether to save or not.  During a save, position in database is lost, so arcs are selected again.  *
/*****************************************************************************************************
/*
  &routine perform-save
/*
    &type \ YOU HAVE PROCESSED 5 ELEVATIONS SINCE YOU LAST \ HAD THE OPPORTUNITY TO SAVE CHANGES.
    &s wish-to-save-updates         =  [QUERY ' DO YOU WISH TO SAVE YOUR CHANGES (y/n)' .TRUE.]
    &if %wish-to-save-updates%      =  .true. &then &do
      &type \ THIS WILL TAKE A FEW MINUTES
      save
      select feature-id             =  %elev%
    &end
    &s counter-for-save             =  0
  &return
/*
```

```
/*******************************************************************************************************************
/*        ROUTINE UPDATING-SEGMENTS-ALREADY-PROCESSED                                                             *
/*                                                                                                                *
/*   Segments which have been previously processed are identified checking the 'SEGMENT' item for values other   *
/*   than 0. The user must update all segments for that elevation in order to assure that records get sorted      *
/*   correctly later on.                                                                                          *
/*******************************************************************************************************************
/*
  &routine updating-segments-already-processed
/*
     &type \ YOU ARE UPDATING SEGMENTS FOR ELEVATION:  %elev%.  YOU MUST UPDATE \ ~
         ALL THE SEGMENTS SHOWN. \
     select feature-id                  =  %elev%
     calculate segment                  =  0
/*
  &return
/*
/*******************************************************************************************************************
/*        ROUTINE DETERMINE-SEG-NUM                                                                               *
/*                                                                                                                *
/*   Segment numbers are automatically incremented by one. If the user makes a mistake in choosing the order to   *
/*   process segments, then auto-incrementation can be interrupted and segment numbers may be input manually. If  *
/*   the user is updating segments previously processed, the previously determined segment number is displayed for *
/*   validation.                                                                                                  *
/*******************************************************************************************************************
/*
  &routine determine-seg-num
/*
     &if %input-seg-num-manually%              =  .true. &then     &do
        &call prompt-for-segment-number                                /**  call routine prompt-for-segment-number
     &end
/*
     &else   &do
        &sv seg-from-aat                       =  [show arc [show select 1] item segment]
        &if %seg-from-aat%         not         =  0  &then &do
           &type \ THE CURRENT SEGMENT NUMBER IS:  %seg-from-aat%
           &s correct-segment                  =  [query ' IS THIS CORRECT (y/n)' .TRUE.]
```

```
/*
          &if %correct-segment%              = .false. &then &do
            &call prompt-for-segment-number                          /** call routine prompt-for-segment-number
            &set input-seg-num-manually      = .true.
          &end
          &else &do
            &s segment-number                = %seg-from-aat%
          &end
        &end
/*
        &else &do
          &s segment-number                  = %segment-number% + 1
          &type \ THE NEW SEGMENT NUMBER IS:  %segment-number%
          &s correct-segment                 = [query ' IS THIS CORRECT (y/n)' .TRUE.]
/*
          &if %correct-segment%              = .false. &then &do
            &call prompt-for-segment-number                          /** call routine prompt-for-segment-number
            &set input-seg-num-manually      = .true.
          &end
        &end
      &end
    &return
/*
/*****************************************************************************************************
/*      ROUTINE PROCESS-REST-OF-ARCS-IN-SEG                                                          *
/*                                                                                                   *
/*   After the arc chosen by the user is processed, a search is made for other arcs in that segment. This is done     *
/*   by selecting an arc which shares the tnode of the arc just processed. Segment numbers are assigned; direction    *
/*   is checked and arcs flipped if necessary. The item ARC_CHEK is used to prevent looping when donut shapes are    *
/*   involved. It is also used to identify the position of the arc within the segment.               *
/*****************************************************************************************************
/*
    &routine process-rest-of-arcs-in-seg
/*
      calculate segment                      = %segment-number%
      &s position-of-arc-in-segment          = 1
      calculate arc_chek                     = %position-of-arc-in-segment%
```

```
/*
    &s end-of-seg                               = .false.
    &do &until %end-of-seg%                     = .true.
      &s prev-tnode                             = [show arc [show select 1] item tnode#]
      &s prev-arcid                             = [show arc [show select 1] item %filename%-id]
/*
      select for tnode#                         = %prev-tnode%  ~
             or fnode#                          = %prev-tnode%  ~
      and %filename%-id                        ne %prev-arcid%  ~
           and feature-id                       = %elev%        ~
          and arc_chek                          = 0
/*
      &severity &error &routine no-more-arcs-in-seg              /** call routine no-more-arcs-in-seg
      &s current-record                         = [show select 1]
      &severity &error &fail
/*
      &if %end-of-seg%                          = .false. &then &do
        &s position-of-arc-in-segment           = %position-of-arc-in-segment% + 1
        calculate arc_chek                      = %position-of-arc-in-segment%
        calculate segment                       = %segment-number%
        &s current-tnode                        = [show arc [show select 1] item tnode#]
        &if %current-tnode%                     = %prev-tnode% &then &do
          flip
        &end
      &end
    &end
/*
  &return
/*
/*****************************************************************************************************
/*       ROUTINE NO-MORE-ARCS-IN-SEG                                                                 *
/*                                                                                                   *
/*    Sets an end-of-seg flag.                                                                       *
/*****************************************************************************************************
  &routine no-more-arcs-in-seg
    &s end-of-seg                               = .true.
  &return
```

```
/*
/*********************************************************************************************************
/*      ROUTINE ALL-SEGS-PROCESSED-FOR-THIS-ELEV                                                          *
/*                                                                                                        *
/*  Increments to the next elevation.  Prompts the user to choose 1) to continue processing at the next elevation,   *
/*  2) to process at some other elevation.  If user chooses to do neither, the program is exited.         *
/*********************************************************************************************************
/*
  &routine all-segs-processed-for-this-elev
/*
    &s done-with-current-elev             =   .true.
    &s next-elev                          =   %elev% + %interval%
    &type \ ALL SEGMENTS FOR FEATURE-ID %elev% HAVE BEEN PROCESSED.  \ THE NEXT FEATURE-ID IS ~
              %next-elev% \
    &s prompt2                            =   DO YOU WISH TO PROCESS SEGMENTS FOR  %next-elev% (y/n)
    &s continue-to-next-elev              =   [query  [quote %prompt2%] .TRUE.]
/*
    &if %continue-to-next-elev%           =   .false. &then &do
      &type
      &s select-a-different-elev          =   ~
              [query ' DO YOU WISH TO PROCESS SEGMENTS FOR A DIFFERENT FEATURE-ID (ELEVATION) (y/n)']
/*
      &if %select-a-different-elev%       =   .true. &then &do
        &call prompt-for-elevation                          /** call routine prompt-for-elevation
      &end
      &else &do
        &s bailout                        =   .true.
      &end
/*
    &end
    &else &do
      &s elev                             =   %next-elev%
    &end
  &return
```

```
/*
/***********************************************************************************************************
/*        ROUTINE CHECK-EDITDISTANCE                                                                        *
/*                                                                                                          *
/*    Prompts for new editdistance if default isn't acceptable.  Performs check for numerics                *
/***********************************************************************************************************
/*
  &routine check-editdistance
/*
    &type \ EDITDISTANCE IS CURRENTLY 20
    &s editdist-ok                      =  [QUERY ' IS THIS THE EDITDISTANCE YOU WISH TO USE (y/n)' .TRUE.]
/*
    &if %editdist-ok%                   =  .false. &then &do
      &s response-is-numeric            =  .false.
      &do &until %response-is-numeric%  =  .true.
        &type
        &s current-editdist             =  [RESPONSE ' ENTER THE EDITDISTANCE YOU WISH TO USE']
        &s passed-numeric-check         =  .true.
/*
        &severity &error &routine numeric-check                /**  call routine numeric-check
/*
        &if %current-editdist%          >  0  &then &do
          &severity &error &fail
          &if %passed-numeric-check%    =  .true.  &then &do
            &s response-is-numeric      =  .true.
          &end
        &end
      &end
    &end
  &return
```

```
/*
/*****************************************************************************************************
/*        ROUTINE FEATURE-DOES-NOT-EXIST                                                             *
/*                                                                                                   *
/*****************************************************************************************************
/*
  &routine feature-does-not-exist
/*
     &s feature-exists                         =  .false.
/*
  &return
/*
/*****************************************************************************************************
/*        ROUTINE PROMPT-FOR-ELEVATION                                                               *
/*                                                                                                   *
/*    Prompts for elevation.  Performs check for numerics.                                           *
/*****************************************************************************************************
/*
  &routine prompt-for-elevation
/*
    &s response-is-numeric                     =  .false.
    &do &until %response-is-numeric%          =  .true.
      &type
      &s elev                                  =  [RESPONSE ' ENTER FEATURE-ID (ELEVATION) YOU WISH TO PROCESS']
      &s passed-numeric-check                  =  .true.
/*
      &severity &error &routine numeric-check                      /**  call routine numeric-check
      &if %elev%                               >  0  &then &do
        &severity &error &fail
        &if %passed-numeric-check%             =  .true.   &then &do
          &s response-is-numeric               =  .true.
        &end
      &end
    &end
  &return
```

```
/*
/*****************************************************************************************************
/*        ROUTINE PROMPT-FOR-CONTOUR-INTERVAL                                                        *
/*                                                                                                   *
/*   Prompts for contour interval.  Performs check for numerics.                                     *
/*****************************************************************************************************
/*
  &routine prompt-for-contour-interval
/*
     &s response-is-numeric                    = .false.
     &do &until %response-is-numeric%          = .true.
        &type
        &s interval                            = [RESPONSE ' ENTER FEATURE-ID INTERVAL (CONTOUR INTERVAL)']
        &s passed-numeric-check                = .true.
/*
        &severity &error &routine numeric-check                       /**  call routine numeric-check
        &if %interval%                         >  0  &then &do
           &severity &error &fail
           &if %passed-numeric-check%          = .true.   &then &do
              &s response-is-numeric           = .true.
           &end
        &end
     &end
  &return
/*****************************************************************************************************
/*        ROUTINE PROMPT-FOR-SEGMENT-NUMBER                                                          *
/*                                                                                                   *
/*   Prompts for segment number.  Performs check for numerics.                                       *
/*****************************************************************************************************
/*
  &routine prompt-for-segment-number
/*
     &s response-is-numeric                    = .false.
     &do &until %response-is-numeric%          = .true.
        &type
        &s segment-number                      = [RESPONSE ' ENTER DESIRED SEGMENT NUMBER']
        &s passed-numeric-check                = .true.
```

```
/*
        &severity &error &routine numeric-check                          /**  call routine numeric-check
        &if %segment-number%              >  0  &then &do
           &severity &error &fail
           &if %passed-numeric-check%        =  .true.   &then &do
              &s response-is-numeric         =  .true.
           &end
        &end
      &end
    &return
/*
/*******************************************************************************************************
/*        ROUTINE NUMERIC-CHECK                                                                       *
/*    If response was not numeric, an error message is sent.                                          *
/*******************************************************************************************************
/*
    &routine numeric-check
      &s passed-numeric-check                =  .false.
      &type \ A POSITIVE NUMBER IS EXPECTED.  PLEASE RE-ENTER RESPONSE.
    &return
/*
```

```
/*****************************************************************************
/* AML:         unload.aml                                                   *
/* Author:      JK Jersey, Department of Plan and Soil Science,              *
/*              Montana State University, Bozeman, MT                        *
/* Date:        June, 1992                                                   *
/* Description: This aml copies the selected coverage to a temporary coverage *
/*              which is sorted in the order needed by preproc. Then an      *
/*              ASCII file is created which contains the attribute information *
/*              (feature-type and elevation) of the contours. Another        *
/*              ASCII file containing coordinate information is created in   *
/*              INFO. The temporary coverage is then deleted.                *
/*                                                                           *
/* Input:       Selected coverage                                            *
/* Output:      tempsort    ---coverage that gets created for the            *
/*                             duration of the AML                           *
/*              'cover'.srt ---sorted attributes                             *
/*              'cover'.pts ---coordinate information                        *
/*****************************************************************************
/*  &echo &on
/*
  &term 9999
  &type              \ SELECT COVERAGE YOU WISH TO USE
/*
  &s COV         =  [GETCOVER]                  /* prompts user for coverage
  &s PATH        =  [DIR [PATHNAME %cov%]]      /* obtains pathname
  &s FILENAME    =  [ENTRYNAME %cov%]           /* obtains filename
/*
/*****************************************************************************
/*  copy selected coverage to a temporary coverage for sorting....this is    *
/*      a precaution because sorting in TABLES scrambles pointers            *
/*****************************************************************************
/*
  copy  %filename% tempsort
/*
/*****************************************************************************
/*   sort the arcs to the specifications needed by TAPES programs            *
/*****************************************************************************
/*
  tables
  select tempsort.aat
  sort sortfeat feature-id segment arc_chek
  quit
  quit
```

Figure 34. AML which unloads ARC/INFO information to two ASCII files.

```
/*****************************************************************************
/*     dump attribute data for the sorted arcs to an ASCII file              *
/*     **note:  INFO is real picky about where you put your commands....need  *
/*              to start them in column 1                                    *
/*****************************************************************************
/*
   &data ARC INFO
arc
calculate $COMMA-SWITCH = -1
output %cov%.srt
select TEMPSORT.AAT
disp FEATURE,FEATURE-ID,TEMPSORT-ID,SEGMENT,ARC_CHEK,FNODE#,TNODE#
PRINT
q stop
   &end
/*
/*****************************************************************************
/*     dump coordinate data to an ASCII file                                 *
/*****************************************************************************
/*
   ungenerate line %filename% %cov%.pts
/*
/*****************************************************************************
/*     delete temporary coverage that was used for sorting                   *
/*****************************************************************************
/*
   kill tempsort
/*
   quit
   &return
```

```
C***********************************************************
C Program:     merge.for                                   *
C Author:      JK Jersey, Department of Plant and Soil Science, *
C              Montana State University, Bozeman, MT       *
C Date:        May, 1992                                   *
C Function:    Merges two input files into one output file *
C              which is formated to be used in the 'preproc' *
C              program.  The first input record is sorted in *
C              the order needed and contains contour and   *
C              feature information.  The second input file *
C              contains coordinate data and is merged to the *
C              first based on userids generated by arc_info. *
C                                                          *
C              This program expects the coordinate data which *
C              is created by the UNGENERATE command to be in *
C              UTM format.  If a different projection was used *
C              the format in this file may be different and *
C              consequently the format statement (330) for the *
C              read  will need to be changed.              *
C                                                          *
C              The command to compile this program on the  *
C              DEC station is:                             *
C     f77 -o merge.exe -L/usr/lib/cmplrs/fort_300 merge.for *
C***********************************************************
      character*1      saveutm        /'n'/
      real             featid_sorted
      integer          x_utm
      integer          y_utm
      integer          o_xcoord
      integer          o_ycoord
      character*3      o_pad1         /'@1+'/
      character*1      o_pad2         /'+'/
      character*14     o_pad3         /'TWO-POINTS- XY'/
      character*14     o_pad4         /'  0.00   0.00'/
      character*10     o_pad5         /'   0.00'/
C
C***********************************************************
C        OPEN FILES                                        *
C***********************************************************
      write(6,200)
      read(5,300) filename
      open(unit=1,file=filename,status='old')
      write(6,210)
      read(5,300) filename
      open(unit=2,file=filename,status='old')
      write(6,220)
      read(5,300) filename
      open(unit=3,file=filename,status='new')
```

Figure 35. FORTRAN program merging two ASCII files into one file useable by the hydrology model.

```
C
      write(6,225)
      read(5,340) saveutm
      if (saveutm .eq. 'y' .or. saveutm .eq. 'Y') then
         write(6,227)
         read(5,300) filename
         open(unit=4,file=filename,status='new')
      endif
C
C**********************************************************
C      match userid from sorted file to userid in         *
C      ungen file                                         *
C**********************************************************
C
      prev_featid            =  '   '
   10 read(1,310,end=80)feat_sorted,featid_sorted,usrid_sorted
C
   20 read(2,320) usrid_ungen
C
      if (usrid_sorted         .ne. usrid_ungen)  then
         goto 20
      else
C
C**********************************************************
C*    output header record for the W-E                    *
C*    line (T), for each new high (H) or saddle point (D) *
C*    and for each new contour elevation (' ')            *
C**********************************************************
C
         if (feat_sorted          .eq.  'T')  then
               o_distance         =  featid_sorted
               write(3,250) o_pad3
               write(3,250) o_pad4
               write(3,251) o_distance,o_pad5
C
         else
            if (featid_sorted              .ne. prev_featid .or.
     *         feat_sorted                 .eq. 'D' .or.
     *         feat_sorted                 .eq. 'H') then
               prev_featid                 =    featid_sorted
               o_featid                    =    featid_sorted
C
               if (feat_sorted             .eq. ' ')  then
                  o_feature                =    'CONTOUR'
               else
                  if (feat_sorted          .eq. 'H') then
                     o_feature             =    'HIGHPOI'
                  else
                     if (feat_sorted       .eq.  'D') then
                        o_feature          =    'D-SADDL'
                     else
                        if (feat_sorted    .eq. 'S') then
                           o_feature       =    'STREAML'
```

```
                else
                  if (feat_sorted     .eq. 'B') then
                    o_feature       =    'BOUNDAR'
                  endif
                endif
              endif
            endif
          endif
C
          write(3,230) o_feature,o_featid
C
        endif
      endif
C
C*********************************************************
C*   output one record for coordinates of high or        *
C*   saddle points.  output two record for the W-E line  *
C*   data.  output multiple coordinate points for contour *
C*   lines and stream lines.                             *
C*********************************************************
C
      if (feat_sorted   .eq. 'D' .or.
     *     feat_sorted  .eq. 'H')  then
        read(2,330) end_ungen,x_utm,x_ungen,
     *              y_utm,y_ungen
        o_xcoord      =     x_ungen + 0.5
        o_ycoord      =     y_ungen + 0.5
        write(3,240) o_pad1,o_xcoord,o_pad2,o_ycoord
C
      else
        if (feat_sorted          .eq. ' '  .or.
     *       feat_sorted         .eq. 'T'  .or.
     *       feat_sorted         .eq. 'B'  .or.
     *       feat_sorted         .eq. 'S')  then
 30        read(2,330) end_ungen,x_utm,x_ungen,
     *                y_utm,y_ungen
C
          if ((saveutm          .eq. 'y'  .or.
     *         saveutm          .eq. 'Y') .and.
     *      feat_sorted .eq. 'T')    then
            write(4,260) x_utm,x_ungen,y_utm,y_ungen
            saveutm  =  'n'
          endif
C
          if (end_ungen        .eq. '   ')  then
            o_xcoord           =     x_ungen + 0.5
            o_ycoord           =     y_ungen + 0.5
            write(3,240) o_pad1,o_xcoord,o_pad2,
     *                  o_ycoord
            goto 30
          endif
        endif
      endif
```

```
C
      endif
      rewind 2
      goto 10
C
   80 continue
C
C**********************************************************
C*  200's    format for write statements                  *
C**********************************************************
  200 format(/1X,'ENTER NAME OF SORTED FILE (---.srt): ',$)
  210 format(/1X,'ENTER NAME OF UNGEN FILE (---.pts): ',$)
  220 format(/1X,'ENTER NAME OF OUTPUT FILE (---.cns): ',$)
  225 format(/1X,'DO YOU WANT UTM INFO SAVED (Y/N)?  ',$)
  227 format(/1x,'ENTER NAME OF UTM FILE (---.utm): ',$)
  230 format(a7,f7.2)
  240 format(a3,i5,a1,i5)
  250 format(a14)
  251 format(f7.2,a7)
  260 format(2x,i1,f7.1,3x,i2,f7.1)
C**********************************************************
C*  300's    format for read statements                   *
C**********************************************************
  300 format(a30)
  310 format(x,a1,2x,f7.2,a6)
  320 format(4x,a6)
  330 format(a3,2x,i1,f7.1,9x,i2,f7.1)
  340 format(1A1)
C
      end
```