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TERRAIN, CLIMATE, AND VEGETATION IN THE BADLANDS OF THE LITTLE MISSOURI RIVER IN NORTH DAKOTA

by
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A Thesis

Submitted to the Graduate Faculty

of the

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for the degree of

Master of Science

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This Thesis submitted by Paula Himmelheber Lee in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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This Thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

A. William Johnson 12/7/83
Dean of the Graduate School

Permission

Title Terrain, Climate, and Vegetation in the Badlands of the Little Missouri River in North Dakota

Department Geography

Degree Master of Science

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Signature Paula H. Lee

Date November 22, 1983

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ABSTRACT

The climate of southwestern North Dakota is typical for the Great Plains of the central and west-central United States. The Rocky Mountains influence the climatic conditions by providing an orographic obstacle to air circulation. Statistical analysis through correlation and regression of 30 years of climatic data from southwestern North Dakota and nearby stations in South Dakota and Montana is consistent with climatic relationships that have been defined by previous research. The influence of the Rocky Mountains is quantified through a variable that represents the linear distance from each weather station to the front range.

The natural vegetation of southwestern North Dakota is mixed grasses; however, in the Badlands of the Little Missouri River, many varieties of plants are encountered. Flora range from desert plants, through mixed grasses, to woodland vegetation of higher elevations. Overall climate is modified into local climates by rough terrain, which provides extremes of conditions that create suitable habitats for migrant species in addition to grasses common to the region. Differences between general climate and terrain climate are contributable to unequal receipt of solar radiation, which causes variations in temperature, humidity, and other related parameters. Radiation estimates (and consequent variable equivalent latitude) are computed for nine stations that have been in the same location for a majority of the 30 year period. Additional correlation shows significant relationships between radiation and average temperature of some fall and winter months. Equivalent latitude proves to be a valuable tool in analyzing the complex interaction of slope and azimuth for a given latitude in regression analysis.

Significant differences between slopes are computed through several analyses of drainageways in the North Killdeer Mountain area. Wilcoxon Tests for Paired Samples show variations in slope angles between east and west, and for northeast and southwest slopes. Chi-square analysis reveals significant results using north/south, northeast/southwest, northeast/west, north/southwest, and northwest/south azimuth pairs, and woodland, shrubland, and native prairie vegetation categories. Radiation estimates are calculated for sample slopes, and comparison of radiation conditions is made.

Vegetation patterns found in Theodore Roosevelt National Park in a previous study are depicted using a circle method to represent azimuth and slope angle. Twelve plants are analyzed, and individual patterns emerge.

CHAPTER 1

INTRODUCTION

Geographic Approach

As one travels through the Badlands of the Little Missouri River in southwestern North Dakota, differences in vegetation on slopes of different aspects are immediately apparent. Patterns found there have been developing over thousands of years, through both droughty and humid periods. Glacial diversion of the Little Missouri River during the Pleistocene caused the onset of erosion which carved the rough terrain; due in part to continued subhumid conditions today, headward erosion proceeds and the landscape changes as drainageways are cut deeper and wider. Studying the causes of such different vegetative conditions as they exist on valley slopes in the Badlands, and the processes that lead to them constitutes geographic research. As Preston James has written:

> Geography is that field of learning in which the characteristics of particular places on the earth's surface are examined. It is concerned with the arrangement of things and with the associations of things that distinguish one area from another. . . . The face of the earth is made up of many different kinds of features, each the momentary result of an ongoing process. A process is a sequence of changes, systematically related as in a chain of cause and effect. There are physical and chemical processes developing

> the forms of the land surface, the shapes of the ocean basins, the differing characteristics of water and climate. There are biotic processes by which plants and animals spread over the earth in complex areal relation to the physical features and to each other. . . . As a result of all these processes the face of the earth is marked off into distinctive areas; geography seeks to interpret the significance of likenesses and differences among places in terms of causes and consequences (Meinig ed. 1971, p. 5).

Geographic Setting

The part of the country in which the Little Missouri River Badlands occur is the Great Plains where the natural vegetation is mixed grasses. The area is in a zone of transition, with tall grass prairie and deciduous forest to the east, and steppe and desert to the west. Depending upon local conditions a wide variety of plant species is present in the study area including shrubs, occasional thickets of woodlands, and desert species originating from the west. Each plant has limits and requirements with regard to light, heat, wind, moisture, soil nutrients, etc. The rough terrain of the Badlands presents a great variety of exposures with varying local conditions that provide suitable habitat for this wide range of plants; environmental gradients affecting vegetation can be very great, as a result of local differences in topography.

Purposes of Study

The aim of this thesis is to use climatic averages to obtain a profile of the study area, and to attempt to relate slope angle and aspect to climatic conditions through calculation of potential radiation. This study also applies previously defined principles of slope/aspect (i.e., slope angle and azimuth) to vegetation in two areas within the Badlands. The general hypothesis is that there is a definite relationship between slope/aspect, climate, and vegetation. Since climatic data in this study are limited to thirty-year means for thirty-two official weather stations, the local climate of a particular slope cannot be determined directly. However, indirect estimates of the local climate through estimates of potential radiation can be made. Vankat (1979) considered climate, soil, topography, biota, and fire as interrelated environmental factors that affect vegetation, although he did note that on a regional level, climate is the most important. Or, in the words of Scott:

> Environmental variables differ in the type and magnitude of their effect on plants. But the response of the plants will be conditioned by "all" environmental variables. Thus, in studying the relationship between plants and particular environmental variables one must take account of possible influence of other variables (Tuxen ed. 1974, p. 50).

Expected Results

Climatic relationships resulting from this study are expected to be similar to those proven to exist at mid-latitude continental locations near a major orographic obstacle. The influence of the Rocky Mountains on the climate of southwestern North Dakota will be quantified. The concept of "equivalent latitude" is expected to indicate the influence of slope angle and azimuth (with latitude) on radiation conditions on slopes. Finally, principles of previous vegetation studies are applied to slopes in southwestern North Dakota, and significant differences in vegetation with respect to azimuth are anticipated.

Terminology

The sense of local or terrain climate is taken from Geiger (1965), whose idea included the effects of topography, soil, and vegetation in a particular place. Thornthwaite (1953) coined the word "topoclimate" for the same general concept. Vegetation terminology is mostly from Stevens (1963), although a few terms not found there are from either Van Bruggen (1976) or Rydberg (1932). In references to previous studies the vegetative terminology of each author is employed, even if the names do not agree with the common names suggested by Stevens, Van Bruggen or Rydberg.

CHAPTER 2

THE STUDY AREA

Location

The North Dakota portion of the Little Missouri River basin drains parts of six southwestern counties. The Little Missouri River forms in northeastern Wyoming, flows northeast through a segment of both Montana and South Dakota, and enters North Dakota in the southwestern edge of Bowman County (Figure 1). Numerous creeks and intermittent streams flow into the river which eventually turns eastward and enters the Missouri River in Dunn County. Badlands topography is found along both sides of the Little Missouri in North Dakota for a number of miles.

Climatic data (1951-1980) for the drainage basin of the Little Missouri River are collected; however, in the southwestern part of North Dakota, weather stations are more widely spaced than to the east. In all of the Little Missouri River basin in North Dakota there are six stations; two presently are inactive, and another collects only precipitation data. In order to ensure an accurate picture of climatic conditions in the study area, as many stations as possible from nine southwestern counties (Figure 2) are utilized as well as five additional North Dakota stations

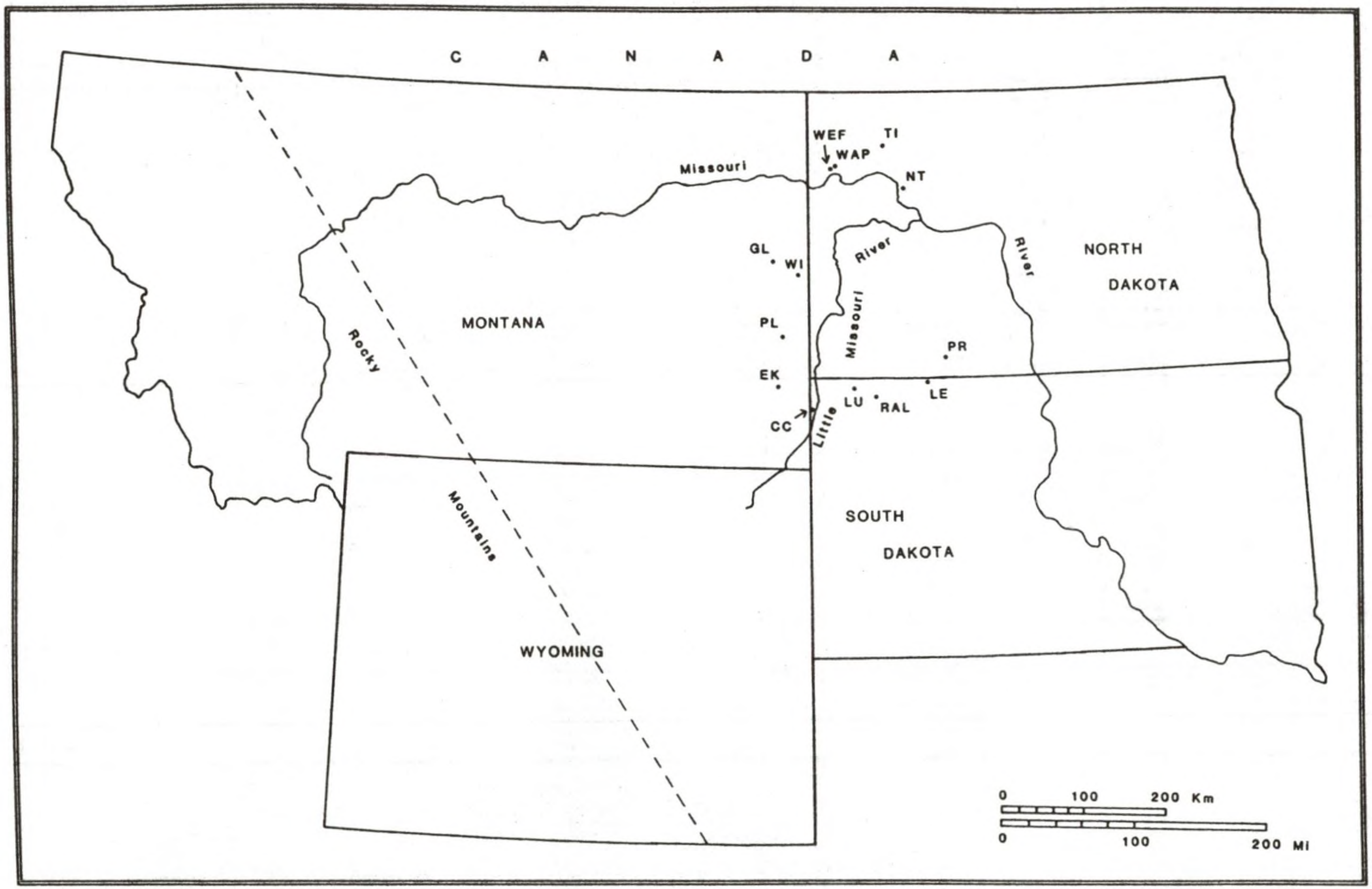

Figure 1: Route of the Little Missouri River. Weather Stations Around Study Area Indicated; Abbreviated Names Defined in Table 26, Appendix B (National Geographic Society 1977; U. S. Department of Commerce 1980).

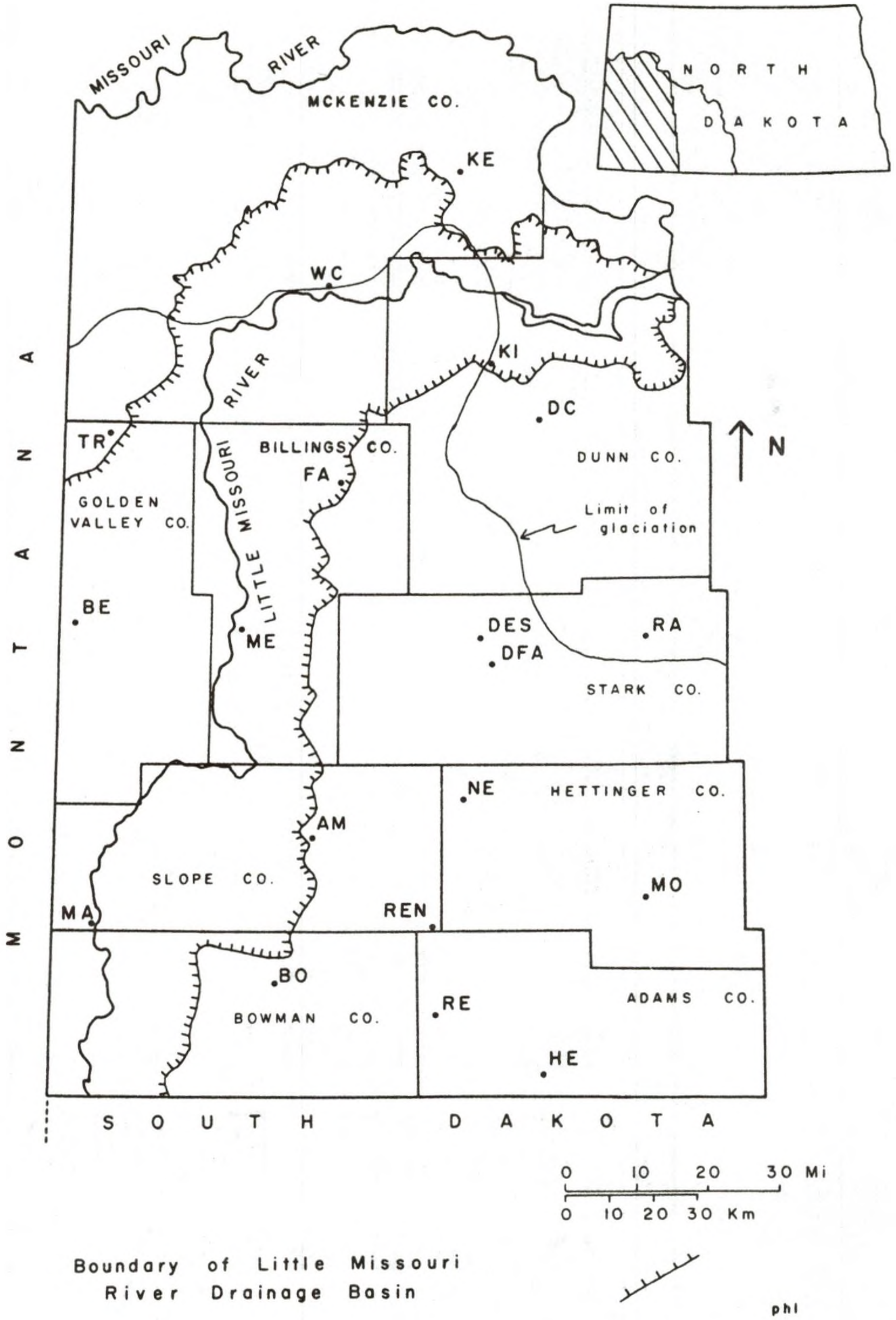

Figure 2: Nine Counties of Southwestern North Dakota. Nineteen Weather Stations Shown; Abbreviated Names Defined in Table 26, Appendix B (North Dakota State University 1973; U. S. Department of Commerce 1980).

close to the study area, four others in South Dakota, and four in Montana (Figure 1).

Two smaller areas within the Little Missouri River basin are used in the analysis of vegetation. The first is in the northwestern part of Dunn County, and is covered by the North Killdeer Mountain 7 1/2 minute topographic quadrangle (Figure 3 to Figure 4). Vegetation maps produced by the Bureau of Land Management (U.S. Department of Interior 1981) are available for this area and are used in this study (Figure 5). The second area includes both units of Theodore Roosevelt National Park; the south unit is located in Billings County, and the north unit is in McKenzie County (Figure 6). Vegetation data for sixty-eight stands are used from a study of the area by Hansen, Hopkins, and Hoffman (1980).

Physiography and Geology

The nine counties in the study area are part of the Missouri Slope topographic region of the state of North Dakota. The Badlands are areas of especially rough terrain characterized by ravines, draws, gullies, and buttes which have formed as a result of stream erosion of soft clays and sands. The term "badland" is a translation of a Sioux term and the French translation "les mauvais terres a' traverser," bad land to cross (Bluemle 1977).

Before glaciation the Little Missouri River flowed northward to Hudson Bay. When glacial ice entered North

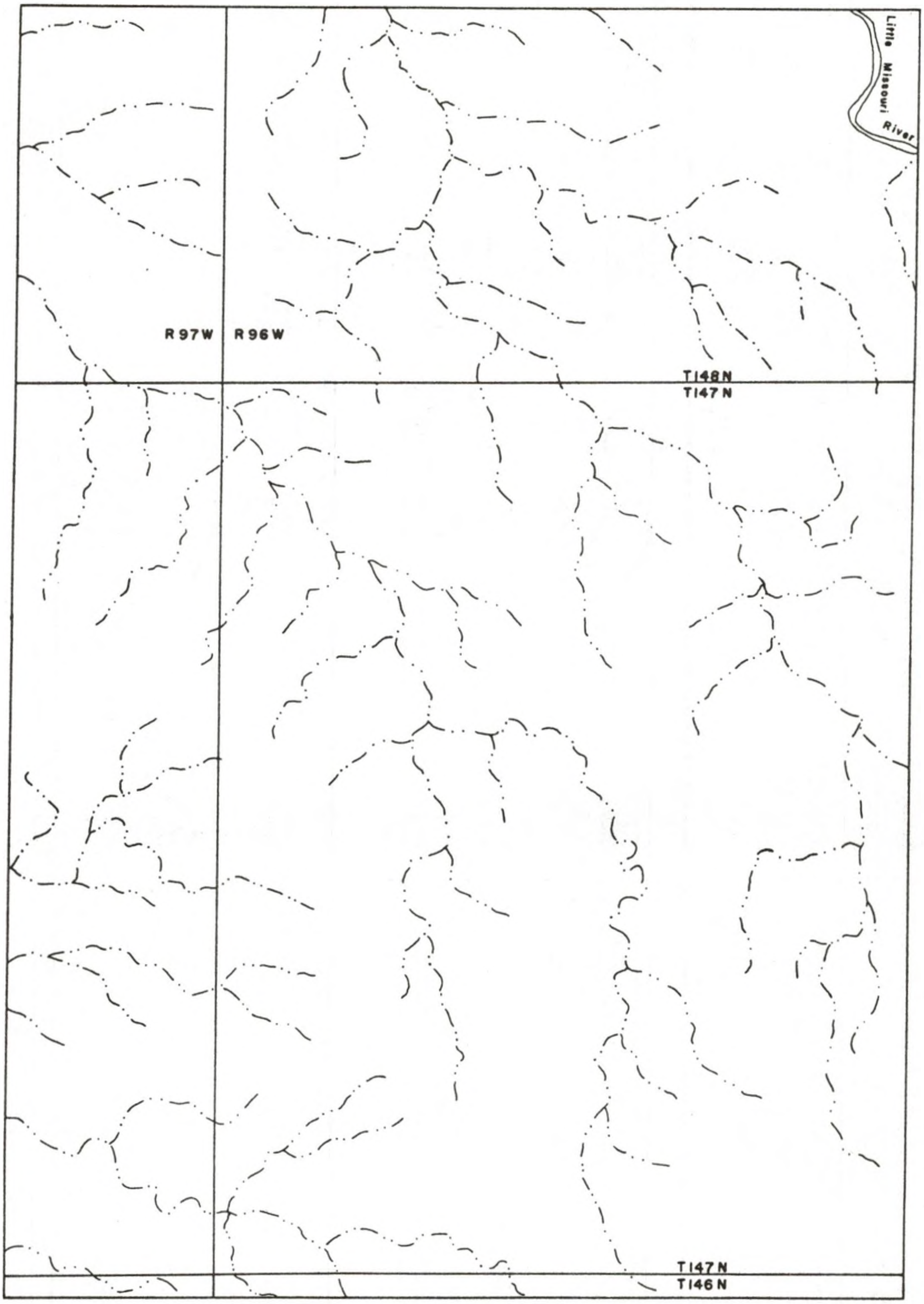

Figure 3: Drainage Pattern of the North Killdeer Mountain Quadrangle (U. S. Department of Interior 1958).

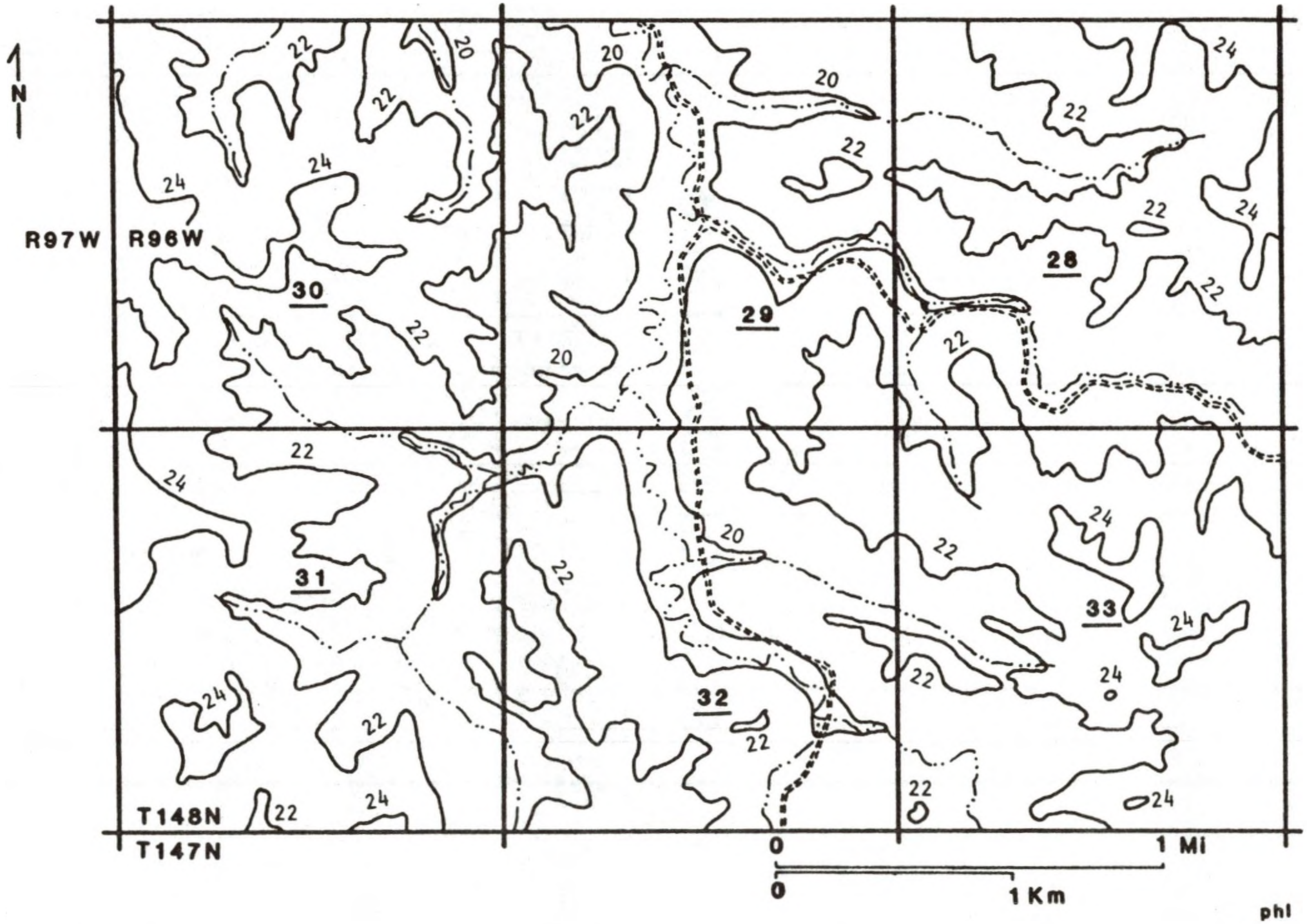

Figure 4: Sample of North Killdeer Mountain Quadrangle, Sections 28 to 33 (underlined). Contours in Hundreds of Feet Above Mean Sea Level (U. S. Department of Interior 1958).

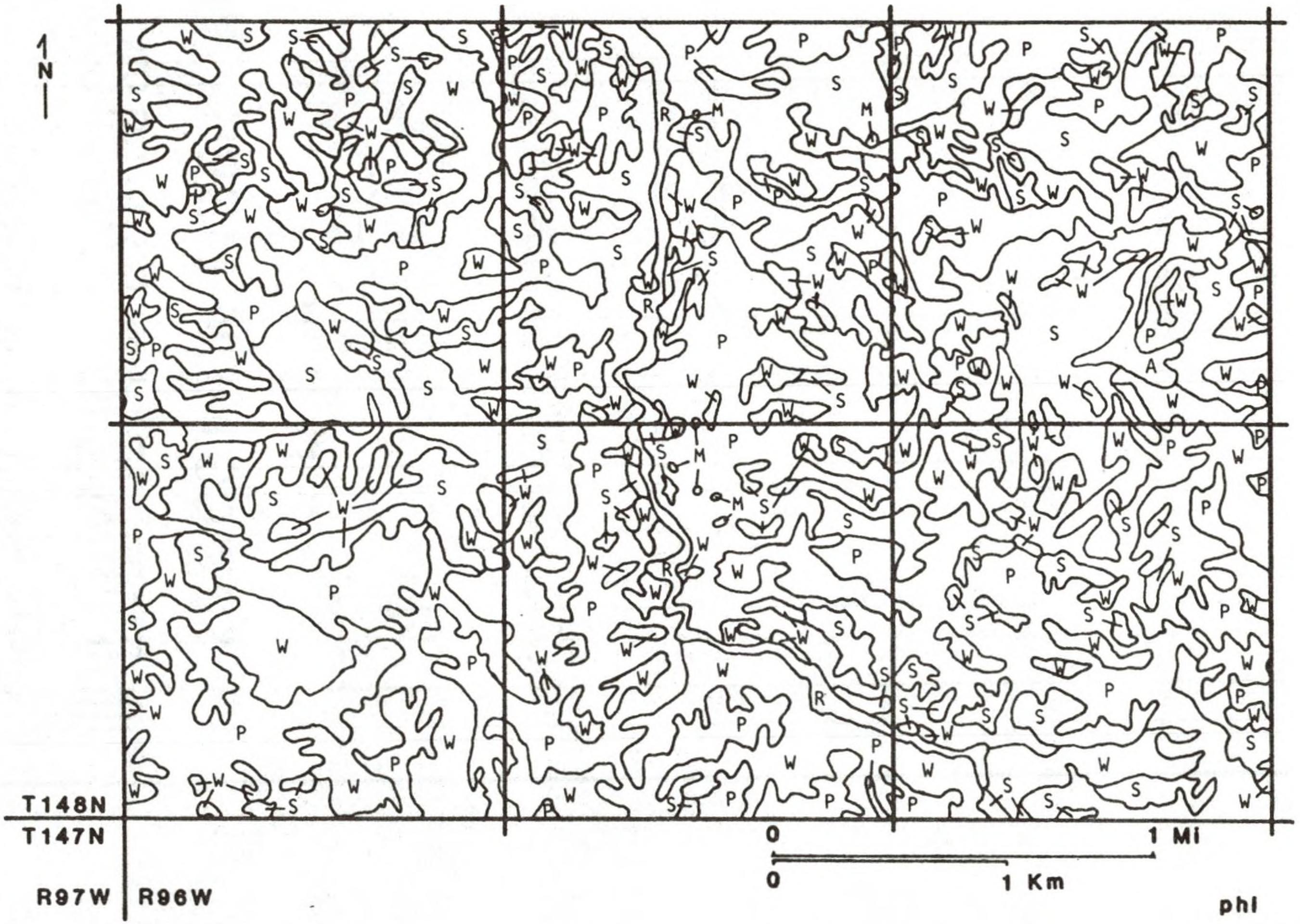

Figure 5: Sample of Vegetation Overlay for North Killdeer Mountain Quadrangle, Sections 28 to 33. A = Agriculturally Disturbed; M = Marshy; P = Native Prairie; R = Riverine; S = Shrubland; W = Woodland (U. S. Department of Interior 1981).

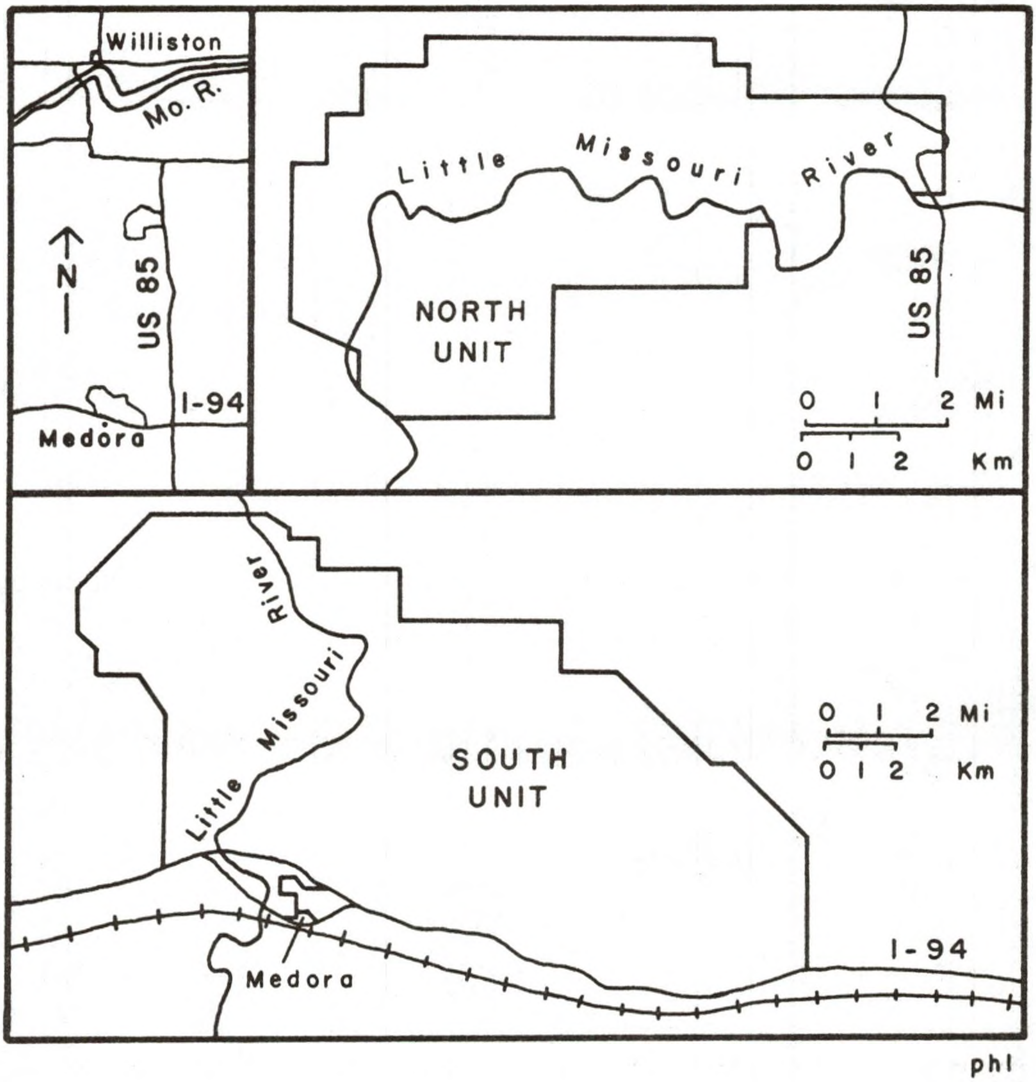

Figure 6: Theodore Roosevelt National Park, North and South Units (U. S. Department of Interior 1974a, 1974b).

Dakota from the north and east the Little Missouri's normal route became blocked (Leonard 1916). At the height of glaciation a glacial lake formed in the valley. Given current breaks and divide heights, Lemke et al. (1965) concluded that the lake, named Lake Glendive, would have occupied the valleys of the Little Missouri and Yellowstone Rivers, with a narrow connection between the two expanses. Clayton, Moran, and Bluemle (1980) agreed with the theoretical existence of a glacial lake, but they pointed out that there are no known beaches, and only small amounts of offshore sediment have been located.

During the glacial period the path of the Little Missouri became diverted to the east. Eventually the stream emptied into the Missouri River which also was diverted by glacial ice. Base level of the Little Missouri was affected due to entrenchment of the stream (Schmitz 1955). With its new course, the river had a much steeper gradient, and heavy erosion was caused. Deep gullies and ravines were cut; where erosion-resistant material was present, downcutting did not take place. These areas stand today as buttes surrounded by dissected land (Bluemle 1977).

The distinctive appearance of the Badlands is the result of the downcutting by the Little Missouri River through the soft materials deposited in nearly horizontal strata. A typical Badlands vista is one of steep gray, yellow, and brown valley slopes with dark interbedded lignite and red "scoria" beds (Figure 7). Numerous buttes

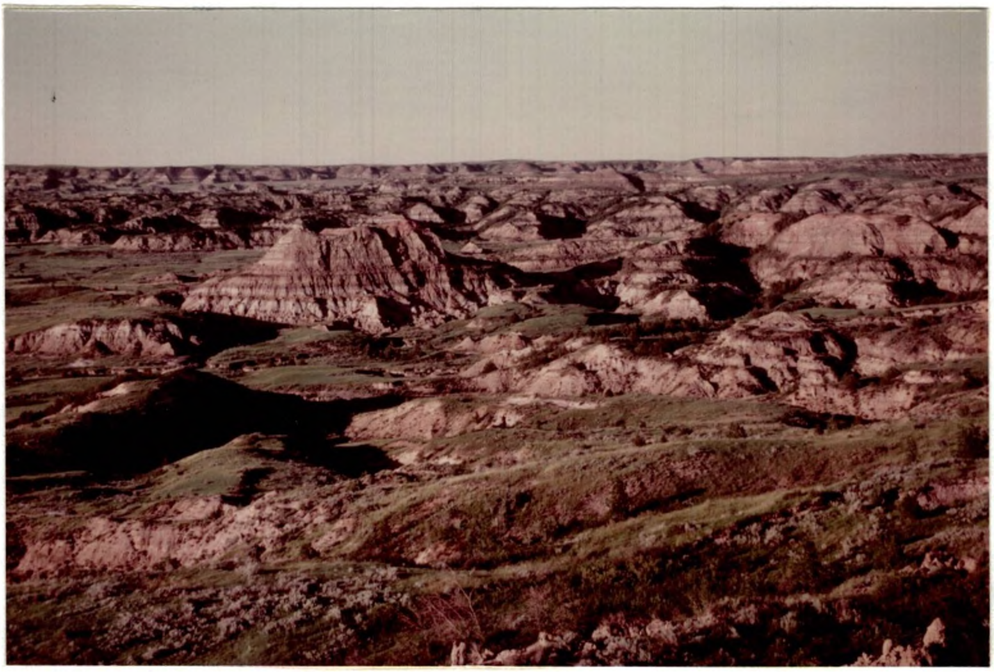

Figure 7: Badlands Vista from Painted Canyon Scenic Overlook off Interstate 94 in Billings County. Taken by Floyd Hickok.

occur in the Badlands and throughout the nine counties. These hills rise 122 to 213 m (400 to 700 ft) above their surroundings. Many are flat-topped, and resemble small mesas (Hainer 1956). Quinnild and Cosby (1958) found relicts of climax vegetation on two mesas in Billings County. Hills are often protected from erosion by a caprock, usually of sandstone, "scoria" or occasionally chert, all of which are present in Paleocene and Eocene deposits (Hainer 1956). "Scoria," the locally used name for clinker, is a hard, rocklike mass that resulted when burning lignite baked surrounding clay and shale; its red color developed from hematite (Bluemle 1977).

Erosion is facilitated by the presence of easily moved soils made up of "poorly cemented sands, clays and silt-stones. . . ." (Laird 1950). Sudden, heavy summer showers that typify the climate of the area continue the erosional work. Topographic unconformities are common where divides between valleys are breached by gulches that are eroded toward a central point (Schmitz 1955). The amount of erosion and appearance of slopes are also dependent upon the material being moved. Jacob (1975) observed that weathered slopes of the Sentinel Butte Formation were steeper and more irregular than slopes of the Bullion Creek Formation, because the former materials were better cemented. Also, drying cracks were more common in materials of the Sentinel Butte Formation due to the higher proportion of montmorillonite.

Leonard (1916) offered five facts that supported the concept of diversion of the Little Missouri River by glacial ice: (1) in the lower portion of the river in McKenzie County, tributaries were shorter than in upper reaches, along the north/south leg; (2) the Badlands along the lower east-flowing leg were less than half as wide as farther upstream; (3) there were no terraces along the lower end of the river, while high, flat terraces were found upstream; (4) the bend toward the east in McKenzie County corresponded "quite closely" with the presumed maximum extent of glacial ice, and the eastward-flowing leg in McKenzie County and Dunn County paralleled it for about forty miles; and (5) the Killdeer Mountains, about six miles to the south of the river, showed little direct stream erosion. All of these reasons supported the interpretation that the lower east-flowing leg of the Little Missouri River was much younger than the upper northward-flowing portion.

Surface geology of southwestern North Dakota is dominated by deposits of the Sentinel Butte and Bullion Creek Formations (Paleocene), with smaller areas of Slope, Hell Creek, Pierre Formation (Cretateous), and the Golden Valley Formation (Eocene). Some glacial till occurs near the boundary of glaciation in the two northern counties (Figure 8 and Table 1).

Cretaceous deposits are exposed at the surface in the western third of Bowman County and in the southwestern

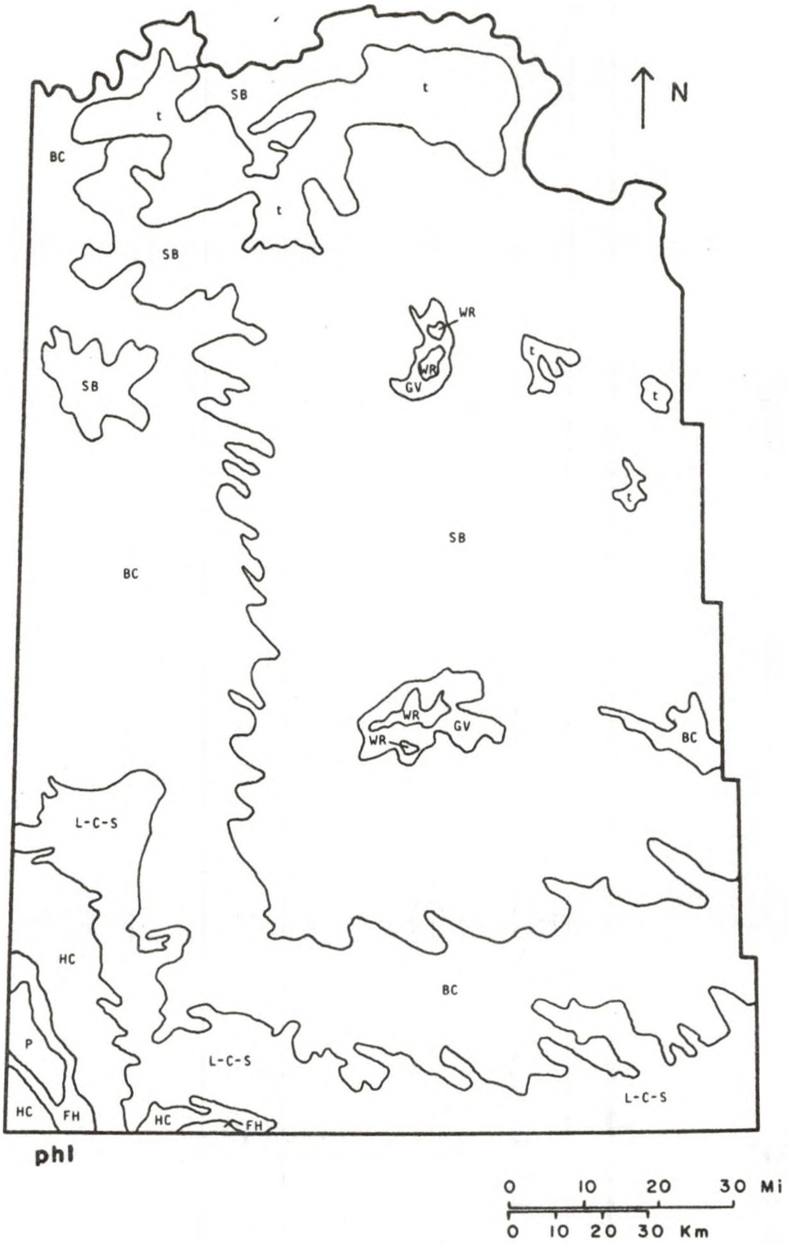

Figure 8: Surface Geology of Nine Southwestern Counties of North Dakota. BC = Bullion Creek Formation; FH = Fox Hills Formation; GV = Golden Valley Formation; HC = Hell Creek Formation; L-C-S = Ludlow/Cannonball/Slope Formations (undifferentiated); SB = Sentinel Butte Formation; t = till; WR = White River Group (North Dakota State University 1973; Bluemle 1977).

TABLE 1

Stratigraphic Column for Southwestern North Dakota[a]

ERA	PERIOD	EPOCH	FORMATION OR GROUP	DOMINANT LITHOLOGY
Cenozoic	Tertiary	Oligocene	White River Group: 1)Brule Fm	Siltstone, clay, sand
			2)Chadron Fm	Sand with quartzite and porphyry, clay
		Eocene	Golden Valley Formation: 1)Camels Butte Mem	Sand, sandstone, silt, clay
			2)Bear Den Member	Clay, silt, sand
		Paleocene	Sentinel Butte Fm	Silt, sand, clay, sandstone, lignite
			Bullion Creek Fm	Silt, sand, clay, sandstone, lignite
			Slope Fm	Silt, sand, clay, sandstone, lignite
			Cannonball Formation	Sand, shale
			Ludlow Fm	Silt, sand, clay, sandstone, lignite
Mesozoic	Cretaceous		Hell Creek Formation	Sand, sandstone, silt, clay
			Fox Hills Formation	Sand, sandstone, shale
			Pierre Fm	Shale

[a] (Clayton, Moran, and Bluemle 1980)

corner of Slope County. The oldest of these formations is the Pierre, which consists of gray shale several hundred meters thick that was deposited in an offshore marine environment. Just above the Pierre lies a thinner stratum of sand and sandstone of the Fox Hills Formation that was deposited in a littoral environment, and shale of an offshore environment. Above the Fox Hills lies the Hell Creek Formation which is of approximately the same thickness as the Fox Hills. This youngest Cretaceous deposit contains cross-bedded sand and sandstone interpreted as fluvial sediment, and overbank deposits of silt and clay (Clayton, Moran, and Bluemle 1980). Exposure of the older Cretaceous rocks is the result of erosion along the crest of the Cedar Creek Anticline (Bluemle 1977).

The oldest Paleocene deposits that crop out in the study area are those of the Slope, Cannonball, and Ludlow Formations. These are found in southern Adams County, and the southeastern part of Bowman County; the Cannonball Formation thins to the west, leaving the Ludlow in contact with the Slope Formation in a band in the western parts of Bowman and Slope counties. Ludlow materials consist of silt, sand, clay, sandstone, and lignite that were deposited in fluvial, lacustrine, and paludal environments. The Cannonball, which is absent in the Badlands, consists of marine sand and marine offshore shale. The Slope Formation, which is "nearly identical" to the Ludlow unit, is distinguishable from it by a distinctive lignite bed at the contact, the T Cross Bed (Clayton, Moran, and Bluemle 1980).

The next oldest Paleocene formation exposed in southwestern North Dakota is the Bullion Creek, which consists of alternating layers of silt, clay, sand, sandstone, and lignite. Organic materials were deposited in swampy areas eventually covered by sand and silt as meandering streams changed course; compaction by overlying layers caused the development of coal. The Bullion Creek Formation occurs in Adams, Hettinger, Bowman, Slope, Billings, Golden Valley, and McKenzie counties, and is the most common one in the surface geology of the Badlands (Bluemle 1977). In 1977 the name Bullion Creek replaced the earlier Tongue River terminology, because of correlation problems with strata in South Dakota and Montana (Clayton et al. 1977; Lerud 1982).

The formation with the greatest area in the nine counties is the Sentinel Butte. This material consists of up to 200 m (656 ft) of silt, sand, clay, sandstone, and lignite that were deposited in fluvial, lacustrine, and paludal environments (Clayton, Moran, and Bluemle 1980). This formation can be distinguished from the underlying Bullion Creek by two means: color, and a marker at the contact. The Sentinel Butte deposits are dark gray or brown, while the underlying Bullion Creek sediment is yellow, buff, or light gray. The marker that serves as the contact between the two formations is referred to as the HT Bed, a stratum of lignite or sometimes "scoria" (clinker). Also, sand is present at the bottom of the Sentinel Butte Formation (Jacob 1975).

Small exposures of Eocene-age Golden Valley Formation and Oligocene White River Group occur throughout the nine study area counties. In the Golden Valley the Bear Den (lower) Member contains up to 20 m (66 ft) of clay, silt, or sand sometimes capped by almost 1 m (3 ft) of chert; the Camels Butte (upper) Member contains as much as 60 m (197 ft) of micaceous sand, sandstone, silt, and clay. The White River Group is composed of two formations: (1) the Chadron Formation, up to 30 m (98 ft) of sand with quartzite and porphyry cobbles and pebbles, overlain by clay; and (2) the Brule Formation, about 30 m (98 ft) of siltstone, clay, and sand (Clayton, Moran, and Bluemle 1980). The "Little Badlands" area southwest of Dickinson in Stark County contains the most extensive deposits of the White River Group, most of which had eroded away (Caldwell 1954).

The soft and poorly cemented surficial materials are subjected to mass wasting. Schmitz (1955) noted four conditions that favored mass wasting in the Badlands environment: (1) exposed unconformities; (2) alternating resistant and nonresistant beds (or nonpermeable and permeable); (3) sparse vegetation; and (4) heavy rain, large range in temperatures, and numerous freeze/thaw cycles. Debris fall and slumps are the most common types of mass wasting in this area (Figure 9 and Figure 10).

> The steep faces of the bluffs are partly maintained by excess of evaporation, imperviousness of the clay, and the angle of slump. Aridity keeps the materials in a dry condition and (prepared for removal) by winds or torrential rains.
>
> Shower and wind effectiveness is most extreme upon the steep slopes that are bare of vegetation. It is quite apparent that the southerly-facing buttes and slopes, devoid of vegetation, are being actively eroded. In contrast, the northerly slopes, protected from exposure to wind and sun are covered with grass and are decidedly more gentle (Schmitz 1955, p. 20).

Soils

A few county soil surveys have been recently completed, while others are up to forty years old. As a result, terminology of both Great Soil Groups and the "7th Approximation" (of the Soil Conservation Service) is used to describe soils of the study area. Mixing of genetic and non-genetic systems occurs in the following discussion, due to the fact that the vocabulary found in the source is retained.

Two major soil types occur in southwestern North Dakota: soils on steep, broken and hilly land (generally regosols and lithosols), and chestnut soils of the grasslands (Figure 11). The former are found in the dissected areas in and around the Badlands, and the latter are on the flatter to rolling area of the southeast half of the study area. A smaller, generalized area of solonetz soils

Figure 9: Landslide in the South Unit of Theodore Roosevelt National Park, Near Visitor Center.

Figure 10: Slump in the North Unit of Theodore Roosevelt National Park, off Scenic Drive in Sec. 33 T145N R99W.

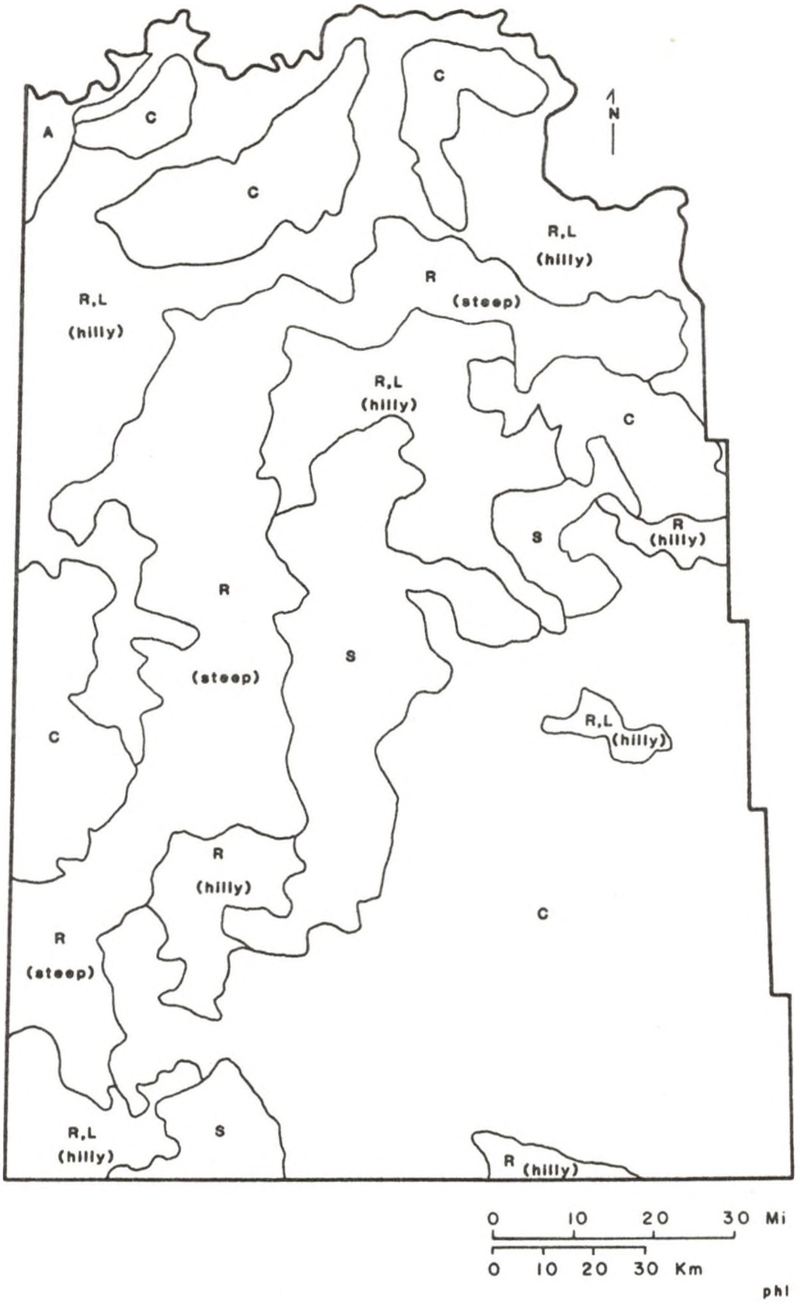

Figure 11: Great Soil Groups for Nine Southwestern Counties of North Dakota. A = Alluvial; C = Chestnut; L = Lithosol; R = Regosol; S = Solonetz (Omodt et al. 1968).

occurs between the two. The steep "Badland" soils are mostly entisols, and the grassland soils are mostly mollisols (Omodt et al. 1968).

The most common soil series in the steep and hilly areas is the Bainville which developed from calcareous, Tertiary material. Textures vary from loam to clay loam, and the color is dark gray to dark grayish brown. Typically a B horizon is absent. The lower C horizon is not as permeable as the higher part; runoff is rapid. Slope angles range to nearly 30 degrees, with 5 to 16 degrees most common. A generalized profile is shown in Table 2. Bainville soils also occur in association with "Badland" soils in the rougher areas, where there are steep slopes of gullies, ravines, buttes, and alluvial fans at the base of slopes. Many of the steepest slopes have little or no vegetation (Omodt et al. 1968).

The use of the name "Badland" as a soil type is midleading, because in some cases the soils of that group have not actually been surveyed due to the extreme rockiness and eroded condition of the material. "Badland" soils are typically very shallow; depth to the bedrock is generally 0-46 cm (0-18 in). As a result "Badland" is more a land type than a soil type (U.S. Department of Agriculture 1942, 1975). The soil varies widely due to the total effect of numerous climatic and topographic conditions.

TABLE 2

Soil Profiles of Bainville and Morton Series[a]

BAINVILLE SERIES

	Cm/In	
A1	0-10/0-4	Very dark brown silt loam with weak granular structure, very friable, slightly calcareous
C	10-152/4-60	Olive silt loam, calcareous

MORTON SERIES

	Cm/In	
A1	0-13/0-5	Very dark grayish brown silt loam with moderate granular structure, very friable
B2t	13-46/5-18	Dark brown silty clay loam with moderate prismatic and blocky structure, firm
Cca	46-66/18-26	Olive gray silt loam with weak prismatic structure, moderately calcareous
C	66-152/26-60	Olive gray silt loam grading to slightly weathered bedded silts, calcareous

[a] (Omodt et al. 1968)

> A large proportion of the total rainfall in the Badlands runs off the surface, and within a few minutes empty valleys may become courses of raging torrents that subside and disappear shortly after the shower is over. In areas of the same soil material the great differences in the amount of moisture that can penetrate the ground owing to differences in the degree of slope, are reflected in the character of the soil, the native vegetation, and the adaptability of various cultivated plants (U.S. Department of Agriculture 1944, p. 13).

An extensive chestnut soil series of the grassland area is the Morton which originated from weathered Tertiary materials. These soils commonly occur on hill crests, ridges, and gentler hill slopes. Slope angles range from nearly flat to about 8 degrees; the most common angles are 1 to 5 degrees. Textures are loam and silt loam in the topmost horizon; permeability is moderate. A typical profile is given in Table 2.

In the area of the North Killdeer Mountain Quadrangle in Dunn County the most common soil units are the Badland-Cabba-Arikara complex, Cohagen-Vebar-Rock outcrop complex, Cohagen-Vebar fine sandy loam and Arikara loam. Cabba and Cohagen are entisols, Arikara is an inceptisol and Vebar is a mollisol. In the Badlands-Cabba-Arikara complex, slopes range from 14 to 50 degrees. The soils can be shallow to deep and are generally well-drained; numerous drainageways dissect the area. The soils of the Cohagen-Vebar-Rock outcrop complex are shallow to moderately deep and well-drained. They occur on uplands, and rock commonly crops out on "shoulder slopes." Elsewhere bedrock is close to the surface. Slope angles range 8 to 22 degrees. The Cohagen-Vebar fine sandy loam is similar to the Cohagen-Vebar-Rock outcrop in depth and moisture characteristics, and also in where it occurs. Bedrock is close to the surface, but does not crop out as in the previous group. Slope angles are not as steep; range is 5 to 14 degrees. The Arikara loam is a deep, well-drained soil that is found on side slopes of uplands that commonly face north and east. Litter from woodland vegetation growing there covers the surface (U.S. Department of Agriculture 1982).

Sixty-eight stands examined from the Hansen, Hopkins, and Hoffman (1980) study are within the Badlands area; slope angles vary widely. The steeper slopes have soils of the Badland-Bainville association referred to above. On the flatter floodplains of streams Havre and Banks soils are found, and Patent soils occur on alluvial fans. A survey of soil textures of the stands studied from Hansen, Hopkins, and Hoffman (1980) reveals that 44 percent are loam, 19 percent clay loam, 16 percent sandy loam, 9 percent silt loam, 6 percent silty clay loam, 3 percent are loamy sand, and another 3 percent are clay.

CHAPTER 3

LITERATURE REVIEW, DATA SOURCE, AND METHODOLOGY

Literature Review

Climate

Bavendick (1952) reviewed a variety of topics related to the climatology of North Dakota. Much of the information was a historical listing of the occurrence of weather incidents such as blizzards, drought, dry periods at Bismarck, dust storms, floods, prairie fires, and tornadoes, over eighty years. Climatic data for a sample of weather stations across the state were given for evaporation, frost penetration, humidity, precipitation, temperature, and wind. Bavendick observed that chinook winds could cause a temperature rise in the western part of the state, and that temperature range was lower there as a result.

A more recent review of North Dakota's climate was done by Jensen (1972). In addition to summarizing the patterns of temperature and precipitation, he included general information on climatic controls, relative humidity, sunshine and cloudiness, obstructions to visibility (e.g., blowing snow), wind, severe storms, and blizzards. Climatic controls listed included air mass sources, day length/solar angle, and topography. Data in tabular form were given for four representative stations across the state, and a series of isoline maps were included to show trends of various conditions throughout the state. Most of the statistics were for 1931-60.

In his thesis, Miller (1965) determined homogeneous climatic regions within the state. Patterns of precipitation, vegetation, and soil were used as input, although precipitation was found to be the most critical variable in delineating areas. Miller's Area VII covered much of the Badlands; only the lower reaches of the Little Missouri River would be included in his Area V which was located between Minot, Bismarck, and Dickinson. Area VII appeared to be part of a larger zone centered in northwestern South Dakota. Area V was quite similar to Area VII in vegetation and soil types; however, precipitation during the growing season was greater in the former area.

A study of the regional climate of the grasslands was done by Borchert (1950), who observed that the Rocky Mountains are a major orographic barrier to zonal air circulation. Steppe and grasslands are found east of the mountains from central Alberta to south Texas. Borchert used 100 degrees west longitude as the generalized border of the regions of differing air flow: in the summer months circulation was zonal to the west, and meridional to the east of that boundary. The temperature gradient across

100 degrees west longitude was not as great as that of precipitation which Borchert believed to be the principal determining variable for the location of the grasslands.

Vegetation

Vegetation types in and near western North Dakota have been investigated by a number of people. Nelson (1961) studied the woody vegetation in North Dakota Badlands. Seven types were distinguished: (1) Green Ash (*Fraxinus pennsylvanica*), found in ravines, on moderately steep north- and northeast-facing slopes, and on bottomlands; (2) Juniper-slope, common on northeast- to northwest-facing, steep slopes; (c) Cottonwood (*Populus deltoides*), limited mostly to floodplains; (4) Sagebrush, characteristic on floodplains, terraces, and in high valleys; (5) Brush complex, found on upper parts of ravines, on slopes with Green Ash, and in upland depressions; (6) Saltbush-Rabbitbrush, typically found on steep, xeric, south-facing slopes, often across the valley from Juniper-slope stand; and (7) Big Sagebrush (*Artemisia tridentata*), dominant on south- and east-facing steep slopes. The Green Ash type was the most common. Wali et al. (1980) investigated the woody and shrubby vegetation, and soil algae found in southwestern North Dakota. They defined six woodland community types: (1) Cottonwood, limited to floodplains; (2) Aspen (*Populus tremuloides*), -Paper Birch (*Betula papyrifera*), found in the Killdeer Mountain area, mostly on north- and west-facing slopes of moderate to steep angle; (3) Green Ash-American Elm (*Ulmus americana*), which favored relatively mesic, moderate to steep slopes of varying azimuth; (4) Bur Oak (*Quercus macrocarpa*), which was encountered on moderately steep to steep, mesic sites; (5) Juniper or Rocky Mountain Red Cedar (*Juniperus scopulorum*), found on steep slopes; (6) Ponderosa Pine (*Pinus ponderosa*), found with Rocky Mountain Red Cedar. Three shrub communities were also identified: (1) Silver Sage (*Artemisia cana*), common in flat lowlands; (2) Buckbrush (*Symphoricarpos occidentalis*), found on flat sites; (3) Buffaloberry (*Shepherdia argentea*), which occurred on moderate slopes of uplands. The Green Ash-American Elm type was the most common woodland found, and the Silver Sage was the dominant shrub type. Potter and Green (1964) studied the occurrence of Ponderosa Pine in the Little Missouri River valley, where the tree was growing on sandstone or "scoria" outcroppings. They considered these groves to be outliers from principal stands in South Dakota (Black Hills) and Wyoming (Bighorn Mountains). Associated with this pine were Rocky Mountain Red Cedar, Green Ash, Chokecherry (*Prunus virginiana*), and Buffaloberry.

Hanson and Whitman (1938) identified nine major grassland types in the Little Missouri River Badlands. These divisions were based on vegetation and topography: (1) Blue Grama (*Bouteloua gracilis*), -Needle and Thread (*Stipa comata*), -Threeleaved Sedge (*Carex filifolia*), which occurred on plateaus and gentle slopes of uplands; (2) Western Wheatgrass (Agropyron smithii), -Blue Grama-Threeleaved Sedge, found on long, gentle slopes; (3) Little Bluestem (Andropogon scoparius), common on steep slopes; (4) Big Sandgrass (Calamovilfa longifolia), which favored sandy hills and ridges; (5) Silver Sagebrush, characteristic of stream flats and in valleys; (6) Saltgrass (Distichlis spicata), -Western Wheatgrass, which was common on stream terraces subjected to occasional flooding; (7) Saltgrass-alkalai meadow grass, which occurred on terraces and in depressions where drainage was poor; (8) Buffalograss (Buchloe dactyloides), found on gentle slopes or flats; and (9) Big Bluestem (Andropogon furcatus), which favored lower portions of steep slopes, where relatively mesic conditions were found because of additional moisture (runoff) from upslope. Hansen, Hopkins, and Hoffman (1980) delimited ten habitat types in and near the Theodore Roosevelt National Park: (1) Needle and Thread-Threeleaved Sedge, found on gentle slopes and upland plateaus; (2) Western Wheatgrass-Threeleaved Sedge, which occurred on long, moderate slopes; (3) Little Bluestem-Threeleaved Sedge, which favored relatively mesic, moderate to steep slopes of varying azimuth; (4) Creeping Cedar (Juniperus horizontalis), -Little Bluestem, which was encountered on moderately steep to steep, mesic sites; (5) Big Sagebrush (Artemisia tridentata), -Western Wheatgrass, found on river terraces and benches;

(6) Silver Sagebrush-Western Wheatgrass, which favored floodplains and terraces; (7) Green Ash-Buckbrush, found on floodplains; (8) Green Ash-Chokecherry, common in upland draws, valleys, and on moderately sloping north-facing sites; (9) Aspen-Mountain Birch (*Betula occidentalis*), common on upper sections of draws on steep slopes facing northwest to east; and (10) Rocky Mountain Red Cedar-Little Ricegrass (*Oryzopsis micrantha*), characteristic of mesic, steep, north- to northwest-facing slopes.

Rudd (1951) investigated the flora of North Dakota, and estimated that 5 percent of the vegetation were Rocky Mountain species, found in the western and southwestern part of the state. The Rocky Mountain group included Limber Pine (*Pinus flexilis*), Ponderosa Pine, Rocky Mountain Red Cedar, and Ill-Scented Sumac (*Rhus trilobata*), among others. Rudd believed these species migrated into the state during glacial periods when the climatic conditions were colder, and alpine vegetation zones were depressed to lower altitudes. As the post-glacial climate became warmer and drier much of that vegetation died out; many of the remaining species grew only on the more mesic sites. Another 5 percent of North Dakota flora were migrant species from the southwestern United States' deserts. Some of these species in North Dakota were Big Sagebrush, Spiny Saltbush (*Atriplex confertifolia*), Yucca (*Yucca glauca*), Greasewood

(*Sarcobatus vermiculatus*), and Winter Fat (*Eurotia lanata*). Most of these plants occupied relatively xeric sites, predominantly although not exclusively in western parts of North Dakota. During dry periods their distribution tended to expand eastward.

Brown (1971) studied plants in the Badlands of southeastern Montana, and identified seven communities. They were: (1) *Sarcobatus*, dominated by Greasewood and found on steep, southwest- to southeast-facing slopes; (2) *Atriplex-Artemisia*, dominated by Spiny Saltbush and Big Sagebrush, and found on very steep slopes of heavier textured soils; (3) *Artemisia-Atriplex-Agropyron*, characterized by Big Sagebrush, Spiny Saltbush and Bluebunch Wheatgrass (*Agropyron spicatum*), and found on steep talus slopes that faced southwest to southeast; (4) *Artemisia-Agropyron*, dominated by Big Sagebrush and Bluebunch Wheatgrass, and found on southwest- to southeast-facing talus slopes of moderate angle; often this community occurred in a lower, less steep portion of the same slopes that supported *Atriplex-Artemisia-Agropyron* stands; (5) *Rhus-Agropyron*, dominated by Ill-Scented Sumac and Bluebunch Wheatgrass, found on steep "scoria" slopes that faced from west to southeast; (6) *Juniperus-Agropyron*, dominated by Rocky Mountain Red Cedar, with Bluebunch Wheatgrass, and found on moderately steep southwest- to northeast-facing slopes; and (7) *Pinus-*

Juniperus, characterized by Ponderosa Pine and Rocky Mountain Red Cedar and found on knolls at the base of valley slopes. The *Artemisia-Atriplex-Agropyron* community was estimated to occupy about 30 percent of the topography studied, while the *Juniperus-Agropyron* covered another 20 percent. Brown concluded that the presence of southwestern United States' desert species represented an extension of salt-desert community dominants to Montana, under a combination of topographic, climatic, and edaphic conditions similar to those in the Great Basin area.

Terrain Climate

Geiger (1965) focused on the differences of climate caused within a relatively small area by variations in solar radiation striking sloping ground, and by different amounts and types of vegetative cover. He pointed out other studies which showed that great differences in radiation and vegetation lead to remarkable temperature, relative humidity, and, at times, wind speed contrasts. Geiger showed also that while solar radiation amounts striking the Earth are equal on either side of solar noon, the effect is asymmetric, due to the fact that in the morning hours, the Sun's energy is usually spent in evaporation of dew. The afternoon sunshine is much more effective in heating the soil and other surfaces. A study of the temperatures of tree bark exposed to sun all day under cloudless conditions indicated that in the northern hemisphere, the warmest slopes are those that face southwest. In reference to precipitation variations in hilly areas where the wind blows from a dominant direction, Geiger (1928) found rain measurements can be lower on the windward side of a hill depending on the orientation of the rain gauge (opening horizontal or into wind); in the case of an untilted rain gauge, Geiger measured the maximum rain on the right and left flanks just over the crest on the leeward side. The differences were also due to variations in wind speed as the air was forced to flow over the hill.

Lee (1963) wrote about the connection between solar radiation and runoff in mountain watersheds, and discussed the "equivalent slope" theory, in which, for every inclined slope of a given latitude, there exists a horizontal surface of different latitude and longitude that receives equivalent solar radiation. The effect of this theory is that for a slope that faces north in the northern hemisphere, away from the Sun, the conditions are similar to those on flat ground at a higher latitude; for a slope facing to the east, the sunrise is earlier than that on flat ground, and is comparable to the sunrise on a flat surface at a lower longitude. Opposite situations hold for locations in the northern hemisphere that face south or west. For slopes that face other than one of the four prime compass points, the radiation received on the inclined surface is comparable to that received on level ground located at a point of different latitude _and_ longitude. Lee reviewed the evolution of the mathematical equations to determine the equivalent differences.

Dix (1958) studied contrasts in vegetation on east- and west-facing slopes in the Little Missouri River Badlands. He concluded that the steeper slope was more xeric regardless of azimuth. Gentler slopes (in this study in a lower portion of a long slope) received precipitation plus runoff from farther upslope. Dix's results were that Blue Grama and Western Wheatgrass preferred more xeric conditions, while Little Bluestem, Side-Oats Grama (_Bouteloua curtipendula_), and Plains Muhly (_Muhlenbergia cuspidata_), were found on more mesic sites. Costello (1931) studied the east- and west-facing river bluffs along the Missouri River between Nebraska and Iowa near Nebraska City, Nebraska. The east-facing slopes (in Nebraska) were generally covered by trees while the west-facing slopes (in Iowa) had mostly grass cover, with some bare spots due to erosion. When trees were found on the west-facing bluffs, they were only on the lower half of the slope. Costello observed that where the same vegetative association occurred on both sides of the river, it was found at a higher level on the Nebraska slopes. He concluded that moisture loss related to the prevailing winds was the major influencing factor. Measurements showed evaporation on prairie bluffs to be at least two times greater than that on wooded bluffs. East-facing slopes were afforded protection from the prevailing winds.

Cottle (1932) studied the differences in vegetation on north- and south-facing slopes in southwestern Texas. The former were covered by trees and tall grasses, while the latter were sparsely vegetated by short grasses and other xeric species. Both types of vegetation intermingled some at the crests of slopes, but the xeric vegetation crossed farther onto the north-facing slope than the mesic vegetation did onto the opposite side. Tests were conducted for three years. Although soil types were very similar on opposite slopes, water content was generally lower on south-facing slopes; north-facing sides averaged 5.5 percent more moisture. Runoff was much higher on slopes facing south; Cottle concluded that denser vegetation on the north-facing slopes retarded runoff, allowing water to percolate through the soil. Differences in evaporation were most striking during the dry season; moisture loss was much greater on south-facing slopes. Soil temperatures at the same depth were generally several degrees Fahrenheit higher on south-facing slopes; it was not uncommon for the temperature on the south-facing side at a 30 cm (12 in) depth to exceed the temperature at a 5 cm (2 in) depth on the north-facing slope. Cottle concluded that conditions on the south-facing slopes were less favorable for growth of vegetation.

A similar study of the effects of slope and aspect on climate was done in Indiana by Potzger (1939).

The generally accepted notion of a "grassland climate" has been challenged by Wells (1965). He observed that the idea of the existence since mid-Tertiary time of a treeless grassland due to lack of water was incorrect. Because much of the present soil has been transported, it is likely that the current conditions in the grasslands (i.e., generally treeless environment) were the result of fairly recent developments. Wells cited studies of tree pollen dated at a radiocarbon age of 5,000 to 15,000 years in Nebraska and Kansas respectively; these pollen were found in higher percentages than expected. Wells pointed out that small areas of scarp woodlands exist throughout the middle third of the United States; in western North Dakota these areas have Ponderosa Pine and Rocky Mountain Red Cedar, amid grasslands of Blue Grama, Western Wheatgrass and Needle and Thread. Wells noted that many scarp woodlands exist in drier rather than more humid parts of the grasslands, and that some tree varieties are resistant to drought. He believed that physiography was more important than climate in influencing where trees could exist, and that fire played an important role also. The great abruptness of scarps may have served as a natural break to fire that spread across the flatter grassland areas; drought would have contributed by drying the grasses and providing readily burnable material. He concluded that trees on scarps were relicts of once extensive woodlands, and that present distributions of trees could not be explained by climatic conditions alone, but that topographic and edaphic conditions must be considered.

The effect of climate on slope morphology has interested climatologists for many years. Hadley (1961) found north-facing slopes in the Cheyenne River basin to be steeper, less eroded, and more densely vegetated than south-facing slopes. His study was made up of nearly horizontal strata, which virtually eliminated the likelihood of control of slope angle by geologic setting. Vegetation cover on south-facing slopes was 28 percent of that on north-facing slopes. Hadley concluded that denser ground cover on the latter protected slopes from dissection. Recently Toy (1977) studied twenty-nine sites in an attempt to establish a relationship between slope form and climate. He concluded that slopes in arid regions tended to be shorter and steeper than those in humid areas. He suggested that *in theory*, south-facing slopes should be steeper than north-facing ones; the latter receive less solar radiation and tend to be more mesic. Churchill (1981) studied unvegetated Badlands hills in South Dakota, and found that north-facing slopes averaged 47 degrees while south-facing slopes had a mean angle of 61 degrees. Geologic structure did not account for the difference. Differential mass movement--

slumps and mudflows on the mesic sides, and rockfalls on the dessicated xeric sides--was concluded to be the mechanism. Churchill observed that his findings on slope angle vs. aspect were opposite to those in much of the literature; he allowed that the lack of vegetation on the slopes largely influenced the results. Schmitz (1955) found the unvegetated south-facing Badlands slopes to be the steepest.

Data Source and Methodology

General Study Area

Climatic data are obtained from the National Oceanic and Atmospheric Administration for twenty-four weather stations in North Dakota (U.S. Department of Commerce 1951-80). The initial data include the average high and the average low temperature, and total precipitation for each month in the thirty-year period. Other information obtained from the same source are the latitude, longitude, and altitude of all weather stations in the study. Computations on the data (SAS Institute 1979) produce 30-year means for each month for both temperature and precipitation, annual temperature, and annual precipitation for twenty-four weather stations. In some cases, raw data are missing. Monthly values are computed on as many of the thirty yearly values as are accessible. The general approach to the problem of missing values is to use the available record for each station.

For interpolation purposes data are used for four South Dakota and four Montana weather stations bordering the study area. Data for the period 1951-80 data are not yet available, so 1941-70 averages are substituted (Department of Commerce 1978). (A comparison of 1941-70 averages to 1951-80 averages for North Dakota stations show only very small changes.) Since western North Dakota is in a zone of climatic transition, it is felt that the South Dakota and Montana data are required, in order to characterize climatic trends properly.

An attempt to establish a relationship to explain the chinook influence is undertaken by measuring the linear distance on a map between each weather station and an imaginary, generalized line that parallels the 9,000 ft (2743 m) contour of the front range of the Rocky Mountains (see Figure 1). The line extends from northwest to southeast and passes through Red Lodge, Montana, and just west of Laramie, Wyoming. This variable is expected to show how weak or strong the influence of the mountains is on western North Dakota.

A variable is needed to measure continentality; Conrad's equation for continentality is used (Barry and Chorley 1976). Conrad determined that the highest values in the United States (index of 55 to 60) were found in eastern North Dakota, just east of 100 degrees west longitude. In western North Dakota values would range from near 50 in the southwestern corner, to just over 55 near the Canadian border. All monthly values and other related data are listed in Appendix B.

These climatic variables are correlated with each other using Pearson's r (SAS Institute 1979). Since four stations collect only precipitation data, the correlation matrix is with thirty-two stations for precipitation variables, latitude, longitude, and distance, and with twenty-eight stations for temperature-related variables. Some partial correlation is computed manually. Some regression analysis is performed on data (SAS Institute 1979). The rejection level is set at 5 percent for all correlation, and for regression.

A subset of nine stations from the larger group of thirty-two is created. These nine represent ones whose equipment was not moved during most of the thirty years, to ensure that climatic data correspond to site-specific measurements. The shortest record among the nine stations is twenty-three years of data for Watford City 14 S (North Unit of Theodore Roosevelt National Park); a complete thirty-year record is available at three stations: Amidon, Dickinson Experiment Station, and Hettinger. New variables were added to the data of this subgroup. Azimuth and angle of slope of the land are determined by field study and the use of topographic maps. Aspect is determined perpendicular to the contours where the station is located. Slope angle is measured around the station on the distance of uninterrupted change in contours. (A stream or ridge top causing a reversal of slope direction, often is used as the boundary of the area on which slope angle is measured.) These distances (run) for the nine stations vary from 84 m (277 ft) to 1445 m (4742 ft). The change in contours (rise) for the measured distance is determined from each map. Photographs and information on the nine weather stations are provided in Figure 15 to Figure 29 (soil data from Patterson et al. 1968, observer name and location of station from U.S. Department of Commerce 1980), and Table 17 to Table 25 in Appendix A. Correlation and regression are again run using the larger data set of these nine stations. An estimate of potential solar radiation on the sloping surface is made for each station using equations from Swift (1976). A resulting quantity, "equivalent latitude," used as a preliminary value in the calculation of potential radiation estimates, is retained as a separate variable, since it combines into one number the effect of slope angle and azimuth together with latitude. The principle behind the variable is that the value represents a latitude where the amount of radiation on level ground is the same as the amount received on the slope in question.

> A more vivid way of expressing these differences is to regard a southerly exposure as yielding some of the advantages of a more southerly latitude and a northerly exposure as involving some of the risks of a more northerly latitude (Crowe 1971, p. 28).

Equivalent latitude is one component of the concept of "equivalent slope" (Lee 1963); the latitude shift is chosen because solar radiation varies with latitude. Values for potential solar radiation on a horizontal surface at the same latitude as each station are also computed. All radiation values are in cal/cm^2/day, estimated for the middle day of each month. For purposes of comparison, an index proposed by Swift (1976) is used: potential radiation on a slope divided by potential radiation on level ground; this ratio is near 1.0 for flatter ground, $<$ 1.0 for north-facing sites, and $>$ 1.0 one for south-facing sites. Through this index the effect of slope angle and azimuth on conditions on horizontal ground is made clear. Additional data for the nine stations are listed in Appendix B where Table 26 shows all of the symbols used for the station and variable names.

North Killdeer Mountain Quadrangle

A vegetation map generated by the Bureau of Land Management (U.S. Department of Interior 1981) is available for a portion of the Little Missouri River basin--the area of the North Killdeer Mountain 7 1/2 minute quadrangle. A slope/aspect study and vegetation analysis are undertaken using data collected from the drainageways of the area (Figure 3 above). Every 1 cm (0.4 in) a measurement of slope angle and azimuth is made on both sides of each valley. (Azimuth is the direction, expresed in degrees, which a surface faces; the measurement is made as the angular displacement from true north, the starting point, and proceeds in a clockwise direction. As a result, an east-facing slope is considered to have an azimuth of 90 degrees.) Slope angle is determined by measuring the gradient from the intermittent stream bed to the highest contour on both sides. The measurement upslope is always made perpendicular to the contours, as is determination of azimuth. Nominal groupings for azimuth are created as shown in Table 3. Vegetation counts are determined by placing the Bureau of Land Management overlay on the 7 1/2 minute quadrangle, and by counting how many vegetation groups of each type are crossed by a perpendicular line from the stream to the contour used to determine slope angle, as explained above. Vegetation categories include woodland, shrubland, native prairie, riverine, agriculturally disturbed, and several palustrine categories. Vegetation species in each group are not identified. Only the first three classes are used, since the others have too few counts to qualify for the test. Chi-square analysis in the form of two-by-three contingency tables as described by Snedecor and Cochran (1967) is performed using azimuth and vegetation data. In each case the test hypothesis is that differences in vegetation are related to differences of azimuth; contingency tables are drawn for valleys with the E/W, SE/NW, N/S,

TABLE 3

Division of Azimuth into Nominal Groups

NOMINAL GROUP	SYMBOL	AZIMUTH RANGE (DEGREES)
north	N	> 337.5 to 22.5
northeast	NE	> 22.5 to 67.5
east	E	> 67.5 to 112.5
southeast	SE	> 112.5 to 157.5
south	S	> 157.5 to 202.5
southwest	SW	> 202.5 to 247.5
west	W	> 247.5 to 292.5
northwest	NW	> 292.5 to 337.5

NE/SW, NE/W, N/SW and NW/S (east vs. west, southeast vs. northwest, north vs. south, northeast vs. southwest, northeast vs. west, north vs. southwest, and northwest vs. south) slope azimuth combinations. In all cases a .05 rejection level is set. Throughout the remainder of the text, azimuth pairs of valley slopes are abbreviated as shown in Table 3, and separated by a slash, as demonstrated above.

Subsets are formed for all pairs of values with reciprocal azimuths, viz., E/W, SE/NW, N/S and NE/SW. Wilcoxon Tests for Paired Samples as demonstrated by Hammond and McCullagh (1978) are made on the data of each set to determine if one slope is consistently steeper than the other. In all four cases the test hypothesis is that one slope is significantly steeper; a .05 rejection level is set.

Theodore Roosevelt National Park

Hansen, Hopkins, and Hoffman (1980) included data for a number of species of shrubs, graminoids, and forbs for seventy stands in and near Theodore Roosevelt National Park. Two stands located outside of the limits of the Park have been eliminated from this analysis, bringing to sixty-eight the number of stands being utilized. Data on slope angle and azimuth were included by the authors. Equivalent latitude is computed using equations by Swift (1976), after the latitude of each stand is determined from 1:24,000 topographic charts (U.S. Department of Interior 1974a, 1974b). A survey is made of the equivalent latitude of all stands in which each of twelve species of plants occurs. In addition the occurrence of each plant with respect to azimuth and slope angle is represented after a method demonstrated by Brown (1971). A circle is used to show 360 degrees of azimuth; concentric circles (shown in part) each represent 10 degrees of slope angle. A vegetation stand is represented by a dot which is positioned on the diagram to reflect the particular combination of slope angle and azimuth in which a species of plant occurs. All species that are found in at least seventeen different stands are graphed; other plants only appear in a few stands. When all stands are shown, the diagram depicts plant distribution.

CHAPTER 4

RESULTS AND ANALYSIS

Climate

Correlation

Raw data shown in Table 27 to Table 32 in Appendix B are correlated using Pearson's r (SAS Institute 1979). Correlation coefficients and corresponding probabilities are shown in Tables 36 to 41 in Appendix C. A list of the definitions of the symbols used for station names and variables is provided in Table 26 in Appendix B. Those variables applied most often to the sample of 32 weather stations are abbreviated using capital letters throughout the rest of the text. When used as a concept (e.g., latitude in general, as opposed to the "variable" latitude), a word is printed in small letters.

V.LAT (variable latitude) correlates with JANTMP, FEBTMP, MARTMP, JUNTMP, NOVTMP, and DECTMP (January, February, March, June, November, and December average temperatures) (range r=-.75, p=.0001 to r=-.41, p=.03). Coefficients for remaining months are not statistically significant. Correlation of V.LAT with monthly temperatures is consistent with expectations since latitude affects solar angle, one of the controls of climate listed by Jensen (1972). V.LONG (variable longitude) correlates weakly with FEBTMP, APRTMP, JULTMP, and DECTMP (February, April, July, and December average temperatures) (to r= .45, p=.02), and may support Borchert's (1950) claim that 100 degrees west longitude is in a zone of transition for precipitation, but not for temperature. There is a definite relationship between the V.DIST and average monthly temperatures. V.DIST (the variable distance to the front range of the Rocky Mountains) correlates with JANTMP, FEBTMP, MARTMP, APRTMP, JULTMP, AUGTMP, NOVTMP, and DECTMP (range r=-.85, p=.0001 to r=-.41, p=.03), and is intended to determine the effect of the Rocky Mountains on the climatic conditions in southwestern North Dakota.

V.ALT (variable altitude) is positively correlated with JANTMP, FEBTMP, and DECTMP, and negatively with MAYTMP and JUNTMP. Positive coefficients for winter months appear to reinforce the idea of a chinook effect in the southwestern part of the state, since V.ALT correlates with V.DIST (r=-.71, p=.0001). Altitude does not have the effect of lowering temperatures in winter, although in the summer it appears to have a moderating effect, as can be seen from the two negative correlations for May and June. V.ALT also correlates negatively with V.LAT (r=-.79, p= .0001). The southwestern corner is the highest part of the state, and altitude decreases with latitude in the study area. CONRAD (index of continentality) showed a very strong correlation with JANTMP (r=-.92, p=.0001); that month averages to be the coldest of the year, and its correlation is a measure of reliability of Conrad's index, which is based on temperature range. TVAR (temperature range) and CONRAD correlate strongly: r= .98, p=.0001. FEBTMP, JUNTMP, NOVTMP, and DECTMP also correlate with CONRAD (lowest r= .45, p=.02). The coefficients of CONRAD with V.LAT and V.ALT are opposite (r= .71, p=.0001 and r=-.71, p=.0001, respectively). This is consistent with Conrad's analysis of continentality in North America, and shows that the altitudes in the southwestern part of the state are not high enough to have the same effect as altitudes in mountainous regions.

TVAR correlates negatively with JANTMP, FEBTMP, JUNTMP, NOVTMP, and DECTMP (range r=-.95, p=.0001 to r= .46, p=.01). TVAR correlates positively with both V.LAT (r= .76, p=.0001) and V.DIST (r = .67, p=.0001). Temperatures of all months except June correlate with TMPAVG (average annual temperature); the coefficient of June is not statistically significant (r= .27, p=.17). Correlation between TMPAVG and V.LAT is less than expected (r=-.51, p= .006), and that between TMPAVG and V.DIST is stronger than expected (r=-.66, p=.0001). This suggests a chinook effect in southwestern North Dakota.

V.LAT correlates negatively with MAYPREC and JUNPREC (May and June mean precipitation), r=-.43, p=.01 and r=.66, p=.0001 respectively, but positively with SEPPREC and DECPREC (Septmeber and December precipitation)(r= .55, p= .001 for both). These coefficients are consistent with Borchert's (1950) observation of zonal air circulation in the grasslands in the winter (transitional in the spring and fall), and meridional flow in the summer. He used 100 degrees west longitude as the general boundary between regions of different air flow, although 100 degrees is not actually a boundary but the eastern edge of a wide transitional zone (Borchert 1953). Correlation coefficients indicate that the summer moisture source is from the south--specifically the Gulf of Mexico. In spite of the fact that there is no moisture source to the north, winter monthly precipitation increases with V.LAT. This fact tends to reinforce the influence of a rainshadow in part of the study area.

V.LONG is in general negatively correlated with monthly precipitation. Highest coefficients are for AUGPREC (r=-.74, p=.0001), MAYPREC (r=-.70, p=.0001), and for APRPREC (r=-.69, p=.0001); other significant coefficients are with MARPREC, SEPPREC, and OCTPREC (lowest r=-.37, p= .03). The source of moisture in the Gulf of Mexico is highlighted, and the importance of spring and fall as transition between the winter (zonal flow, lower precipitation) and summer (meridional flow, higher precipitation) patterns is emphasized. (Zonal circulation in the mid-latitudes is generally west to east; meridional flow is south to north.) V.DIST correlates in descending order with SEPPREC, AUGPREC, FEBPREC and DECPREC (range r= .72, p=.0001 to r= .44, p= .01); it is possible that there may be a mild rainshadow effect created by the Rocky Mountains in September when circulation is returning to a zonal pattern, while moisture from the Gulf is available. SEPPREC correlates significantly more often than any other variable; it is related at least weakly with eight monthly mean temperatures, with V.LAT, V.LONG, V.ALT, V.DIST, CONRAD, TVAR, TMPAVG, and PRECTOT (mean annual precipitation). The only plausible explanation is that SEPPREC generally parallels other conditions. PRECTOT correlates at least weakly with monthly precipitation _except_ in January and December; the strongest correlations are with APRPREC and MAYPREC (r= .80, p=.0001 for both). PRECTOT correlates significantly only with V.LONG (r=-.72, p=.0001); this reflects the precipitation gradient in the grasslands (Borchert 1950).

Since there are a number of interesting overlapping correlations, partial correlation coefficients among three variables are computed; the results are shown in Table 4. While JANTMP, FEBTMP, NOVTMP, and DECTMP each correlate significantly with both V.LAT and V.DIST, the results of partial correlation show that all coefficients decrease.

TABLE 4

Partial Correlation

N = 32 or 28

1) Var1=V.DIST Var2=V.LAT Var3=JANTMP (N=28)
r12.3= .20
r13.2= -.52 **
r23.1= -.52 **

2) Var1=V.DIST Var2=V.LAT Var3=FEBTMP (N=28)
r12.3= .09
r13.2= -.67 **
r23.1= -.49 **

3) Var1=V.DIST Var2=V.LAT Var3=NOVTMP (N=28)
r12.3= .38
r13.2= -.51 **
r23.1= -.30

4) Var1=V.DIST Var2=V.LAT Var3=DECTMP (N=28)
r12.3= .01
r13.2= -.73 **
r23.1= -.51 **

5) Var1=V.DIST Var2=V.LAT Var3=SEPPREC (N=32)
r12.3= .47 *
r13.2= .64 **
r23.1= .13

6) Var1=V.DIST Var2=V.LAT Var3=DECPREC (N=32)
r12.3= .58 **
r13.2= .11
r23.1= .38 *

7) Var1=V.DIST Var2=V.LONG Var3=AUGPREC (N=32)
r12.3= -.53 **
r13.2= .14
r23.1= -.53 **

8) Var1=V.LAT Var2=V.ALT Var3=DECPREC (N=32)
r12.3= -.70 **
r13.2= .18
r23.1= -.28

9) Var1=V.DIST Var2=V.LAT Var3=TMPAVG (N=28)
r12.3= .47 *
r13.2= -.50 **
r23.1= -.12

**Significant at .01 *Significant at .05

However, the coefficient between V.DIST and each monthly temperature remains stronger than or equal to that between V.LAT and JANTMP, FEBTMP, NOVTMP, and DECTMP. These new coefficients give added support to the idea of a chinook effect on temperature. SEPPREC and DECPREC correlate positively with both V.DIST and V.LAT. For SEPPREC, partial correlation with V.LAT is not significant, while the coefficient with V.DIST is. On the other hand DECPREC has a weak but significant partial correlation with V.LAT, and an insignificant one with V.DIST.

AUGPREC, V.DIST, and V.LONG correlate with each other. The significant relationship between V.DIST and AUGPREC disappears with partial correlation, while a moderate and significant partial correlation remains between AUGPREC and V.LONG. The partial coefficients of DECPREC with both V.LAT and V.ALT decrease and are insignificant. As expected, V.LAT and V.ALT vary inversely to a strong degree. Finally, a mild but significant partial correlation is computed between TMPAVG and V.DIST. No co-relationship remains between TMPAVG and V.LAT.

Additional data for the subset of nine stations (found in Table 33 to Table 35 in Appendix B) are correlated using Pearson's r (SAS Institute 1979), and the resulting coefficients and probabilities are listed in Tables 42 to 56 in Appendix C. JANTMP, FEBTMP, MARTMP, NOVTMP, and DECTMP correlate with JANR4, FEBR4, MARR4, NOVR4, and DECR4 respectively (January, February, March, November, and December potential radiation on sloping surface at each weather station) (range r= .84, p=.005 to 4= .71, p=.03). Monthly values that do not correlate significantly are months of higher Sun angle. There is no significant correlation between monthly temperatures and either V.AZIM (variable azimuth) or V.SA (variable slope angle); however, V.EQL (variable equivalent latitude) correlates with JANTMP, FEBTMP, MARTMP, NOVTMP, and DECTMP. V.EQL combines the effects of V.LAT with V.AZIM and V.SA. Months that correlate are the same whose values of R4 and temperature correlate. In fact, the coefficients are nearly identical with the opposite sign for each month. A possible explanation involves the correlation coefficients between V.EQL and monthly R4. Eight of the results show a nearly perfect correlation (r=-.99, p=.0001); only the coefficient for June is not significant (r=-.62, p=.08). At the same time, monthly R4 values do not correlate significantly with either V.AZIM or V.SA, nor is there any significant corelationship among V.AZIM, V.SA and V.EQL.

Monthly R4 values correlate above the rejection level with V.LAT; however, examination of the results shows negative coefficients. Perhaps in a larger sample size these values would be statistically significant. TMPAVG correlates with monthly R4 except during May, June, and July when the probabilities are above the rejection level. TMPAVG correlates significantly with V.EQL (r=-.70, p=.04).

CONRAD correlates significantly with V.SA (r= .72, p=.03), but not with V.AZIM (r= .57, p=.11). The suggestion is that a steeper slope angle of _any_ azimuth would cause the conditions to be more extreme (i.e., continental). Again, a larger sample size may be needed to get an accurate reading of the effect of the relationship between azimuth, slope angle and continentality.

Interrelationships among monthly temperatures, V.EQL, and monthly R4 in the subset are examined through partial correlation. Results are shown in Table 5. In all five analyses, coefficients between monthly temperature and R4, and between monthly temperature and V.EQL weaken considerably, and are not significant. The relationship between V.EQL and monthly R4 remains very strong. No distinction can be made statistically between V.EQL and monthly R4.

Regression

A stepwise regression procedure (SAS Institute 1979) is run on some of the data listed in Table 27 to Table 35 in Appendix B. Regression models, listed in Table 6, are created for the large group of 32 stations (or 28), and for the subset of 9 stations with long uninterrupted records.

TMPAVG is analyzed from the sample of 28 stations. Variation in APRTMP and NOVTMP accounts for 96.5 percent

TABLE 5

Partial Correlation
N = 9

---

1) Var1=JANR4 Var2=V.EQL Var3=JANTMP

r12.3= -.97 **
r13.2= .11
r23.1= -.11

2) Var1=FEBR4 Var2=V.EQL Var3=FEBTMP

r12.3= -.97 **
r13.2= -.02
r23.1= -.45

3) Var1=MARR4 Var2=V.EQL Var3=MARTMP

r12.3= -.98 **
r13.2= .09
r23.1= -.09

4) Var1=NOVR4 Var2=V.EQL Var3=NOVTMP

r12.3= -.98 **
r13.2= -.24
r23.1= -.37

5) Var1=DECR4 Var2=V.EQL Var3=DECTMP

r12.3= -.97 **
r13.2= -.15
r23.1= -.34

**Significant at .01

TABLE 6

Seven Stepwise Regression Models

N = 32, 28, or 9

1)STEPWISE REGRESSION FOR DEPENDENT VARIABLE TMPAVG (N=28)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	10.00385776			
NOVTMP	0.57231207	148.05	0.0001	91.6
APRTMP	0.36114467	34.96	0.0001	96.5

2)STEPWISE REGRESSION FOR DEPENDENT VARIABLE PRECTOT (N=32)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	3.21119450			
MAYPREC	2.78271261	136.37	0.0001	64.5
NOVPREC	7.22992615	56.93	0.0001	77.8
JULPREC	1.13262770	39.93	0.0001	90.9

3)STEPWISE REGRESSION FOR DEPENDENT VARIABLE JANTMP (N=9)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	34.35691643			
V.EQL	-0.50427821	15.11	0.0060	68.3

TABLE 6--continued

4)STEPWISE REGRESSION FOR DEPENDENT VARIABLE FEBTMP (N=9)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	43.32680601			
V.EQL	-0.54235424	18.48	0.0036	72.5

5)STEPWISE REGRESSION FOR DEPENDENT VARIABLE MARTMP (N=9)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	48.74934605			
V.EQL	-0.46351302	10.15	0.0154	59.2

6)STEPWISE REGRESSION FOR DEPENDENT VARIABLE NOVTMP (N=9)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	43.83441307			
V.EQL	-0.30479159	8.56	0.0221	55.0

7)STEPWISE REGRESSION FOR DEPENDENT VARIABLE DECTMP (N=9)

	B VALUE	F	PROB>F	CUMULATIVE R-SQUARE
INTERCEPT	38.76660962			
V.EQL	-0.43295441	15.74	0.0054	69.2

of the variation in TMPAVG; NOVTMP accounts for 91.6 percent alone. November is one of the months when the Sun angle is low. In the model for PRECTOT (for 32 stations), MAYPREC, JULPREC, and NOVPREC explain 90.9 percent of the variation in PRECTOT; MAYPREC alone accounts for 64.5 percent. Precipitation conditions among all of the weather stations appear to be relatively homogeneous in June when the heaviest amount of rain during the year is received. Residuals for these two models are listed in Table 7.

Data from the subset of nine stations are analyzed, to see how much influence V.EQL has on JANTMP, FEBTMP, MARTMP, NOVTMP, and DECTMP. Regression models show that the variation in V.EQL can account for at least 55.0 percent (for NOVTMP) and up to 72.5 percent (for FEBTMP) of the variation. Residuals for these five models are listed in Table 8.

Swift's Slope Factor

Swift (1976) created a Slope Factor ratio (F) using his monthly R4, and monthly R3 (potential radiation if ground at each weather station were level). By dividing monthly R4/R3, an index to express the effect of slope and aspect on potential radiation is computed. When F is near 1.0, the potential radiation on the slope is nearly the same as radiation on flat ground. An index very much above or below 1.0 means an increase or decrease respectively in potential radiation attributable to the effects

TABLE 7

Residuals for Two Regression Models of Table 6

STATION	TMPAVG RESID (DEG F)	PRECTOT RESID (IN)
(North Dakota)		
AM	0.03873	0.03839
BE	0.09212	-0.51676
BO	0.03980	0.12040
DFA	0.09824	0.24033
DES	-0.05998	0.47138
DC	-0.27329	0.86437
FA	0.31448	0.06146
HE	-0.08523	-0.26861
KE	0.62241	0.09822
KI	M[a]	0.21402
MA	0.05040	-0.19860
ME	0.12256	-0.50462
MO	0.11216	0.20319
NE	0.07375	-0.36347
NT	-0.63173	0.61256
PR	0.08768	0.10397
RA	0.08149	0.03026
RE	M	-0.19356
REN	M	-0.06607
TI	-0.10067	0.12494
TR	-0.55452	0.17598
WC	0.29524	0.27968
WAP	-0.16502	-0.19688
WEF	0.06831	-0.85909
(South Dakota and Montana)		
CC	M	-0.57541
LE	0.04927	0.49221
LU	-0.11089	-0.02499
RAL	-0.14569	-0.24159
EK	0.37688	-0.51402
GL	-0.14617	0.25041
PL	0.05255	0.25619
WI	-0.30288	-0.11428

[a] M = Missing

TABLE 8

Residuals for Five Regression Models of Table 6

STATION	JANTMP RESID	FEBTMP RESID	MARTMP RESID	NOVTMP RESID	DECTMP RESID
		(DEGREES	FAHRENHEIT)		
AM	1.09	0.80	-0.20	0.60	1.05
BO	-0.12	0.11	-0.22	0.03	0.40
DES	-1.56	-1.85	-1.75	-1.33	-1.29
DC	-0.78	-0.38	-0.79	0.08	-0.40
FA	0.10	-0.28	0.69	-0.75	-0.34
HE	0.28	0.21	-0.32	0.03	-0.40
NE	0.44	0.01	-0.12	-0.27	-0.14
RA	1.20	1.31	1.30	0.99	1.08
WC	-0.67	0.07	1.42	0.62	0.03

of slope and aspect. Table 9 shows F for the nine stations with long records for which potential radiation values are computed. (Ratios are only to be compared between stations when latitudes are the same.) The most consistent list is that of Amidon whose ratio varies between 0.98 and 1.0; the nearly flat ground around that weather station accounts for the pattern. At the extremes are Dunn Center and Watford City. Due to its 6.3 degree, northwest-facing slope, Dunn Center receives 0.75 and 0.71 of the potential radiation on a horizontal surface for January and December respectively. At the same time, the Watford City station receives 1.15 (for January) and 1.17 (for December) of the potential radiation for a flat surface, due to its 3.6 degree slope and approximately southwest azimuth. Values of F for other months show similar patterns except for the approach of all ratios to 1.0 during the summer months; this pattern is the result of higher Sun angles that occur near the summer solstice, when the Sun is directly overhead at solar noon at 23 1/2 degrees north latitude. Of the nine stations, Dunn Center has the lowest January and December mean temperatures; the opposite, however, does not hold for Watford City's January and December mean temperatures. However, the latter station's statistics are among the higher values. Other factors not considered here are involved.

TABLE 9

Slope Factor Ratios for Nine Stations[a]

(R4/R3)

STATION	JANF	FEBF	MARF	APRF	MAYF	JUNF	JULF	AUGF	SEPF	OCTF	NOVF	DECF
AM	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.98
BO	1.09	1.04	1.04	1.02	1.01	1.00	1.00	1.01	1.03	1.05	1.08	1.10
DES	1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.02
DC	0.75	0.82	0.89	0.95	0.98	0.99	0.99	0.96	0.92	0.86	0.78	0.71
FA	0.92	0.93	0.95	0.96	0.97	0.97	0.97	0.97	0.96	0.95	0.93	0.92
HE	1.06	1.05	1.03	1.01	1.00	1.00	1.00	1.01	1.02	1.04	1.05	1.09
NE	1.04	1.02	1.02	1.01	1.00	1.00	1.00	1.00	1.01	1.02	1.03	1.04
RA	0.87	0.91	0.95	0.97	0.99	1.00	1.00	0.98	0.96	0.93	0.88	0.85
WC	1.15	1.10	1.05	1.03	1.01	1.00	1.00	1.02	1.04	1.08	1.13	1.17

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[a] After Method by Swift 1976

Wind Patterns

Long-term wind data are not available for any station within the study area. The closest station where such data are collected is Bismarck, North Dakota; a wind rose depicting U.S. Department of Commerce (1973) data for Bismarck is shown in Figure 12. The percentages are based on hourly observation between 1951-60. Some data were collected from March 1975 to February 1976 near Bowman, North Dakota by the U.S. Environmental Protection Agency (1976). Figure 13 shows the resulting data, which were collected by a sensor 30 m (98 ft) above the ground on a tower located on a hill 60 m (200 ft) high. As a result, these data may show less effect of friction than the U.S. Department of Commerce data which are specifically for surface winds. Slopes with a west-facing component (e.g., SW, NW, etc.) are exposed to the drying effect of wind more than slopes with an east-facing component. Geiger (1928) studied a hill where wind flow was from one predominant direction. He measured precipitation amounts with a rain gauge that was horizontal at the top opening (as opposed to tilted into the wind). A local maximum occurred on the leeward flanks of the hill close to the crest. The explanation offered was that increased wind speeds as air was forced over the hill maintained the raindrops suspended; where the wind speed dropped--just over the crest--rain reached the ground. By applying this conclusion it is possible

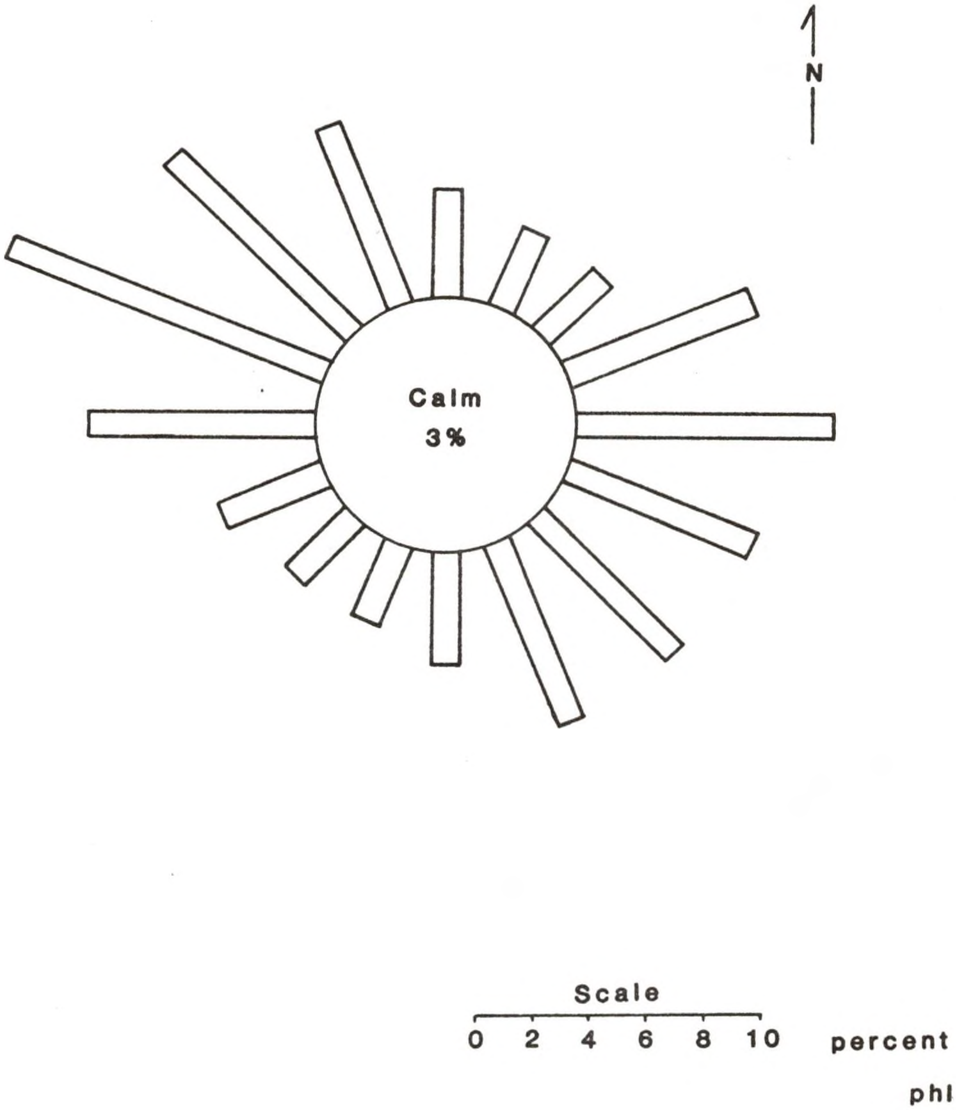


Figure 12: Wind Rose for Bismarck, North Dakota 1951-60 (U. S. Department of Commerce 1973).

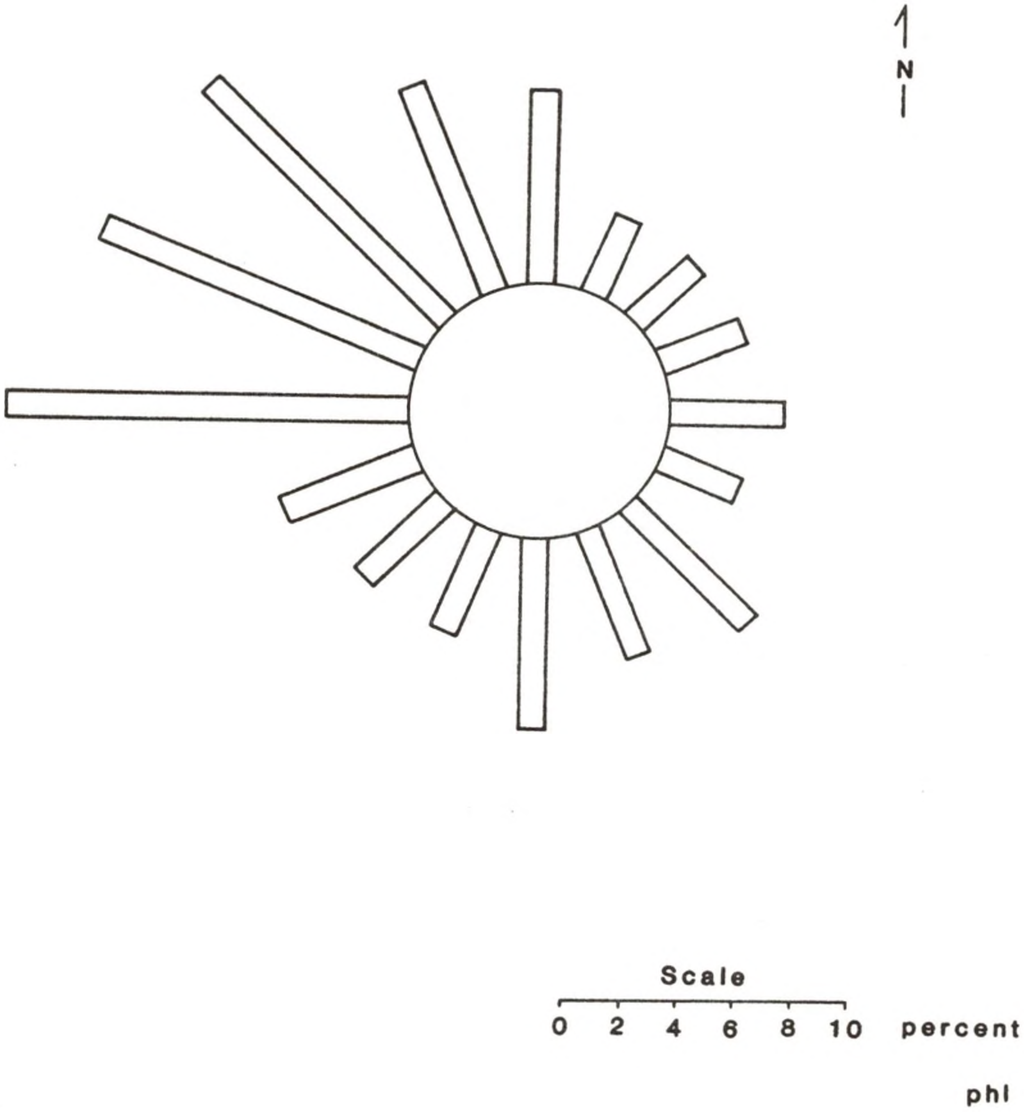


Figure 13: Wind Rose for Bowman, North Dakota 1975-76 (U. S. Environmental Protection Agency 1976).

that slopes with a west-facing component may be more xeric initially based on precipitation receipt than eastward-facing hills. The official weather stations in the nine counties are so far apart, and slope angles are so gentle that no corroboration can be made from the mean data used. Additional field research is needed to collect wind data and to determine the effect of wind on precipitation patterns.

Slope Angles

Data for 420 pairs of points along drainageways in the area of the North Killdeer Mountain Quadrangle are listed in Table 57 in Appendix D. Wilcoxon Tests for Paired Sample for four subsets of points with reciprocal azimuth are run on slope angle data; however, the Wilcoxon Test requires that measurements with the same angle on both sides of a valley be excluded. Table 10 shows the number of points eliminated, and the breakdown of the remaining pairs. Results of Wilcoxon tests are shown in Table 11. Each rank of the difference between slope angles is listed in one of two columns determined by which slope is steeper; the smaller sum of ranks of differences between slopes is designated "T." A critical value of T for samples from six to twenty-five is obtained from a table (Hammond and McCullagh 1978), which also gives the probability associated with the critical value. For samples larger than twenty-five the value of T is converted into a Z-score.

TABLE 10

Distribution of Slope Pairs With Reciprocal Azimuth and Number and Percent With Tied Slope Angle

AZIMUTH PAIR	TOTAL NUMBER	TIED SLOPE ANGLE	PERCENT	PAIRS REMAINING	PERCENT OF TOTAL
E/W	40	7	17.5	33	21.2
SE/NW	28	5	17.9	23	14.7
N/S	56	13	23.2	43	27.6
NE/SW	63	6	9.5	57	36.5
TOTAL	187	31	16.6	156	100.0

TABLE 11

Results of Wilcoxon Tests on Four Paired Samples

AZIMUTH PAIR	TEST TOTAL	$\Sigma R1$	$\Sigma R2$	T	Z-SCORE OR (CRITICAL T)	PROBABILITY
E/W	33	418	141	141	-2.49	.006
SE/NW	23	175	99	99	(73)	not sig.
N/S	43	560	386	386	-1.05	not sig.
NE/SW	57	1113	540	540	-2.26	.014

Results show no significant differences between slope angles of SE/NW and N/S pairs. Twenty-three southeast-facing slopes average 15.4 degrees, while the opposite ones average 14.0 degrees. North-facing slopes have a mean angle of 15.6 degrees, while south-facing sides average 14.7 degrees. The greater similarity of slope angle of the N/S pairs is re-emphasized by the fact that nearly one quarter of the original 56 points has to be eliminated because slope angles are equal. However, test results on E/W and NE/SW pairs are significant. In both cases actual probabilities are considerably better than the .05 rejection level set prior to the test. East-facing slopes average 16.6 degrees, while west-facing slopes average 14.5 degrees. Fifty-seven northeast-facing hills average 15.8 degrees, while the southwest slopes have a mean angle of 14.2 degrees. The differential between NE/SW slopes (1.6 degrees) is very close to that between SE/NW slopes (1.4 degrees). The test on the former shows significant difference in slope angle, while the test on the latter does not. However, SE/NW slopes are less consistently different; before the test 17.9 percent of the points are eliminated due to tied slope angle, compared to 9.5 percent of the NE/SW pairs. Data for the test on NE/SW slopes agree with the conclusion of Hadley (1961), and differ from the conclusion by Toy (1977) and with the findings of Churchill (1981). Absence of vegetation on hills is cited by

Churchill as one explanation for the results in his study. In the area of the North Killdeer Mountain Quadrangle, the hills are generally vegetated.

Analysis of Vegetation and Terrain Climate

Vegetation counts determined from the Bureau of Land Management's North Killdeer Mountain Quadrangle overlay (U.S. Department of Interior 1981) for valley slopes listed in Table 57 in Appendix D, are shown along with results of Chi-square analysis of azimuth vs. vegetation group in Table 58 in Appendix E. Five tests with probabilities lower than the rejection level reflect several common tendencies: (1) woodland strongly favors the north-, northeast- or northwest-facing slopes; (2) shrubland shows a moderate to strong likelihood of occurring on southwest-facing slopes; and (3) native prairie is more likely to occur on south- and southwest-facing surfaces, or those facing west. Given the statements of Geiger (1965), that southwest-facing slopes in the northern hemisphere are the warmest, it follows that the shrubland and prairie vegetation found in the area of the North Killdeer Mountain Quadrangle is found on more xeric sites, while the woodland varieties grow on more mesic slopes. Species in each class are not identified by the Bureau of Land Management, although the U.S. Department of Agriculture (1982) stated that, in general, the common woody vegetation in Dunn

County is Bur Oak, Green Ash, American Elm, Quaking Aspen, Juneberry (Amelanchier alnifolia), Gooseberry (Ribes setosa) and Prairie Rose (Rosa arkansana). Wali et al. (1980) found Bur Oak, Green Ash and American Elm on mesic sites of various azimuth, and Aspen on north- and west-facing slopes. Findings of the Chi-square analysis are consistent with those of the Wali et al. (1980) study.

A demonstration of conditions in the North Killdeer Mountain Quadrangle area can be made by again using Swift's (1976) potential radiation equations. Slopes of NE, SE, SW and NW azimuth average commonly between 10-20 degrees (see Table 57 in Appendix D). Table 12 shows the values of radiation on flat ground and on slopes of 10 and 20 degree angle for four azimuths listed above. The center-point of the appropriate group shown in Table 3 above is used in the equation to represent NE, SE, SW, and NW nominal azimuth. Since radiation is symmetric, northeast and northwest are listed together, as are southeast and southwest. Latitude used in all computations is 47.5 degrees. Swift's Slope Factor (F) also is computed by dividing potential radiation on a slope by the potential on level ground, to determine an index. Results are shown in Table 13, and these indices are comparable, since they are computed for the same latitude. Tremendous differences in potential radiation receipt result from variations in slope and aspect. In the extreme case--NE/SW 20 degree slopes

TABLE 12

Values of R3 and R4 for Midpoint of Each Month for Two Slope Angles and Four Azimuths[a] (Cal/Cm^2/Day)

	R3	R4			
		10 deg		20 deg	
		NE & NW	SE & SW	NE & NW	SE & SW
J	187.8	160.8	356.6	93.1	446.0
F	303.6	281.3	476.0	202.3	559.5
M	490.5	480.8	651.4	394.0	721.6
A	702.0	712.9	829.6	634.6	867.3
M	861.5	895.3	949.2	833.1	954.0
J	931.4	975.2	990.9	925.9	977.4
J	899.4	933.9	967.4	882.7	962.6
A	772.4	792.6	881.4	724.6	903.6
S	563.2	561.4	708.9	479.4	763.8
O	366.7	350.0	534.5	266.7	612.2
N	219.2	195.6	386.4	120.7	473.0
D	155.7	133.0	322.7	67.0	410.5

[a] After Method by Swift 1976

TABLE 13

Slope Factor Ratios for Data in Table 12[a]
(R4/R3)

	10 deg		20 deg	
	NE & NW	SE & SW	NE & NW	SE & SW
J	0.86	1.90	0.50	2.37
F	0.93	1.57	0.67	1.84
M	0.98	1.32	0.80	1.47
A	1.02	1.18	0.90	1.24
M	1.04	1.10	0.97	1.11
J	1.05	1.06	0.99	1.05
J	1.04	1.08	0.98	1.07
A	1.03	1.14	0.94	1.17
S	1.00	1.26	0.85	1.36
O	0.95	1.46	0.73	1.67
N	0.89	1.76	0.55	2.16
D	0.85	2.04	0.43	2.64

[a] After Method by Swift 1976

(or SE/NW)--in December the southwest-facing slope potentially receives 2.64 times as much radiation as a flat surface, and 6.14 times (2.64 divided by 0.43) as much radiation as the northeast-facing slope. In the same situation for 10 degree slopes, the southwest-facing slope receives 2.04 times as much direct radiation as a horizontal surface. A northeast-facing slope gets 0.85 of the amount of potential radiation on a flat surface, or 41.7 percent (0.85 divided by 2.04) of the amount of sun received by the opposite slope.

Comparable differences occur in other months; however, the degree of difference decreases and reaches a minimum in the summer. This is due, at least in part, to the receipt of radiation at a higher latitude. Summer days are long, and the Sun rises and sets toward the northeast and northwest respectively. Slopes with a north component in azimuth receive radiation during the morning and evening, when slopes with a south component are blocked from receiving sunshine. The overall effect is that differences in potential radiation all but disappear in June, the month of the summer solstice.

Data for slope angle and azimuth of sixty-eight stands are used from Hansen, Hopkins, and Hoffman (1980); latitude of each stand is determined from maps. Equivalent latitude computed from the equations by Swift (1976) is listed with latitude for each stand in Table 14. Twelve

TABLE 14

Latitude and Equivalent Latitude of Sixty-Eight Stands[a]

STAND	V.LAT	V.EQL	STAND	V.LAT	V.EQL
1	47.0	47.0	36	47.0	47.0
2	47.0	47.0	37	46.9	52.1
3	47.0	38.5	38	46.9	67.0
4	47.0	46.4	39	47.0	47.0
5	47.0	36.9	40	47.0	48.5
6	47.0	45.7	41	47.0	47.0
7	47.0	47.8	42	47.0	47.4
8	47.0	45.2	43	46.9	70.0
9	47.0	62.2	44	47.0	68.5
10	47.0	40.5	45	E[b]	E
11	46.9	52.5	46	E	E
12	47.0	63.4	47	47.6	63.3
13	47.0	44.1	48	47.6	39.9
14	47.0	53.2	49	47.6	56.0
15	47.0	41.5	50	47.6	50.0
16	46.9	45.9	51	47.6	48.6
17	47.0	51.5	52	47.6	47.6
18	46.9	40.2	53	47.6	80.1
19	47.0	45.4	54	47.6	52.7
20	46.9	39.1	55	47.6	44.3
21	46.9	37.0	56	47.6	37.4
22	47.0	50.1	57	47.6	50.8
23	47.0	31.5	58	47.6	54.7
24	47.0	24.8	59	47.6	44.4
25	47.0	48.6	60	47.6	49.3
26	46.9	49.3	61	47.6	47.5
27	47.0	47.0	62	47.6	42.7
28	47.0	54.9	63	47.6	38.5
29	47.0	47.0	64	47.6	47.6
30	47.0	52.5	65	47.6	47.6
31	47.0	45.2	66	47.6	47.6
32	47.0	47.0	67	47.6	59.6
33	47.0	66.1	68	47.6	62.8
34	47.0	79.9	69	47.6	47.6

[a] Stands Utilized from Hansen, Hopkins, and Hoffman 1980

[b] E = Eliminated

plants are chosen from the Hansen, Hopkins, and Hoffman (1980) study, and a survey is made of the equivalent latitude of stands in which each plant occurs. Vegetation includes four shrubs, viz. Silver Sagebrush, Chokecherry, Buckbrush, and Little Sage (*Artemisia frigida*), six graminoids, viz. Western Wheatgrass, Slender Wheatgrass (*Agropyron caninum*), Threeleaved Sedge, Needle and Thread, Big Sandgrass, and Green Needlegrass (*Stipa viridula*), and two forbs, Milfoil (*Achillea millefolium*) and Blue Lettuce (*Lactuca oblongifolia*). Table 15 shows the percent of stands in each equivalent latitude class for each plant; numbers at the bottom show the distribution of the sixty-eight stands by equivalent latitude. (If a species occurs on horizontal ground, equivalent latitude and latitude are identical.)

Since only one stand occurs each in the lowest class and the two highest classes, percentages in those categories are extreme: either zero if the plant does not occur, or 100 percent if it does. The remaining four classes have less extreme ranges. A profile of the most common conditions in which a species is found can be determined from examination of Table 15. For example, (1) Buckbrush is concentrated toward the higher equivalent latitude, (2) Green Needlegrass generally does not favor any one equivalent latitude class, while (3) Needle and Thread is concentrated on stands of lower equivalent latitude.

TABLE 15

Percent of Stands in Each Equivalent Latitude Group for Twelve Plants

	EQUIVALENT LATITUDE (DEGREES)						
	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Chokecherry	-	-	16	42	50	-	-
Buckbrush	-	-	43	67	62	100	100
Slender Wheatgrass	-	-	49	58	50	100	-
Milfoil	-	-	35	58	50	100	100
Threeleaved Sedge	100	88	43	33	50	-	-
Big Sandgrass	100	38	24	17	50	-	-
Silver Sage	-	25	39	8		-	-
Green Needlegrass	-	25	32	33	-	-	-
Western Wheatgrass	-	75	65	50	-	-	-
Blue Lettuce	100	75	54	42	-	-	-
Little Sage	100	75	54	33	12	-	-
Needle and Thread	100	75	27	17	-	-	-
Total number of stands	1	8	37	12	8	1	1

A species' distribution is shown in Table 16, in which the percentages are based on the total number of stands in which the species occurs. Amounts are rounded to total 100 percent. The table demonstrates another way of viewing where each species is found, as several examples may show: (1) Buckbrush, which appears to favor higher equivalent latitude from the data in Table 15, is found 52 percent of the time in stands of 40-50 degree equivalent latitude; (2) Silver Sage occurs 82 percent of the time on stands of 40-50 degree equivalent latitude.

A third method is used to define conditions under which each species is found. Azimuth and slope angle are depicted in Figure 14 (a to l) after a method presented by Brown (1971). The outside of the large circle represents 360 degrees of azimuth, and concentric circles (shown inside large circle as arcs) symbolize 10 degrees of slope; up to 40 degrees of slope can be represented. Although the center of each diagram represents flat ground, for clarity the number of stands with no slope are indicated to the side. Each dot represents one stand, and the figure reflects the growth pattern of each plant.

Chokecherry (Figure 14a) occurs on steeply sloping ground, and prefers azimuth between west and north (270 to 360 degrees). Buckbrush prefers steep ground of the same azimuth, and it also occurs on nearly flat sites of varying aspect. This dual pattern of occurrence is reflected

TABLE 16

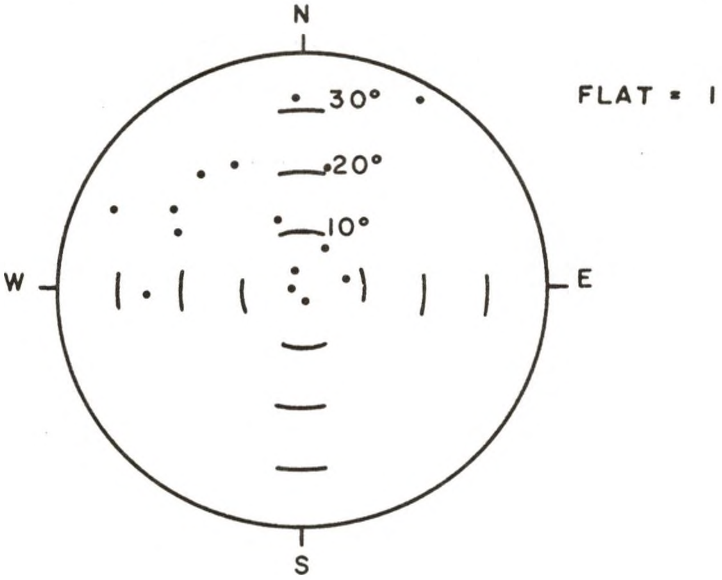
Percent of Stands in Which a Plant Species Occurs by Equivalent Latitude

			EQUIVALENT		LATITUDE			
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	Total
			(DEGREES)					
Chokecherry	-	-	38	31	25	-	6	100
Buckbrush	-	-	52	26	16	3	3	100
Slender Wheatgrass	-	-	60	24	13	3	-	100
Milfoil	-	-	50	27	15	4	4	100
Threeleaved Sedge	3	22	50	12	13	-	-	100
Big Sandgrass	5	16	47	11	21	-	-	100
Silver Sage	-	12	82	6	-	-	-	100
Green Needlegrass	-	11	67	22	-	-	-	100
Western Wheatgrass	-	17	66	17	-	-	-	100
Blue Lettuce	3	19	62	16	-	-	-	100
Little Sagebrush	3	18	61	15	3	-	-	100
Needle and Thread	5	32	52	11	-	-	-	100

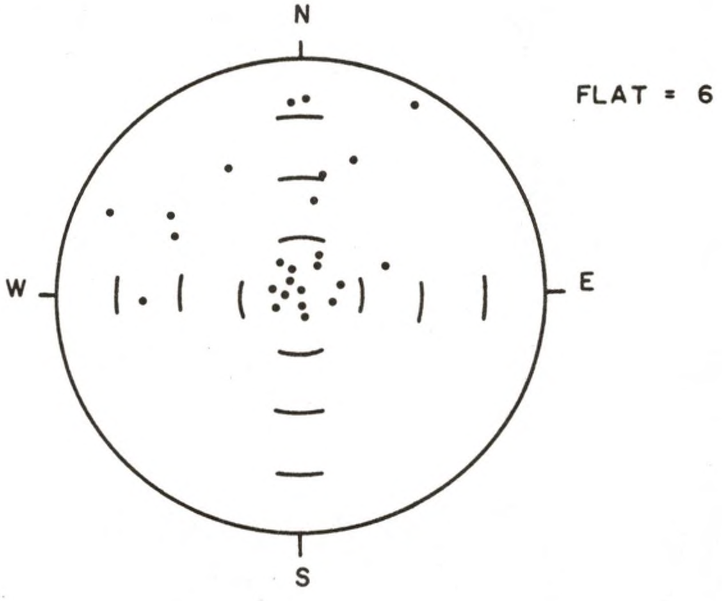
Figure 14: Vegetation Patterns by Azimuth and Slope Angle for Twelve Plants:

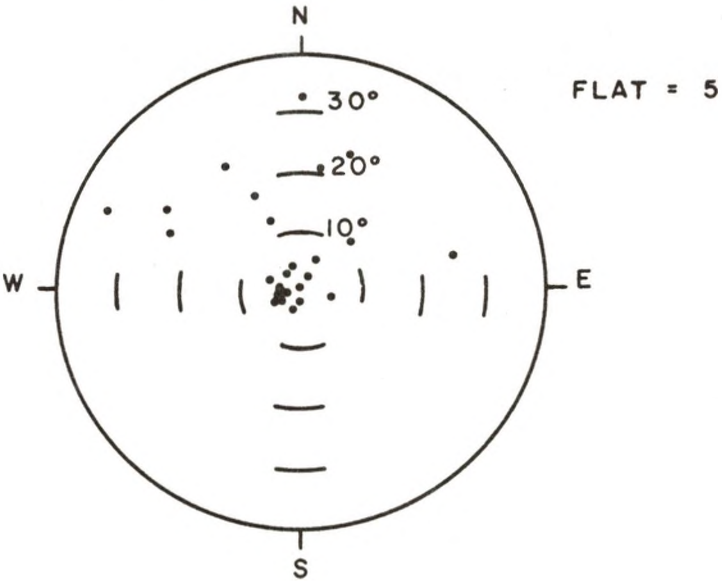
a. *Prunus virginiana* (Chokecherry);
b. *Symphoricarpos occidentalis* (Buckbrush);
c. *Agropyron caninum* (Slender Wheatgrass);
d. *Achillea millefolium* (Milfoil);
e. *Carex filifolia* (Threeleaved Sedge);
f. *Calamovilfa longifolia* (Big Sandgrass);
g. *Artemisia cana* (Silver Sage);
h. *Stipa viridula* (Green Needlegrass);
i. *Agropyron smithii* (Western Wheatgrass);
j. *Lactuca oblongifolia* (Blue Lettuce);
k. *Artemisia frigida* (Little Sage);
l. *Stipa comata* (Needle and Thread).

a. Prunus virginiana

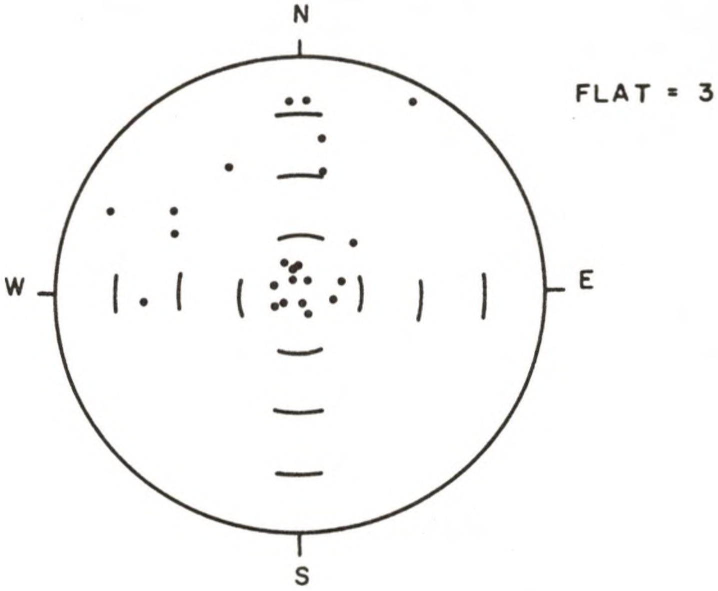


b. Symphoricarpos occidentalis



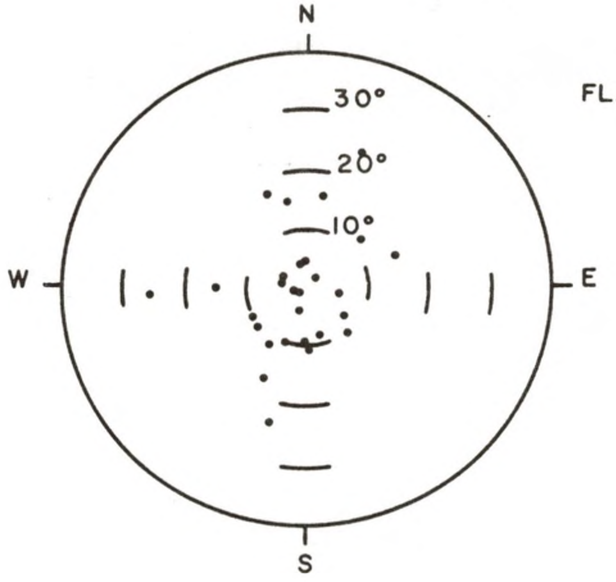


c. Agropyron caninum



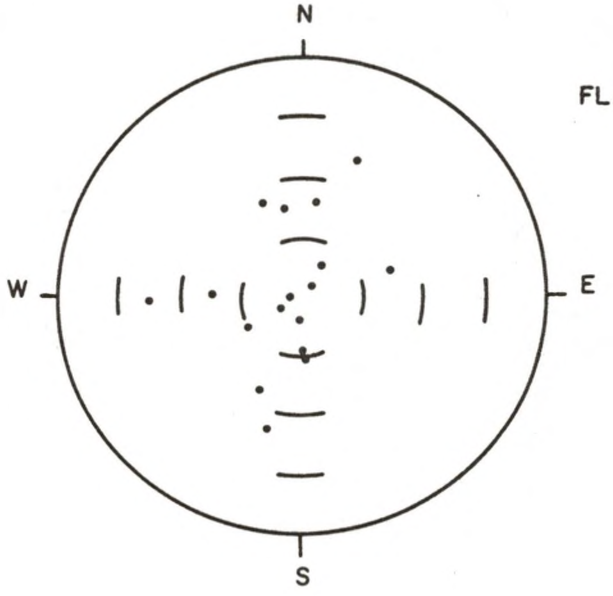
d. Achillea millefolium

e. Carex filifolia



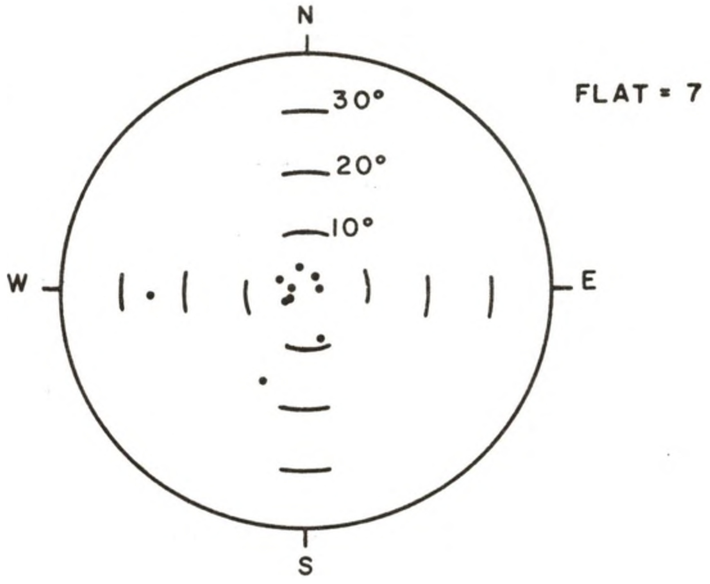
FLAT = 4

f. Calamovilfa longifolia

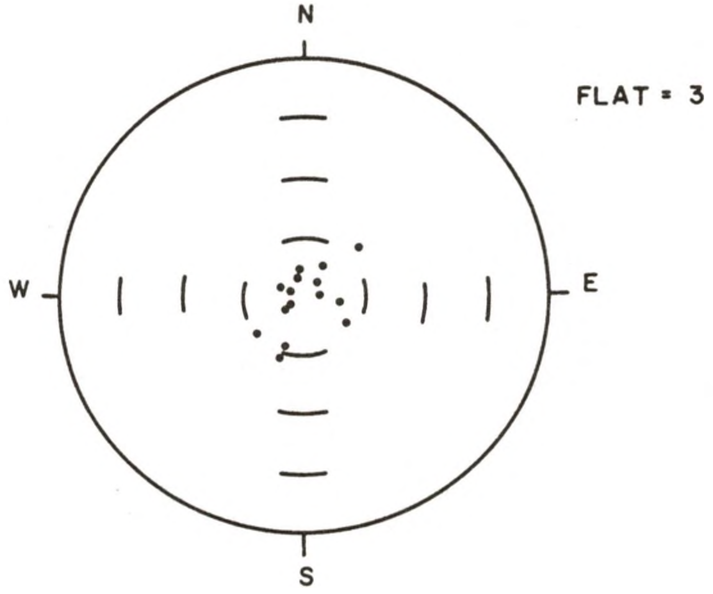


FLAT = 2

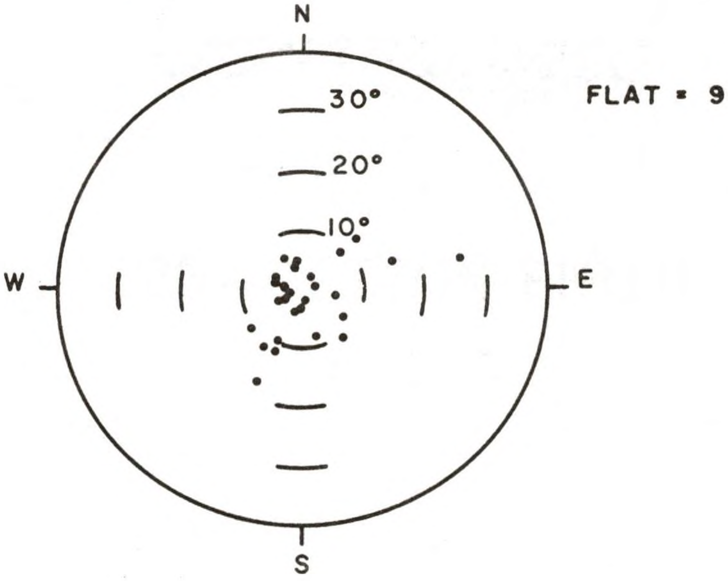
g. Artemisia cana



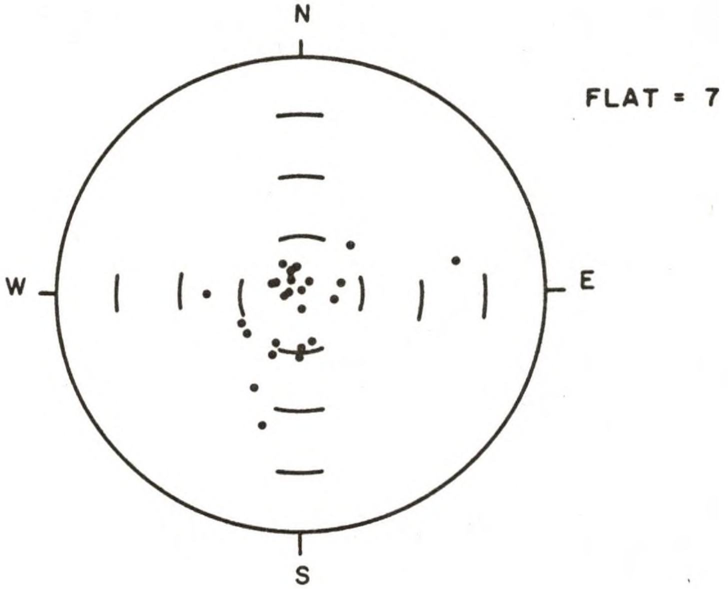
h. Stipa viridula



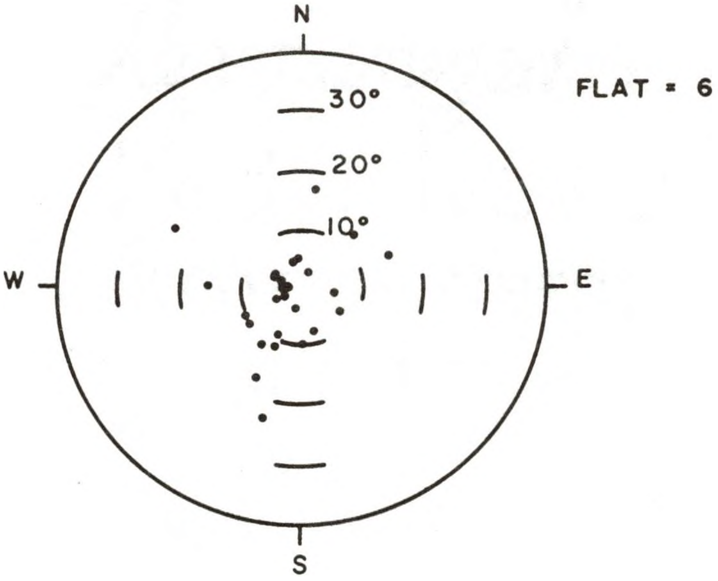
i. **Agropyron smithii**



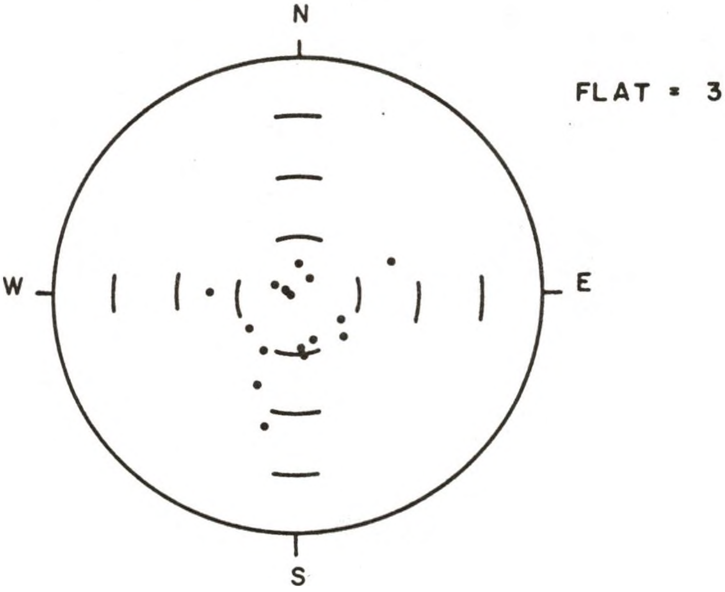
j. **Lactuca oblongifolia**



k. Artemisia frigida



l. Stipa comata



in the percentages in Table 15 and Table 16 above, and is supported by earlier literature. In their study Wali et al. (1980) found Buckbrush (Figure 14b) on flat terrain. Stevens (1963) listed the plant to occur ". . . in lower places on the prairie or in coulees." Slender Wheatgrass (Figure 14c) also is divided into two groups: one which occurs on moderate slopes that mostly face northwest to north (from 315 to 0 degrees), and another which favors flatter ground facing generally west to northeast (270 to 45 degrees). Only stands of very low slope angle face south, southeast, or southwest. The pattern of Milfoil (Figure 14d) is similar to that of Slender Wheatgrass; however, Milfoil occurs on sloping ground between west to northeast azimuth (270 to 45 degrees). Threeleaved Sedge (Figure 14e) prefers moderately sloping ground of various azimuth. Table 15 shows that it occurs in 88 percent of the stands in the 30-40 degree equivalent latitude class, and in 50 percent of the stands in the 60-70 degree class. These findings generally agree with those of Hanson and Whitman (1938). Stevens (1963) stated Threeleaved Sedge was common on ". . . dry prairie and hillsides." Perhaps the preference is to relatively xeric sites, regardless of azimuth. Big Sandgrass (Figure 14f) prefers sites of moderate slope of various aspect; however, it occurs on few stands with azimuth between east and south (90 to 180 degrees). The latter fact may be coincidental, and related to the relatively small number of stands available for depiction. Also, Stevens (1963) and Hanson and Whitman (1938) noted the species was found on sandy soils.

Silver Sage (Figure 14g) has one of the most consistent patterns of any species used. Forty-one percent of the stands in which it occurs are on flat ground, and another 47 percent are stands with slope angles of less than 10 degrees. This agrees with the findings of Wali et al. (1980) and Hanson and Whitman (1938). Green Needlegrass (Figure 14h) also prefers stands of gentler slope angle; of the eighteen stands in which it is found, Green Needlegrass occurs just in three with slope angle greater than 10 degrees. Western Wheatgrass (Figure 14i) is found on flatter sites, but also on sloping stands that face between east and southwest (90 to 225 degrees). The suggestion is possible that this grass prefers more xeric conditions, and that even the flatter stands that face toward the north or northwest are relatively xeric ones, although additional research is necessary to verify this. The pattern of Western Wheatgrass depicted in Figure 14i agrees at least in part with the findings of Hanson and Whitman (1938), although they also found the grass on sites that occasionally flooded. Blue Lettuce (Figure 14j) seems to favor gentler and flat slopes, but does occur on some moderate slopes that face between south and west (100 to 225 degrees). Little Sage (Figure 14k) seems to prefer gentle slopes and moderately sloping, south- to southwest-facing stands (180 to 225 degrees), although it also occurs on a few moderate slopes that face northeast, north or northwest. Steven's (1963) statement that Little Sage occurred on ". . . gravelly hills and prairie" may show a preference for drier conditions. Finally Needle and Thread (Figure 141) shows a strong preference for southeast- to southwest-facing stands (135 to 225 degrees) of moderate slope angle. This preference for more xeric conditions is not mentioned in the findings of Hanson and Whitman (1938), but neither is it contradictory to them.

CHAPTER 5

CONCLUSIONS AND SUMMARY

Conclusions

Relationships among climatic elements are revealed by correlation and regression are similar to those in earlier literature. The nine counties of the southwestern corner of North Dakota are part of a large zone of transition between the humid east and arid west. In the case of precipitation, V.LONG correlates best and reflects a high precipitation gradient throughout the study area. For TVAR and CONRAD, V.LAT is most significant. A chinook effect as suggested by Bavendick (1952) is qualified in the strong negative correlation of V.DIST with monthly temperature. V.DIST estimates the influence of the Rocky Mountains on the climate of southwestern North Dakota.

Borchert's (1950) observation of different air circulation in summer and winter as the main cause of precipitation patterns in the grasslands is supported by correlation results: negative coefficients between V.LONG and monthly precipitation, and a split pattern between monthly precipitation and V.LAT, with a negative coefficient with JUNPREC and a positive one with DECPREC. However, a further conclusion can be reached using regression of PRECTOT and monthly precipitation: that most of the variation in PRECTOT occurs in transitional months (May, November), Conversely, the winter precipitation is consistently low and the summer precipitation consistently high at all stations. Most of the variation occurs in the spring or fall, when the previous season's air circulation pattern is dissolving and the opposite pattern is becoming increasingly dominant.

V.ALT shows a mild cooling effect on MAYTMP and JUNTMP. In general, altitude has not been considered to be a control of climate in North Dakota; Jensen (1972) did not list it as such. While V.ALT in the study area reach 1067 m (3500 ft), the gradient is quite low and relief is not great enough to cause orographic precipitation. To the contrary, positive correlation between SEPPREC and V.DIST suggests the intrusion of a rain shadow from the Rockies into southwestern North Dakota at a time when moisture from the south (Gulf of Mexico) is still available.

One major concusion reached from this research is that climatic differences are more apparent during months of low Sun angle. Evidence leading to this includes the overwhelming importance of variation in NOVTMP in explaining TMPAVG, and the fact that five monthly values of R4 at nine stations relate to five corresponding temperatures, via., JANTMP, FEBTMP, MARTMP, NOVTMP, and DECTMP. These five positive correlations infer that where values of radiation on a slope are high (as on a south-facing surface), mean temperature is high, too. On a north-facing surface the opposite situation exists. (In a larger study area, latitude would ultimately become important; the study area of this research spans less than 2 degrees of latitude, which therefore is not a significant variable with respect to radiation.)

Equivalent latitude is successfully used to reflect conditions on slopes of all aspects. Since V.EQL correlates in a negative direction so closely with monthly R4, they are virtually interchangeable. Therefore, the same pattern as mentioned above emerges: strong correlation between V.EQL and JANTMP, FEBTMP, MARTMP, NOVTMP, and DECTMP. V.EQL is unique in that it combines V.LAT, V.AZIM, and V.SA into one number that correlates well with many other variables. V.LAT has displayed a similar pattern of correlation with monthly temperatures; the coefficients are lower, but due to the larger sample size the probabilities are higher than those between five monthly temperatures and V.EQL. V.AZIM and V.SA showed no statistically significant correlation with monthly temperatures, a fact which is understandable when the complex interaction between slope and aspect is examined. A steep slope angle alone does not predict either warmer or cooler temperatures, because the aspect toward or away from the Sun combines with the slope angle to produce a specific radiation climate for that terrain. A north-facing surface is not radically different in temperature from a south-facing slope if both are of extremely low slope angle. (Note, however, that the positive correlation between V.SA and CONRAD suggests that a steeper slope angle produces a higher index of continentality regardless of azimuth; either warmer or cooler conditions tend to increase the range which is part of the input for the index.) In regression analysis V.EQL accounts for from 55.0 percent (for NOVTMP) to 72.5 percent (for FEBTMP) of the variation in mean monthly temperature. Unless actual estimates of radiation are needed for research, a value of equivalent latitude is an excellent substitute. Correlations between a climatic variable and either monthly R4 and V.EQL are very close due to the strong negative correlation between monthly R4 and V.EQL. In addition equivalent latitude is easy to calculate.

A significant relationship exists between slope angle and azimuth in the area of the North Killdeer Mountain Quadrangle. Further investigation is needed to establish any cause. Also, a statistically significant relationship exists between some azimuth and vegetation categories. Tests reveal that woodland tends to occur more often on slopes that face northwest to northeast (315 to 45 degrees), that shrubland shows a tendency to occur on southwest-facing slopes, and that native prairie tends to grow on slopes that face south to west (180 to 270 degrees). The tests, however, can be improved by the use of individual vegetation species rather than broad groups, in that different species within the category "prairie" may tend to grow under more mesic or xeric conditions. Variations in soil conditions can have a great effect on vegetation; also, a perched water table can create mesic conditions in a locale, even on the side of the slope that is generally characterized as xeric. Such variations from average conditions are probably not uncommon in the Little Missouri drainage basin, since exposed ledges of impermeable material are part of its geologic composition. Ultimately, field work is needed to obtain the detailed data necessary for more involved conclusions.

Summary

In the Little Missouri River drainage basin, Badlands topography was formed as a result of erosion due to diversion and lowered base level after a glacial episode in the Pleistocene. The area involved is part of the Great Plains of the United States, and is in a zone of transition between the eastern deciduous forests and the western deserts. Such change is evident in climate and vegetation. In a zone of transition local factors will strongly influence conditions based on terrain.

Badlands topography is rough, and due to variations in solar radiation reaching a slope, temperature, humidity, soil conditions, and numerous other factors, great extremes in local climate and vegetation can occur in a small distance, most commonly on opposite slopes across a valley.

Climatic data are collected for weather stations in the Little Missouri drainage basin. Due to the sparseness of these stations and the fact that in this area of transition certain gradients are very steep, data from a total of thirty-two weather stations in southwestern North Dakota, northwestern South Dakota and eastern Montana are used to analyze the overall climate of that section of the Great Plains. One major impact of differences in slope and aspect is in receipt of solar radiation; estimates are made of potential solar radiation on both horizontal and sloping ground at nine stations. Vegetation patterns are used as a reflection of conditions on a slope. Radiation and vegetation analyses infer local or terrain climate that results from the influence of slope and aspect.

Slopes along drainageways in the area of the North Killdeer Mountain Quadrangle are used for slope angle and vegetation testing with regard to azimuth. Significant differences in slope angle are computed for slopes of E/W and NE/SW azimuth combinations. Statistically significant differences in vegetation groups on opposing slopes are identified in the same area for N/S, NE/SW, NE/W, N/SW and NW/S slope combinations. Specific species of plants that occur in sixty-eight stands tested by Hansen, Hopkins, and Hoffman (1980) are surveyed by equivalent latitude of stands, and are graphed by a method demonstrated by Brown (1971). Results of both methods reflect the differing patterns of occurrence of the twelve species. A comparison of monthly potential radiation on a slope to the radiation on level ground reveals great disparity in radiation receipt caused by slope angle and aspect. Estimates are made of the range of differences in solar radiation among NE/SW and SE/NW slopes of 10 and 20 degrees. In the most extreme potential case a southwest-facing slope receives slightly more than six times as much radiation in December as an opposite northeast-facing surface. Other investigations by Cottle (1932) and Geiger (1965) showed that variations in slope and aspect lead to differences in air temperature, soil temperature, evaporation, and humidity. Vegetation may flourish, recede, or merely tolerate local conditions, but these set the limits of existence for plant species.

> The relationships between climatic factors and plant growth are complex and are still imperfectly understood. Attempts to discover the optimum climatic conditions for the growth of a particular species, and the limits within which it can exist are exceedingly difficult. Whether a particular plant or group of plants can occupy a given habitat does not depend entirely on the presence of favourable climatic conditions. These are essential. But soil and other biotic conditions must also be suitable. Climate sets the scene, climate provides certain opportunities--a certain potential--for plant growth. . . (Tivy 1971, pp. 58-59).

APPENDICES

APPENDIX A

WEATHER STATION PHOTOGRAPHS AND DATA

Figure 15: Amidon Weather Station, Viewed from the Northeast.

TABLE 17

Data for Amidon Weather Station
as of April 29, 1982

LOCATION: in Sec. 26 T135 R101W (on grounds of Slope County Court House)

OBSERVER: Roy Frederick

LENGTH OF RECORD AT SAME LOCATION: 30 years

AZIMUTH: 57 degrees

SLOPE ANGLE: 0.4 degrees

SOIL SERIES: Talley fine sandy loam

COMMENTS: Equipment is somewhat protected on the south side by the Court House.

Figure 16: Bowman Weather Station, Viewed from the Southwest.

Figure 17: Bowman Weather Station, Viewed from the West-Northwest.

TABLE 18

Data for Bowman Weather Station
as of April 29, 1982

LOCATION: in Sec. 11 T131N R102W (on grounds of Bowman County Court House)

OBSERVER: Alfred Bolte

LENGTH OF RECORD AT SAME LOCATION: 27 years

AZIMUTH: 218 degrees

SLOPE ANGLE: 2.1 degrees

SOIL SERIES: Vebar-Talley fine sandy loam, gently sloping

COMMENTS: The parking lot (paved) for the Court House is directly north of the equipment.

Figure 18: Dickinson Experiment Station Weather Station, Viewed from the South-Southeast.

TABLE 19

Data for Dickinson Experiment Station Weather Station
as of April 29, 1982

LOCATION: in Sec. 5 T139 R96W

OBSERVER: Thomas Conlon

LENGTH OF RECORD AT SAME LOCATION: 30 years

AZIMUTH: 162.5 degrees

SLOPE ANGLE: 0.3 degrees

SOIL SERIES: Vebar-Parshall fine sandy loam

COMMENTS: Equipment is protected on the north and west sides by trees and buildings.

Figure 19: Dunn Center Weather Station. Instrument Shelter, Viewed from the East-Southeast.

Figure 20: Dunn Center Weather Station. Rain Gauges, Viewed from the West-Southwest.

TABLE 20

Data for Dunn Center Weather Station
as of April 30, 1982

LOCATION: in Sec. 28 T145N R95W (on grounds of Lake Ilo National Wildlife Refuge)

OBSERVER: Chesley Dinkins

LENGTH OF RECORD AT SAME LOCATION: 25 years

AZIMUTH: 319 degrees

SLOPE ANGLE: 6.3 degrees

SOIL SERIES: Ruso sandy loam

COMMENTS: Temperature and precipitation equipment are separated by about 27 m (90 ft). Lake Ilo is directly to the north.

Figure 21: Fairfield Weather Station,
Viewed from the North-Northwest.

Figure 22: Fairfield Weather Station, Viewed from the Southwest.

TABLE 21

Data for Fairfield Weather Station
as of April 30, 1982

LOCATION: in Sec. 22 T143N R99W

OBSERVER: Dwaine Bolke

LENGTH OF RECORD AT SAME LOCATION: 29 years

AZIMUTH: 40 degrees

SLOPE ANGLE: 3.0 degrees

SOIL SERIES: Morton-Rhoades loam

COMMENTS: Equipment is located north of a grocery store and house. Weather shelter used to be south of house; minor change was not listed in U. S. Department of Commerce publication.

Figure 23: Hettinger Weather Station, Viewed from the North-Northwest.

Figure 24: Hettinger Weather Station, Viewed from the Southwest.

TABLE 22

Data for Hettinger Weather Station
as of April 28, 1982

LOCATION: in Sec. 14 T129N R96W (along ND Hwy. 8, on grounds of Forthun Florist)

OBSERVER: Fred Forthun

LENGTH OF RECORD AT SAME LOCATION: 30 years

AZIMUTH: 105.5 degrees

SLOPE ANGLE: 4.8 degrees

SOIL SERIES: Vebar sandy loam

COMMENTS: Equipment is now south of Hettinger. It may have been located "in town" before 1960; no change of location was found in U. S. Department of Commerce publication.

Figure 25: New England Weather Station, Viewed from the East-Southeast.

TABLE 23

Data for New England Weather Station
as of April 28, 1982

LOCATION: in Sec. 4 T135N R97W (in yard of private home)

OBSERVER: Anton Selinger

LENGTH OF RECORD AT SAME LOCATION: 29 years

AZIMUTH: 159 degrees

SLOPE ANGLE: 0.8 degrees

SOIL SERIES: Parshall sandy loam

COMMENTS:

Figure 26: Richardton Abbey Weather Station, Viewed from the West-Northwest.

Figure 27: Richardton Abbey Grounds.
Weather Station (Bottom Right)
Viewed from the Southeast.

TABLE 24

Data for Richardton Abbey Weather Station as of April 28, 1982

LOCATION: in Sec. 5 T139N R92W (on grounds of Assumption Abbey)

OBSERVER: Brother Philip Kress

LENGTH OF RECORD AT SAME LOCATION: 25 years

AZIMUTH: 11 degrees

SLOPE ANGLE: 2.4 degrees

SOIL SERIES: Morton and Farland silt loams

COMMENTS: Ground around Assumption Abbey has many trees which may alter wind movement. The church is a short distance west of the equipment and may provide protection and heat.

Figure 28: Watford City 14 S Weather Station, Viewed from the South-Southeast.

Figure 29: Watford City 14 S Weather Station, Viewed from the Northeast.

TABLE 25

Data for Watford City 14 S Weather Station as of April 30, 1982

LOCATION: in Sec. 35 T148N R99W (in the North Unit of Theodore Roosevelt National Park)

OBSERVER: Rangers at Theodore Roosevelt National Park

LENGTH OF RECORD AT SAME LOCATION: 23 years

AZIMUTH: 221 degrees

SLOPE ANGLE: 3.6 degrees

SOIL SERIES: Bainville clay loam

COMMENTS:

APPENDIX B

RAW CLIMATIC DATA

TABLE 26

Symbols Used for Weather Stations and Variables

SYMBOL	WEATHER STATION
	North Dakota Stations
AM	Amidon
BE	Beach
BO	Bowman Court House
DFA	Dickinson FAA AP
DES	Dickinson Experiment Station
DC	Dunn Center 2 SW
FA	Fairfield
HE	Hettinger
KE	Keene 4 S
KI	Killdeer 8 NW
MA	Marmarth
ME	Medora
MO	Mott
NE	New England
NT	New Town
PR	Pretty Rock
RA	Richardton Abbey
RE	Reeder
REN	Reeder 13 N
TI	Tioga 1 E
TR	Trotters 3 SSE
WAP	Williston WSO AP
WC	Watford City 14 S
WEF	Williston Experiment Farm
	South Dakota Stations
CC	Camp Crook
LE	Lemmon
LU	Ludlow
RAL	Ralph
	Montana Stations
EK	Ekalaka
GL	Glendive
PL	Plevna
WI	Wibaux 2 E

TABLE 26--continued

SYMBOL	VARIABLE
JANTMP-DECTMP	January to December monthly mean temperature
JANPREC-DECPREC	January to December monthly mean precipitation
V.LAT	Latitude
V.LONG	Longitude
V.ALT	Altitude
V.DIST	Distance to 9,000 ft contour
CONRAD	Conrad's index of continentality
TVAR	Temperature range
TMPAVG	Mean annual temperature
PRECTOT	Mean annual precipitation
JANR4-DECR4	January to December estimates of potential solar radiation on sloping surface for middle day of month
JANR3-DECR3	January to December estimates of potential solar radiation on horizontal ground for middle day of month
V.AZIM	Azimuth of ground
V.SA	Slope angle of ground
V.EQL	Equivalent latitude of sloping surface
F	Ratio of R4/R3

TABLE 27

Average Monthly Temperature for North Dakota Stations 1951-80[a]

(Degrees Fahrenheit)

STATION	JANTMP	FEBTMP	MARTMP	APRTMP	MAYTMP	JUNTMP	JULTMP	AUGTMP	SEPTMP	OCTTMP	NOVTMP	DECTMP
AM	11.9	18.8	26.9	40.7	53.0	62.5	69.2	68.4	57.1	46.0	30.2	19.6
BE	12.4	18.4	26.6	40.9	53.0	62.3	69.1	68.3	55.9	45.6	29.5	19.0
BO	11.8	19.3	27.9	41.6	53.6	62.9	69.9	68.4	57.0	46.3	30.3	19.9
DFA	11.0	17.8	26.6	41.2	53.3	62.6	69.7	68.2	56.7	46.0	29.3	18.6
DES	9.3	16.2	25.4	40.5	53.1	62.2	68.6	67.4	55.9	45.0	28.3	17.3
DC	7.4	14.8	23.9	40.3	53.2	62.6	69.0	67.7	56.3	45.2	28.1	15.9
FA	9.5	16.2	26.5	40.7	53.2	62.5	68.9	67.8	56.6	45.6	28.0	17.0
HE	12.2	19.4	27.8	42.5	54.0	63.5	70.2	68.8	57.2	46.3	30.3	19.1
KE	6.0	14.2	26.2	41.2	53.1	66.4	68.8	67.1	57.1	44.7	26.2	15.0
KI	M[b]	M	M	M	M	M	M	M	M	M	M	M
MA	12.6	18.6	28.0	42.4	53.7	63.5	69.9	67.9	56.4	44.7	29.5	19.8
ME	12.1	20.0	28.7	43.0	55.0	64.2	71.0	66.9	57.7	46.2	30.0	19.1
MO	10.7	18.1	27.2	41.7	53.8	63.0	69.1	67.6	56.5	45.6	28.8	17.8
NE	11.7	18.5	27.4	41.6	53.8	63.1	69.4	68.1	56.8	45.7	29.6	18.8
NT	6.8	14.3	26.1	42.0	54.6	63.8	66.9	68.4	57.4	46.6	28.6	15.4
PR	8.4	16.5	28.8	41.8	54.4	63.9	70.5	68.4	57.8	45.6	29.1	16.9
RA	10.7	17.9	27.2	42.3	54.8	63.8	70.2	69.1	57.9	46.8	29.8	18.5
RE	M	M	M	M	M	M	M	M	M	M	M	M
REN	M	M	M	M	M	M	M	M	M	M	M	M
TI	3.1	9.7	22.1	39.1	52.5	61.8	67.4	65.9	54.2	42.6	24.1	11.3
TR	1.4	18.0	27.9	42.0	53.8	63.3	69.6	68.1	57.0	45.9	28.8	17.4
WC	11.1	19.1	29.4	43.7	56.2	65.3	71.7	70.4	59.1	48.3	30.8	19.4
WAP	7.0	15.0	25.7	42.1	54.7	64.0	70.4	68.5	56.8	45.7	28.1	15.5
WEF	7.4	14.9	27.0	42.4	55.2	64.0	70.3	68.9	57.8	46.2	28.1	15.4

[a] (U. S. Department of Commerce 1951-80)

[b] M = Missing

TABLE 28

Average Monthly Precipitation for North Dakota Stations 1951-80[a]

(Inches)

STATION	JANPREC	FEBPREC	MARPREC	APRPREC	MAYPREC	JUNPREC	JULPREC	AUGPREC	SEPPREC	OCTPREC	NOVPREC	DECPREC
AM	0.37	0.37	0.55	1.53	2.54	3.85	2.23	1.49	1.40	0.74	0.42	0.39
BE	0.47	0.39	0.56	1.34	2.00	3.14	1.82	1.56	1.42	0.77	0.56	0.34
BO	0.33	0.42	0.52	1.47	2.43	3.68	2.11	1.63	1.41	0.76	0.42	0.34
DFA	0.41	0.49	0.68	1.71	2.36	3.34	2.06	1.58	1.53	0.76	0.47	0.36
DES	0.34	0.40	0.57	1.73	2.54	3.69	2.08	1.86	1.51	0.85	0.45	0.34
DC	0.40	0.48	0.60	1.60	2.35	3.69	2.17	2.05	1.65	0.87	0.51	0.39
FA	0.33	0.36	0.48	1.44	2.45	3.60	1.99	1.84	1.64	0.77	0.46	0.31
HE	0.31	0.31	0.49	1.68	2.76	3.64	2.04	1.77	1.43	0.85	0.42	0.27
KE	0.35	0.46	0.50	1.40	2.04	3.30	1.90	1.84	1.52	0.74	0.53	0.39
KI	0.51	0.58	0.71	1.72	2.29	3.70	2.18	1.85	1.77	0.91	0.71	0.47
MA	0.38	0.37	0.56	1.34	2.29	3.83	2.14	1.25	1.19	0.78	0.44	0.42
ME	0.43	0.42	0.57	1.41	2.40	3.53	1.96	1.45	1.42	0.75	0.50	0.38
MO	0.39	0.40	0.57	1.65	2.55	3.80	1.99	1.80	1.42	0.70	0.46	0.36
NE	0.39	0.51	0.65	1.75	2.70	3.71	2.13	1.65	1.52	0.77	0.55	0.42
NT	0.42	0.41	0.47	1.33	2.26	3.25	2.07	1.66	1.76	0.63	0.36	0.44
PR	0.29	0.30	0.63	1.65	2.85	3.59	2.22	2.08	1.38	0.88	0.39	0.32
RA	0.47	0.54	0.76	1.81	2.77	3.78	2.35	1.81	1.55	0.81	0.56	0.45
RE	0.32	0.45	0.56	1.62	2.95	4.04	2.36	1.85	1.60	0.85	0.48	0.29
REN	0.25	0.33	0.49	1.29	2.36	3.59	1.98	1.57	1.40	0.74	0.37	0.26
TI	0.38	0.42	0.35	1.27	1.99	2.75	1.79	1.89	1.68	0.69	0.43	0.37
TR	0.35	0.34	0.43	1.19	2.17	3.57	1.70	1.50	1.65	0.76	0.43	0.37
WC	0.36	0.40	0.49	1.45	2.28	3.59	2.16	1.68	1.60	0.80	0.47	0.40
WAP	0.55	0.50	0.57	1.29	1.85	2.68	1.83	1.42	1.37	0.74	0.50	0.55
WEF	0.33	0.36	0.43	1.32	2.23	2.68	1.97	1.56	1.48	0.76	0.44	0.41

[a] (U. S. Department of Commerce 1951-80)

TABLE 29

Other Climatic Variables for North Dakota Stations 1951-80[a]

STATION	V.LAT	V.LONG	V.ALT	V.DIST	CONRAD	TVAR	TMPAVG	PRECTOT
	(DEGREES)		(FT)	(MI)	(INDEX)	(DEGREE F)		(IN)
AM	46.5	103.3	2910	340	51.0	57.3	42.0	15.88
BE	46.9	103.9	2825	335	49.9	56.7	41.8	14.37
BO	46.2	103.4	2980	340	52.1	58.1	42.4	15.52
DFA	46.8	102.8	2581	390	52.2	58.7	41.8	15.75
DES	46.9	102.8	2460	390	52.8	59.3	40.8	16.36
DC	47.3	102.6	2232	415	55.3	61.6	40.4	16.76
FA	47.2	103.2	2750	380	52.9	59.4	41.0	15.67
HE	46.0	102.6	2680	360	52.0	58.0	42.6	15.97
KE	47.8	102.9	2470	425	55.9	62.8	40.5	14.97
KI	47.4	102.8	1895	410	M[b]	M	M	17.40
MA	46.3	103.9	2710	305	51.2	57.3	42.2	14.99
ME	46.9	103.5	2290	360	52.6	58.9	42.8	15.22
MO	46.3	102.3	2420	390	52.2	58.4	41.7	16.09
NE	46.5	102.8	2621	375	51.4	57.7	42.0	16.75
NT	48.0	102.5	1910	450	54.6	61.6	40.9	15.06
PR	46.1	101.8	2480	405	56.7	62.1	41.8	16.58
RA	46.9	102.3	2470	415	53.0	59.5	42.4	17.66
RE	46.1	102.9	2812	355	M	M	M	17.37
REN	46.3	102.9	2755	360	M	M	M	14.63
TI	48.4	102.9	2245	450	57.4	64.3	37.8	14.01
TR	47.3	103.9	2420	355	62.6	68.2	41.1	14.46
WC	47.6	103.3	1965	390	53.9	60.6	43.7	15.68
WAP	48.2	103.6	1899	405	59.9	63.4	41.1	13.85
WEF	48.1	103.6	2105	405	56.1	62.9	41.5	13.97

[a] (U. S. Department of Commerce 1951-80)

[b] M = Missing

TABLE 30

Average Monthly Temperature for South Dakota and Montana Stations 1941-70[a]

(Degrees Fahrenheit)

STATION	JANTMP	FEBTMP	MARTMP	APRTMP	MAYTMP	JUNTMP	JULTMP	AUGTMP	SEPTMP	OCTTMP	NOVTMP	DECTMP
CC	M[b]	M	M	M	M	M	M	M	M	M	M	M
LE	13.9	17.8	26.2	42.0	53.3	62.4	70.2	69.1	57.2	46.7	29.9	19.3
LU	16.7	20.8	27.5	42.4	53.1	61.8	69.7	68.8	57.3	47.1	31.5	22.1
RAL	14.2	18.9	26.7	41.7	52.6	61.2	69.1	67.7	55.9	45.1	29.6	19.6
EK	17.5	22.5	28.6	42.8	53.6	61.9	70.5	69.5	57.5	47.0	31.4	22.9
GL	14.9	20.5	30.4	46.4	57.8	65.9	74.0	72.2	60.2	49.4	33.1	21.9
PL	14.3	19.2	27.3	42.6	53.6	62.1	70.4	69.3	57.3	46.2	30.2	20.2
WI	11.6	18.0	26.5	41.8	52.9	61.4	68.9	67.9	56.1	45.2	29.2	18.6

[a] (U. S. Department of Commerce 1951-80)

[b] M = Missing

TABLE 31

Average Monthly Precipitation for South Dakota and Montana Stations 1941-70[a]

(Inches)

STATION	JANPREC	FEBPREC	MARPREC	APRPREC	MAYPREC	JUNPREC	JULPREC	AUGPREC	SEPPREC	OCTPREC	NOVPREC	DECPREC
CC	0.35	0.33	0.49	1.31	2.23	3.19	1.71	1.53	1.20	0.64	0.40	0.29
LE	0.55	0.49	0.84	1.66	2.56	4.23	2.09	1.95	1.41	0.69	0.59	0.40
LU	0.33	0.35	0.46	1.39	2.31	4.17	1.85	1.64	1.20	0.74	0.48	0.26
RAL	0.28	0.27	0.46	1.28	2.32	3.88	4.16	1.62	1.16	0.71	0.36	0.24
EK	0.46	0.41	0.63	1.30	2.25	3.67	1.89	1.50	1.41	0.73	0.57	0.40
GL	0.43	0.38	0.53	1.26	1.84	3.47	1.88	1.63	1.05	0.60	0.43	0.32
PL	0.41	0.37	0.48	1.42	1.61	3.02	1.97	1.36	1.27	0.67	0.44	0.34
WI	0.36	0.30	0.51	1.25	1.96	3.38	2.17	1.59	1.33	0.66	0.44	0.24

[a] (U. S. Department of Commerce 1951-80)

TABLE 32

Other Climatic Variables for South Dakota and Montana Stations 1941-70[a]

STATION	V.LAT	V.LONG	V.ALT	V.DIST	CONRAD	TVAR	TMPAVG	PRECTOT
	(DEGREES)		(FT)	(MI)	(INDEX)	(DEGREE F)		(IN)
CC	45.6	104.0	3120	280	M[b]	M	M	13.67
LE	45.9	102.2	2596	380	50.3	56.3	42.3	17.46
LU	45.8	103.4	3050	325	46.4	53.0	43.2	15.18
RAL	45.8	103.1	3165	335	48.7	54.9	41.9	16.74
EK	45.9	104.5	3425	265	46.6	53.0	43.8	15.22
GL	47.1	104.7	2076	310	52.4	59.1	45.6	13.82
PL	46.4	104.5	2765	290	49.5	56.1	42.7	13.36
WI	47.0	104.2	2670	330	50.5	57.3	41.5	14.19

[a] (U. S. Department of Commerce 1951-80)

[b] M = Missing

TABLE 33

R4 Computed for Middle of Each Month[a]

(Cal/Cm^2/Day)

STATION	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
AM	268.8	389.5	580.3	785.0	934.0	993.2	960.9	849.8	648.3	454.3	300.9	234.5
BO	299.0	413.9	606.8	801.4	939.2	993.8	966.2	862.1	670.1	483.8	332.7	268.1
DES	269.4	391.2	581.5	785.8	934.3	993.8	961.4	850.7	649.3	455.6	302.6	238.5
DC	192.4	314.8	512.1	737.9	908.4	983.9	947.5	814.5	590.0	382.2	226.4	161.1
FA	240.2	357.8	546.8	752.8	902.4	964.8	935.7	818.6	615.8	422.9	272.3	209.3
HE	296.6	419.3	604.7	800.1	938.5	993.6	963.0	859.1	668.4	481.7	330.4	266.0
NE	279.7	402.4	591.3	791.3	936.6	994.2	962.4	854.2	657.6	466.3	311.9	248.7
RA	230.3	352.5	550.3	763.5	924.1	990.3	958.2	834.0	620.9	418.8	264.0	198.0
WC	293.4	415.5	600.0	798.4	938.5	993.1	965.6	859.1	667.2	478.7	325.2	262.2

[a] After Method by Swift 1976

TABLE 34

R3 Computed for Middle of Each Month[a]

(Cal/Cm^2/Day)

STATION	JANR3	FEBR3	MARR3	APRR3	MAYR3	JUNR3	JULR3	AUGR3	SEPR3	OCTR3	NOVR3	DECR3
AM	268.9	392.6	582.4	786.6	932.3	994.2	962.0	851.2	650.3	457.2	301.8	238.4
BO	275.1	397.1	586.1	789.1	934.3	992.3	963.2	851.4	653.4	461.3	306.9	244.1
DES	265.0	389.0	577.8	783.2	933.7	994.0	964.4	849.2	646.2	451.6	299.9	234.1
DC	257.9	382.1	572.9	779.7	930.3	993.2	960.5	845.6	642.0	445.9	290.4	226.5
FA	259.8	383.5	574.1	780.6	931.0	993.7	961.1	846.1	643.1	447.4	292.2	228.4
HE	278.5	400.2	588.5	789.4	935.2	993.3	964.3	852.8	655.5	464.2	310.1	244.5
NE	269.4	392.6	582.4	786.6	932.3	994.2	962.0	851.2	650.3	457.2	301.8	238.4
RA	265.0	386.4	577.8	783.2	933.7	994.0	961.3	849.2	646.2	451.6	299.9	234.1
WC	255.1	377.3	569.2	777.0	930.9	991.7	961.9	843.3	638.9	441.7	288.1	224.2

[a] After Method by Swift 1976

TABLE 35

Slope Variables

(Degrees)

STATION	AZIM	SA	EQL
AM	57.0	0.4	46.7
BO	218.0	2.1	44.5
DES	162.5	0.3	46.6
DC	319.0	6.3	51.9
FA	40.0	3.0	49.5
HE	105.5	4.8	44.5
NE	159.0	0.8	45.8
RA	11.0	2.4	49.3
WC	221.0	3.6	44.8

APPENDIX C

CORRELATION RESULTS

TABLE 36

Pearson Correlation Coefficients and Probabilities for Monthly Temperature

N = 28

	JANTMP	FEBTMP	MARTMP	APRTMP	MAYTMP	JUNTMP	JULTMP	AUGTMP	SEPTMP	OCTTMP	NOVTMP	DECTMP
JANTMP	1.00000 0.0000	0.80993 0.0001	0.50268 0.0064	0.46178 0.0134	0.07362 0.7097	-0.24549 0.2080	0.44780 0.0169	0.48619 0.0087	0.31658 0.1007	0.50468 0.0062	0.78895 0.0001	0.88263 0.0001
FEBTMP	. .	1.00000 0.0000	0.78934 0.0001	0.60797 0.0006	0.22213 0.2559	-0.07641 0.6991	0.58990 0.0010	0.54912 0.0025	0.49407 0.0075	0.64963 0.0002	0.91645 0.0001	0.97185 0.0001
MARTMP	. .	. .	1.00000 0.0000	0.82552 0.0001	0.63405 0.0003	0.42803 0.0231	0.76299 0.0001	0.67597 0.0001	0.80320 0.0001	0.75691 0.0001	0.80788 0.0001	0.72668 0.0001
APRTMP	. .	. .	. .	1.00000 0.0000	0.83737 0.0001	0.52384 0.0042	0.84918 0.0001	0.82939 0.0001	0.87240 0.0001	0.84469 0.0001	0.75906 0.0001	0.60086 0.0007
MAYTMP	. .	. .	. .	. .	1.00000 0.0000	0.73510 0.0001	0.75868 0.0001	0.72304 0.0001	0.86075 0.0001	0.74549 0.0001	0.46532 0.0126	0.19155 0.3288
JUNTMP	. .	. .	. .	. .	. .	1.00000 0.0000	0.47714 0.0102	0.35563 0.0633	0.67168 0.0001	0.40016 0.0349	0.06060 0.7594	-0.12725 0.5188
JULTMP	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.77680 0.0001	0.80201 0.0001	0.74431 0.0001	0.70254 0.0001	0.57859 0.0013
AUGTMP	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.84108 0.0001	0.90899 0.0001	0.78041 0.0001	0.60816 0.0006
SEPTMP	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.90951 0.0001	0.69130 0.0001	0.48135 0.0095
OCTTMP	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.84382 0.0001	0.66033 0.0001
NOVTMP	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.93310 0.0001
DECTMP	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000

TABLE 37

Pearson Correlation Coefficients and Probabilities Between Monthly Temperature and Monthly Precipitation

N = 28

	JANPREC	FEBPREC	MARPREC	APRPREC	MAYPREC	JUNPREC	JULPREC	AUGPREC	SEPPREC	OCTPREC	NOVPREC	DECPREC
JANTMP	0.12745 0.5181	-0.12690 0.5199	0.33829 0.0783	0.12040 0.5417	0.06395 0.7465	0.49263 0.0077	0.24460 0.2097	-0.27805 0.1520	-0.69203 0.0001	-0.17940 0.3610	0.22084 0.2588	-0.34018 0.0765
FEBTMP	0.02593 0.8958	-0.21760 0.2660	0.27319 0.1595	0.04954 0.8023	0.12874 0.5138	0.55540 0.0022	0.12301 0.5329	-0.43363 0.0211	-0.58380 0.0011	-0.04563 0.8177	0.16101 0.4131	-0.30308 0.1169
MARTMP	-0.10101 0.6090	-0.27497 0.1567	0.13679 0.4876	-0.03838 0.8463	0.12727 0.5187	0.31297 0.1049	-0.00247 0.9901	-0.35474 0.0640	-0.47920 0.0099	-0.03509 0.8593	-0.04961 0.8020	-0.13981 0.4780
APRTMP	0.15994 0.4162	-0.12672 0.5205	0.07470 0.7056	-0.21032 0.2827	-0.18852 0.3367	0.10272 0.6030	-0.04872 0.8055	-0.34651 0.0709	-0.53506 0.0034	-0.32730 0.0891	-0.02417 0.9028	-0.01027 0.9587
MAYTMP	0.18560 0.3444	0.08456 0.6688	0.03823 0.8468	-0.08621 0.6627	-0.09031 0.6477	-0.15820 0.4214	-0.19408 0.3224	-0.12815 0.5158	-0.16369 0.4052	-0.14850 0.4508	-0.06459 0.7440	0.27778 0.1524
JUNTMP	0.07007 0.7231	0.23500 0.2287	0.00264 0.9894	-0.01405 0.9434	-0.04614 0.8157	-0.19233 0.3268	-0.28145 0.1468	0.03470 0.8608	0.05640 0.7756	0.02828 0.8864	0.04853 0.8063	0.39461 0.0377
JULTMP	0.17739 0.3665	-0.01645 0.9338	0.23099 0.2369	-0.02750 0.8895	-0.09512 0.6302	0.10108 0.6088	-0.09129 0.6441	-0.22229 0.2556	-0.55384 0.0022	-0.02952 0.8815	0.15175 0.4408	0.00803 0.9677
AUGTMP	0.22543 0.2487	-0.02939 0.8820	0.19448 0.3214	-0.04724 0.8113	-0.14255 0.4693	0.11845 0.5483	-0.08125 0.6811	-0.17342 0.3775	-0.40232 0.0338	-0.22436 0.2511	0.06189 0.7544	0.02151 0.9135
SEPTMP	0.10635 0.5901	0.02423 0.9026	0.18612 0.3430	0.02268 0.9088	0.02818 0.8868	0.14187 0.4714	-0.13896 0.4807	-0.11054 0.5755	-0.26010 0.1813	-0.10962 0.5787	0.03526 0.8586	0.12048 0.5414
OCTTMP	0.21285 0.2768	0.02964 0.8810	0.23170 0.2355	0.02513 0.8990	0.00842 0.9661	0.26227 0.1776	-0.10160 0.6069	-0.16300 0.4072	-0.28988 0.1346	-0.19679 0.3155	0.10490 0.5953	0.01432 0.9423
NOVTMP	0.10449 0.5967	-0.16729 0.3948	0.29487 0.1277	0.05927 0.7645	0.09406 0.6340	0.49348 0.0076	0.09471 0.6316	-0.34413 0.0729	-0.59282 0.0009	-0.12178 0.5370	0.06406 0.7461	-0.22430 0.2512
DECTMP	0.06229 0.7529	-0.19119 0.3298	0.29686 0.1250	0.03801 0.8477	0.06722 0.7340	0.58193 0.0012	0.14160 0.4723	-0.40648 0.0318	-0.64920 0.0002	-0.11670 0.5543	0.16650 0.3971	-0.32154 0.0952

TABLE 38

Pearson Correlation Coefficients and Probabilities Between Monthly Temperature and Other Climatic Variables

N = 28

	V.LAT	V.LONG	V.ALT	V.DIST	CONRAD	TVAR	TMPAVG	PRECTOT
JANTMP	-0.74229 0.0001	0.30843 0.1103	0.60010 0.0007	-0.73707 0.0001	-0.91958 0.0001	-0.94674 0.0001	0.76437 0.0001	0.15819 0.4214
FEBTMP	-0.73974 0.0001	0.41567 0.0278	0.55148 0.0024	-0.82290 0.0001	-0.64488 0.0002	-0.68689 0.0001	0.87836 0.0001	0.11782 0.5504
MARTMP	-0.42288 0.0250	0.33463 0.0818	0.13487 0.4938	-0.54933 0.0025	-0.24493 0.2090	-0.26956 0.1654	0.88494 0.0001	-0.02180 0.9123
APRTMP	-0.15331 0.4360	0.44566 0.0175	-0.17176 0.3821	-0.43872 0.0195	-0.16458 0.4026	-0.18079 0.3572	0.87052 0.0001	-0.21810 0.2649
MAYTMP	0.25163 0.1965	0.20547 0.2942	-0.58597 0.0011	0.01034 0.9583	0.22075 0.2590	0.22120 0.2580	0.60494 0.0007	-0.18772 0.3388
JUNTMP	0.41123 0.0297	-0.03369 0.8649	-0.61068 0.0006	0.29579 0.1264	0.44531 0.0176	0.46293 0.0131	0.26842 0.1672	-0.12615 0.5224
JULTMP	-0.21085 0.2815	0.39744 0.0362	-0.09871 0.6172	-0.44661 0.0172	-0.09886 0.6167	-0.14413 0.4643	0.82459 0.0001	-0.11233 0.5693
AUGTMP	-0.16853 0.3913	0.37143 0.0516	-0.07747 0.6952	-0.40523 0.0324	-0.22331 0.2534	-0.23655 0.2255	0.82989 0.0001	-0.10419 0.5977
SEPTMP	-0.06154 0.7558	0.19983 0.3079	-0.25933 0.1827	-0.19676 0.3156	-0.03449 0.8617	-0.03439 0.8621	0.80629 0.0001	-0.02334 0.9062
OCTTMP	-0.20249 0.3014	0.26817 0.1677	-0.09532 0.6295	-0.33998 0.0767	-0.25404 0.1921	-0.26120 0.1794	0.88042 0.0001	0.01662 0.9331
NOVTMP	-0.61213 0.0005	0.37331 0.0504	0.31492 0.1026	-0.70297 0.0001	-0.56913 0.0016	-0.60599 0.0006	0.95712 0.0001	0.09733 0.6222
DECTMP	-0.75478 0.0001	0.43995 0.0191	0.58702 0.0010	-0.85050 0.0001	-0.73486 0.0001	-0.76939 0.0001	0.88674 0.0001	0.11191 0.5707

TABLE 39

Pearson Correlation Coefficients and Probabilities for Monthly Precipitation

N = 32

	JANPREC	FEBPREC	MARPREC	APRPREC	MAYPREC	JUNPREC	JULPREC	AUGPREC	SEPPREC	OCTPREC	NOVPREC	DECPREC
JANPREC	1.00000 0.0000	0.69710 0.0001	0.59986 0.0003	0.14265 0.4361	-0.27528 0.1273	-0.12867 0.4828	-0.25905 0.1522	-0.08034 0.6620	0.13028 0.4773	-0.11356 0.5360	0.69870 0.0001	0.71381 0.0001
FEBPREC	. .	1.00000 0.0000	0.63884 0.0001	0.52608 0.0020	0.10375 0.5720	0.03207 0.8617	-0.18533 0.3099	0.24037 0.1851	0.50313 0.0033	0.28658 0.1118	0.77005 0.0001	0.72920 0.0001
MARPREC	. .	. .	1.00000 0.0000	0.68768 0.0001	0.41643 0.0177	0.44235 0.0112	0.05366 0.7705	0.27442 0.1285	0.08423 0.6467	0.31771 0.0764	0.66136 0.0001	0.38791 0.0283
APRPREC	. .	. .	. .	1.00000 0.0000	0.70373 0.0001	0.44656 0.0104	0.09780 0.5944	0.54667 0.0012	0.32789 0.0669	0.60692 0.0002	0.41748 0.0174	0.17540 0.3369
MAYPREC	. .	. .	. .	. .	1.00000 0.0000	0.63836 0.0001	0.24635 0.1741	0.48543 0.0049	0.25039 0.1669	0.57150 0.0006	0.04192 0.8198	-0.10640 0.5622
JUNPREC	. .	. .	. .	. .	. .	1.00000 0.0000	0.34629 0.0522	0.27384 0.1294	-0.09431 0.6077	0.29102 0.1061	0.17642 0.3341	-0.27117 0.1333
JULPREC	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.09934 0.5885	-0.17688 0.3328	0.10463 0.5687	-0.18584 0.3085	-0.25150 0.1650
AUGPREC	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.45758 0.0085	0.43200 0.0135	0.20573 0.2586	-0.08594 0.6400
SEPPREC	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.44665 0.0104	0.32251 0.0718	0.41257 0.0189
OCTPREC	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.37093 0.0366	0.15000 0.4126
NOVPREC	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.50652 0.0031
DECPREC	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000

TABLE 40

Pearson Correlation Coefficients and Probabilities Between Monthly Precipitation and Other Climatic Variables

N = 32 or 28

	V.LAT	V.LONG	V.ALT	V.DIST	CONRAD	TVAR	TMPAVG	PRECTOT
JANPREC	0.26211 0.1473 32	0.08927 0.6271 32	-0.34676 0.0519 32	0.10437 0.5697 32	-0.00921 0.9629 28	-0.06450 0.7444 28	0.12651 0.5212 28	0.05895 0.7486 32
FEBPREC	0.33081 0.0644 32	-0.30028 0.0949 32	-0.41297 0.0188 32	0.44762 0.0102 32	0.14976 0.4469 28	0.13578 0.4909 28	-0.12063 0.5409 28	0.42213 0.0161 32
MARPREC	-0.27176 0.1324 32	-0.37624 0.0338 32	-0.02923 0.8738 32	0.08297 0.6517 32	-0.23909 0.2205 28	-0.29637 0.1257 28	0.27707 0.1535 28	0.65571 0.0001 32
APRPREC	-0.22767 0.2101 32	-0.69012 0.0001 32	-0.08920 0.6273 32	0.34539 0.0528 32	-0.14294 0.4681 28	-0.15523 0.4303 28	0.01720 0.9308 28	0.79839 0.0001 32
MAYPREC	-0.43185 0.0136 32	-0.70228 0.0001 32	0.17856 0.3282 32	0.21275 0.2424 32	-0.09075 0.6460 28	-0.10981 0.5780 28	0.02693 0.8918 28	0.80312 0.0001 32
JUNPREC	-0.65644 0.0001 32	-0.32277 0.0716 32	0.38532 0.0294 32	-0.21341 0.2409 32	-0.49731 0.0071 28	-0.51536 0.0050 28	0.39305 0.0385 28	0.72708 0.0001 32
JULPREC	-0.27573 0.1266 32	-0.22517 0.2153 32	0.22965 0.2061 32	-0.01528 0.9339 32	-0.28884 0.1360 28	-0.30585 0.1135 28	0.03633 0.8544 28	0.46859 0.0068 32
AUGPREC	0.07152 0.6973 32	-0.73728 0.0001 32	-0.22357 0.2187 32	0.59987 0.0003 32	0.18402 0.3486 28	0.22038 0.2598 28	-0.34368 0.0733 28	0.61135 0.0002 32
SEPPREC	0.55221 0.0011 32	-0.48597 0.0048 32	-0.46182 0.0078 32	0.71959 0.0001 32	0.51795 0.0048 28	0.58073 0.0012 28	-0.61190 0.0005 28	0.35284 0.0476 32
OCTPREC	-0.01999 0.9135 32	-0.47540 0.0060 32	-0.12043 0.5115 32	0.31530 0.0788 32	0.19276 0.3257 28	0.15745 0.4236 28	-0.15473 0.4318 28	0.61888 0.0002 32
NOVPREC	0.10342 0.5732 32	-0.07787 0.6718 32	-0.15489 0.3973 32	0.12373 0.4999 32	-0.19711 0.3147 28	-0.21374 0.2748 28	0.12542 0.5248 28	0.39869 0.0238 32
DECPREC	0.55203 0.0011 32	-0.11704 0.5235 32	-0.57775 0.0005 32	0.43731 0.0123 32	0.44506 0.0176 28	0.39642 0.0368 28	-0.14849 0.4508 28	0.09123 0.6195 32

TABLE 41

Pearson Correlation Coefficients and Probabilities for Other Climatic Variables

N = 32 or 28

	V.LAT	V.LONG	V.ALT	V.DIST	CONRAD	TVAR	TMPAVG	PRECTOT
V.LAT	1.00000 0.0000 32	0.00071 0.9969 32	-0.79194 0.0001 32	0.67368 0.0001 32	0.70797 0.0001 28	0.76140 0.0001 28	-0.51005 0.0056 28	-0.29857 0.0969 32
V.LONG	. .	1.00000 0.0000 32	0.24282 0.1805 32	-0.73411 0.0001 32	-0.20601 0.2929 28	-0.20301 0.3002 28	0.40843 0.0309 28	-0.72407 0.0001 32
V.ALT	. .	. .	1.00000 0.0000 32	-0.71100 0.0001 32	-0.70753 0.0001 28	-0.72702 0.0001 28	0.21557 0.2706 28	0.02926 0.8737 32
V.DIST	. .	. .	. .	1.00000 0.0000 32	0.63387 0.0003 28	0.66920 0.0001 28	-0.66034 0.0001 28	0.32230 0.0720 32
CONRAD	. .	. .	. .	. .	1.00000 0.0000 28	0.98359 0.0001 28	-0.50805 0.0058 28	-0.20364 0.2986 28
TVAR	. .	. .	. .	. .	. .	1.00000 0.0000 28	-0.53699 0.0032 28	-0.22270 0.2547 28
TMPAVG	. .	. .	. .	. .	. .	. .	1.00000 0.0000 28	0.02212 0.9111 28
PRECTOT	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000 32

TABLE 42

Pearson Correlation Coefficients and Probabilities Between Monthly Temperature and Monthly R4

N = 9

	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
JANTMP	0.82647 0.0060	0.82763 0.0059	0.84342 0.0043	0.83017 0.0056	0.76128 0.0172	0.51488 0.1561	0.66059 0.0528	0.80748 0.0085	0.83257 0.0053	0.82891 0.0057	0.82583 0.0061	0.81523 0.0074
FEBTMP	0.83805 0.0048	0.84009 0.0046	0.85708 0.0032	0.85604 0.0032	0.80269 0.0092	0.57915 0.1022	0.73758 0.0233	0.84305 0.0043	0.85432 0.0034	0.84496 0.0041	0.83866 0.0047	0.82832 0.0058
MARTMP	0.78041 0.0131	0.77998 0.0132	0.77366 0.0144	0.74755 0.0206	0.62527 0.0717	0.32975 0.3862	0.55187 0.1234	0.70802 0.0328	0.76985 0.0152	0.77783 0.0136	0.77540 0.0141	0.77679 0.0138
APRTMP	0.52934 0.1428	0.55231 0.1231	0.54264 0.1312	0.54932 0.1255	0.51859 0.1526	0.37919 0.3142	0.53137 0.1410	0.53810 0.1351	0.55265 0.1228	0.54082 0.1327	0.52922 0.1429	0.53221 0.1402
MAYTMP	0.29033 0.4485	0.31585 0.4077	0.30351 0.4272	0.32260 0.3972	0.33517 0.3779	0.27462 0.4745	0.39621 0.2911	0.32693 0.3905	0.32225 0.3977	0.30334 0.4275	0.28692 0.4541	0.29301 0.4442
JUNTMP	0.32834 0.3883	0.35494 0.3486	0.33784 0.3739	0.35609 0.3469	0.35782 0.3444	0.28644 0.4549	0.40843 0.2751	0.35606 0.3470	0.35738 0.3451	0.34090 0.3693	0.32494 0.3935	0.33010 0.3856
JULTMP	0.44520 0.2298	0.46156 0.2111	0.45479 0.2187	0.47133 0.2003	0.45711 0.2161	0.35659 0.3462	0.50243 0.1681	0.47036 0.2013	0.47144 0.2002	0.45709 0.2161	0.44452 0.2306	0.44530 0.2297
AUGTMP	0.39621 0.2911	0.41517 0.2665	0.40576 0.2786	0.42378 0.2557	0.42108 0.2590	0.32525 0.3931	0.46206 0.2105	0.42314 0.2565	0.42252 0.2572	0.40580 0.2785	0.39245 0.2961	0.39062 0.2986
SEPTMP	0.33216 0.3825	0.34781 0.3590	0.33900 0.3722	0.35153 0.3536	0.34525 0.3628	0.24944 0.5175	0.38864 0.3013	0.34866 0.3578	0.35374 0.3503	0.33934 0.3717	0.32635 0.3914	0.32528 0.3930
OCTTMP	0.41736 0.2637	0.42746 0.2511	0.41986 0.2606	0.42834 0.2500	0.39975 0.2864	0.27178 0.4793	0.43457 0.2425	0.42121 0.2589	0.43366 0.2436	0.42328 0.2563	0.41285 0.2694	0.41259 0.2698
NOVTMP	0.70385 0.0343	0.71403 0.0307	0.73502 0.0241	0.76312 0.0167	0.78066 0.0130	0.65779 0.0541	0.78250 0.0127	0.77694 0.0138	0.74599 0.0210	0.71945 0.0289	0.70501 0.0339	0.69179 0.0390
DECTMP	0.82068 0.0067	0.81530 0.0074	0.84247 0.0044	0.84763 0.0039	0.81237 0.0078	0.60291 0.0857	0.75940 0.0176	0.84502 0.0041	0.84128 0.0045	0.82745 0.0059	0.82028 0.0068	0.80718 0.0085

TABLE 43

Pearson Correlation Coefficients and Probabilities Between Monthly Temperature and Monthly R3

N = 9

	JANR3	FEBR3	MARR3	APRR3	MAYR3	JUNR3	JULR3	AUGR3	SEPR3	OCTR3	NOVR3	DECR3
JANTMP	0.67516 0.0460	0.61806 0.0761	0.65769 0.0542	0.65421 0.0559	0.57526 0.1051	-0.07287 0.8522	0.43270 0.2447	0.61759 0.0764	0.66232 0.0519	0.66289 0.0517	0.65918 0.0535	0.69040 0.0395
FEBTMP	0.58462 0.0983	0.50993 0.1608	0.55324 0.1223	0.54263 0.1312	0.52338 0.1482	-0.29280 0.4445	0.40195 0.2835	0.48161 0.1893	0.55753 0.1188	0.55752 0.1188	0.56164 0.1156	0.59494 0.0910
MARTMP	0.23250 0.5472	0.13798 0.7233	0.18160 0.6401	0.16571 0.6701	0.27425 0.4751	-0.47502 0.1963	0.22912 0.5532	0.09471 0.8085	0.18630 0.6313	0.18596 0.6319	0.20821 0.5909	0.23469 0.5433
APRTMP	0.03272 0.9334	-0.08434 0.8292	-0.03929 0.9201	-0.08319 0.8315	0.19898 0.6078	-0.58028 0.1014	0.13152 0.7359	-0.12546 0.7477	-0.03707 0.9246	-0.03777 0.9231	0.02272 0.9537	0.00049 0.9990
MAYTMP	-0.30283 0.4283	-0.41415 0.2678	-0.36937 0.3279	-0.40128 0.2844	-0.07193 0.8541	-0.59940 0.0880	-0.10199 0.7940	-0.42168 0.2583	-0.36783 0.3301	-0.36845 0.3292	-0.29555 0.4400	-0.32163 0.3987
JUNTMP	-0.24611 0.5232	-0.35569 0.3475	-0.30887 0.4187	-0.34722 0.3599	-0.07627 0.8454	-0.62899 0.0696	-0.09967 0.7986	-0.38250 0.3096	-0.30642 0.4226	-0.30695 0.4217	-0.25746 0.5036	-0.27356 0.4763
JULTMP	-0.08385 0.8302	-0.19795 0.6097	-0.14967 0.7007	-0.18798 0.6281	0.05566 0.8869	-0.71087 0.0318	0.00286 0.9942	-0.25532 0.5073	-0.14733 0.7052	-0.14834 0.7033	-0.10604 0.7860	-0.10832 0.7815
AUGTMP	-0.14497 0.7098	-0.25501 0.5078	-0.20087 0.6043	-0.23336 0.5456	-0.00380 0.9923	-0.60946 0.0814	-0.07300 0.8520	-0.27643 0.4715	-0.19786 0.6098	-0.19832 0.6090	-0.15553 0.6895	-0.16031 0.6803
SEPTMP	-0.21357 0.5811	-0.32270 0.3970	-0.26248 0.4950	-0.28605 0.4556	-0.07997 0.8380	-0.56720 0.1112	-0.18099 0.6412	-0.32436 0.3945	-0.25919 0.5006	-0.25949 0.5001	-0.22168 0.5665	-0.21975 0.5700
OCTTMP	-0.17119 0.6597	-0.28199 0.4623	-0.22873 0.5539	-0.25427 0.5091	-0.02310 0.9530	-0.65624 0.0549	-0.08600 0.8259	-0.31243 0.4130	-0.22577 0.5592	-0.22651 0.5578	-0.18354 0.6364	-0.17839 0.6461
NOVTMP	0.40491 0.2797	0.31848 0.4036	0.37045 0.3264	0.35673 0.3460	0.38656 0.3041	-0.42741 0.2512	0.25830 0.5022	0.29889 0.4346	0.37416 0.3212	0.37397 0.3214	0.38720 0.3032	0.41564 0.2659
DECTMP	0.54746 0.1271	0.48138 0.1895	0.52414 0.1475	0.53070 0.1416	0.49306 0.1774	-0.27709 0.4704	0.37593 0.3187	0.47121 0.2004	0.52819 0.1438	0.52814 0.1439	0.53623 0.1367	0.58128 0.1007

TABLE 44

Pearson Correlation Coefficients and Probabilities Between Monthly Precipitation and Monthly R4

N = 9

	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
JANPREC	-0.57861 0.1026	-0.55457 0.1212	-0.51272 0.1581	-0.45295 0.2208	-0.21029 0.5871	0.10520 0.7877	-0.03204 0.9348	-0.37535 0.3195	-0.49944 0.1710	-0.55361 0.1220	-0.57917 0.1022	-0.58851 0.0955
FEBPREC	-0.46525 0.2070	-0.45339 0.2203	-0.40212 0.2833	-0.34990 0.3560	-0.13517 0.7288	0.15150 0.6972	0.03574 0.9273	-0.27103 0.4806	-0.38948 0.3001	-0.43771 0.2387	-0.46367 0.2087	-0.46493 0.2073
MARPREC	-0.45578 0.2176	-0.43091 0.2469	-0.37518 0.3198	-0.31699 0.4059	-0.06748 0.8631	0.23619 0.5406	0.08251 0.8329	-0.23612 0.5408	-0.37001 0.3270	-0.42719 0.2515	-0.45154 0.2224	-0.46181 0.2108
APRPREC	-0.16947 0.6629	-0.12276 0.7530	-0.08997 0.8179	-0.03579 0.9272	0.17493 0.6526	0.40328 0.2818	0.24050 0.5331	0.02508 0.9489	-0.08772 0.8224	-0.13990 0.7196	-0.16032 0.6803	-0.16766 0.6663
MAYPREC	0.12134 0.7558	0.14958 0.7009	0.17512 0.6522	0.17716 0.6484	0.24735 0.5211	0.27092 0.4807	0.21011 0.5874	0.18316 0.6372	0.15343 0.6935	0.13304 0.7329	0.12880 0.7412	0.11785 0.7627
JUNPREC	-0.19879 0.6081	-0.18977 0.6248	-0.13255 0.7339	-0.07025 0.8575	0.15086 0.6984	0.37395 0.3215	0.22519 0.5602	0.00492 0.9900	-0.12741 0.7439	-0.18048 0.6422	-0.19773 0.6101	-0.22467 0.5611
JULPREC	-0.30894 0.4186	-0.28805 0.4523	-0.23253 0.5471	-0.15142 0.6974	0.11254 0.7731	0.39832 0.2883	0.29318 0.4439	-0.05942 0.8793	-0.21237 0.5833	-0.27968 0.4661	-0.30774 0.4205	-0.32821 0.3885
AUGPREC	-0.71846 0.0292	-0.70846 0.0327	-0.72416 0.0274	-0.71814 0.0293	-0.66538 0.0505	-0.43826 0.2380	-0.56897 0.1099	-0.70643 0.0334	-0.72118 0.0283	-0.71580 0.0301	-0.71022 0.0320	-0.69857 0.0363
SEPPREC	-0.66422 0.0510	-0.65599 0.0550	-0.70014 0.0357	-0.71939 0.0289	-0.73922 0.0229	-0.63676 0.0652	-0.67531 0.0459	-0.73591 0.0238	-0.69238 0.0387	-0.67304 0.0469	-0.67236 0.0472	-0.65016 0.0580
OCTPREC	-0.36973 0.3274	-0.33204 0.3827	-0.34486 0.3634	-0.29584 0.4396	-0.17133 0.6594	0.07123 0.8555	-0.07497 0.8480	-0.25784 0.5030	-0.32663 0.3910	-0.35030 0.3554	-0.35670 0.3460	-0.35313 0.3512
NOVPREC	-0.51646 0.1546	-0.48692 0.1837	-0.47137 0.2002	-0.44197 0.2336	-0.28137 0.4633	-0.04834 0.9017	-0.15924 0.6824	-0.39597 0.2914	-0.46311 0.2093	-0.49627 0.1742	-0.51910 0.1521	-0.51201 0.1588
DECPREC	-0.33206 0.3827	-0.30991 0.4170	-0.27341 0.4765	-0.20642 0.5941	0.02065 0.9580	0.26713 0.4871	0.17582 0.6509	-0.12562 0.7474	-0.24859 0.5189	-0.30609 0.4231	-0.33882 0.3724	-0.34495 0.3633

TABLE 45

Pearson Correlation Coefficients and Probabilities Between Monthly Precipitation and Monthly R3

N = 9

	JANR3	FEBR3	MARR3	APRR3	MAYR3	JUNR3	JULR3	AUGR3	SEPR3	OCTR3	NOVR3	DECR3
JANPREC	-0.32971 0.3862	-0.36540 0.3335	-0.30568 0.4237	-0.27163 0.4795	-0.21187 0.5842	0.31075 0.4157	-0.60768 0.0826	-0.15860 0.6836	-0.30802 0.4200	-0.30693 0.4218	-0.25526 0.5074	-0.28688 0.4542
FEBPREC	-0.25923 0.5006	-0.28108 0.4638	-0.23687 0.5395	-0.18649 0.6309	-0.19288 0.6190	0.20172 0.6027	-0.50908 0.1616	-0.11674 0.7649	-0.23964 0.5346	-0.23928 0.5352	-0.20366 0.5992	-0.20321 0.6000
MARPREC	-0.04253 0.9135	-0.06550 0.8670	-0.02070 0.9578	0.01665 0.9661	0.08828 0.8213	0.50669 0.1639	-0.32323 0.3962	0.15260 0.6951	-0.02449 0.9501	-0.02339 0.9524	0.05181 0.8947	0.00296 0.9940
APRPREC	0.27401 0.4756	0.26570 0.4896	0.27189 0.4791	0.26738 0.4867	0.44203 0.2335	0.61164 0.0801	0.21429 0.5798	0.43114 0.2466	0.26769 0.4862	0.26907 0.4839	0.37094 0.3257	0.26999 0.4823
MAYPREC	0.63542 0.0659	0.61034 0.0809	0.63550 0.0659	0.62178 0.0738	0.67268 0.0471	0.65411 0.0560	0.31571 0.4079	0.73859 0.0230	0.63413 0.0666	0.63567 0.0658	0.69445 0.0379	0.61991 0.0750
JUNPREC	0.26664 0.4880	0.29357 0.4433	0.32734 0.3899	0.37895 0.3145	0.18840 0.6274	0.61075 0.0806	-0.11494 0.7684	0.48669 0.1840	0.32681 0.3907	0.32869 0.3878	0.33599 0.3767	0.33896 0.3722
JULPREC	-0.14756 0.7048	-0.19626 0.6128	-0.13199 0.7350	-0.09908 0.7998	-0.02287 0.9534	0.14896 0.7021	-0.39913 0.2873	-0.00989 0.9799	-0.13371 0.7316	-0.13293 0.7332	-0.07017 0.8576	-0.09088 0.8161
AUGPREC	-0.42888 0.2494	-0.41018 0.2729	-0.44461 0.2305	-0.47800 0.1931	-0.26022 0.4989	0.02614 0.9468	-0.22808 0.5550	-0.44360 0.2317	-0.45080 0.2233	-0.45194 0.2220	-0.41530 0.2663	-0.48935 0.1812
SEPPREC	-0.86795 0.0024	-0.86514 0.0026	-0.86945 0.0023	-0.87817 0.0018	-0.76409 0.0165	-0.11837 0.7617	-0.66654 0.0499	-0.85907 0.0030	-0.87032 0.0023	-0.87039 0.0023	-0.87775 0.0019	-0.89786 0.0010
OCTPREC	-0.15975 0.6814	-0.15827 0.6842	-0.19946 0.6069	-0.26027 0.4988	0.06622 0.8656	-0.06149 0.8751	0.18885 0.6265	-0.20382 0.5989	-0.20545 0.5959	-0.20635 0.5943	-0.13050 0.7379	-0.23745 0.5384
NOVPREC	-0.37778 0.3161	-0.40424 0.2806	-0.36141 0.3393	-0.33793 0.3738	-0.30163 0.4302	0.29717 0.4374	-0.57211 0.1075	-0.23740 0.5385	-0.36274 0.3373	-0.36154 0.3391	-0.33142 0.3836	-0.36040 0.3407
DECPREC	-0.41212 0.2704	-0.43825 0.2380	-0.38163 0.3108	-0.32767 0.3894	-0.35910 0.3426	0.13915 0.7211	-0.58352 0.0990	-0.24303 0.5286	-0.38114 0.3115	-0.37977 0.3134	-0.35336 0.3509	-0.33931 0.3717

TABLE 46

Pearson Correlation Coefficients and Probabilities Between Other Climatic Variables and Monthly R4

N = 9

	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
V.LAT	-0.51265 0.1582	-0.50395 0.1666	-0.54354 0.1304	-0.53835 0.1348	-0.52286 0.1486	-0.43385 0.2433	-0.44536 0.2296	-0.53632 0.1366	-0.52277 0.1487	-0.51910 0.1521	-0.52475 0.1469	-0.50853 0.1621
V.LONG	0.48307 0.1877	0.43837 0.2379	0.42114 0.2590	0.37608 0.3185	0.18465 0.6344	-0.10533 0.7874	0.07662 0.8447	0.32666 0.3909	0.41910 0.2615	0.45812 0.2149	0.47159 0.2000	0.47596 0.1953
V.ALT	0.27277 0.4776	0.22913 0.5532	0.26288 0.4944	0.21126 0.5853	0.10065 0.7967	-0.06459 0.8689	-0.01328 0.9729	0.17576 0.6510	0.22603 0.5587	0.25492 0.5080	0.27642 0.4715	0.26357 0.4932
V.DIST	-0.70758 0.0330	-0.67604 0.0456	-0.68554 0.0415	-0.65227 0.0569	-0.51071 0.1600	-0.24262 0.5293	-0.36671 0.3317	-0.61374 0.0787	-0.67013 0.0483	-0.69384 0.0382	-0.70691 0.0332	-0.69653 0.0371
CONRAD	-0.63150 0.0681	-0.62465 0.0721	-0.64220 0.0622	-0.61453 0.0783	-0.54455 0.1295	-0.31961 0.4018	-0.39428 0.2937	-0.58714 0.0965	-0.61957 0.0752	-0.62468 0.0721	-0.62843 0.0699	-0.61740 0.0765
TVAR	-0.62829 0.0700	-0.61866 0.0757	-0.64086 0.0629	-0.61498 0.0780	-0.54733 0.1272	-0.33850 0.3729	-0.40431 0.2805	-0.59022 0.0943	-0.61760 0.0764	-0.62308 0.0730	-0.62802 0.0701	-0.61563 0.0776
TMPAVG	0.68161 0.0432	0.69308 0.0385	0.69564 0.0374	0.70126 0.0353	0.66209 0.0520	0.47562 0.1957	0.64830 0.0590	0.69102 0.0393	0.70286 0.0347	0.69027 0.0396	0.67937 0.0441	0.67526 0.0459
PRECTOT	-0.57301 0.1068	-0.53596 0.1369	-0.49831 0.1721	-0.44006 0.2359	-0.19221 0.6203	0.14301 0.7136	-0.04216 0.9142	-0.36582 0.3329	-0.49110 0.1794	-0.54465 0.1295	-0.56738 0.1111	-0.57403 0.1060

TABLE 47

Pearson Correlation Coefficients and Probabilities Between Other Climatic Variables and Monthly R3

N = 9

	JANR3	FEBR3	MARR3	APRR3	MAYR3	JUNR3	JULR3	AUGR3	SEPR3	OCTR3	NOVR3	DECR3
V.LAT	-0.99412 0.0001	-0.99523 0.0001	-0.99992 0.0001	-0.99522 0.0001	-0.81330 0.0077	-0.25627 0.5057	-0.60639 0.0834	-0.96956 0.0001	-0.99999 0.0001	-0.99998 0.0001	-0.97886 0.0001	-0.99198 0.0001
V.LONG	-0.06126 0.8756	-0.04009 0.9184	-0.05062 0.8971	-0.01833 0.9627	-0.23966 0.5345	-0.44661 0.2282	0.03950 0.9196	-0.15274 0.6948	-0.04523 0.9080	-0.04588 0.9067	-0.12910 0.7406	-0.01527 0.9689
V.ALT	0.73217 0.0249	0.76614 0.0161	0.77008 0.0152	0.80280 0.0092	0.49255 0.1780	0.38381 0.3078	0.27372 0.4760	0.75963 0.0176	0.77099 0.0150	0.77105 0.0150	0.71122 0.0317	0.76644 0.0160
V.DIST	-0.68048 0.0437	-0.70062 0.0355	-0.69731 0.0368	-0.71144 0.0316	-0.40636 0.2778	0.06583 0.8664	-0.46496 0.2073	-0.61300 0.0792	-0.70186 0.0351	-0.70186 0.0351	-0.62176 0.0738	-0.70594 0.0336
CONRAD	-0.72712 0.0264	-0.73819 0.0231	-0.75157 0.0195	-0.77749 0.0137	-0.55337 0.1222	-0.42399 0.2554	-0.45079 0.2233	-0.79814 0.0099	-0.75564 0.0185	-0.75726 0.0181	-0.73522 0.0240	-0.76739 0.0158
TVAR	-0.81211 0.0078	-0.82435 0.0063	-0.83649 0.0049	-0.85818 0.0031	-0.60707 0.0830	-0.39308 0.2953	-0.48268 0.1882	-0.86214 0.0028	-0.84011 0.0046	-0.84143 0.0045	-0.80902 0.0083	-0.84551 0.0041
TMPAVG	0.19964 0.6066	0.09420 0.8095	0.14727 0.7054	0.12437 0.7499	0.26625 0.4886	-0.51744 0.1537	0.17062 0.6607	0.06734 0.8633	0.15117 0.6978	0.15083 0.6985	0.18356 0.6364	0.19725 0.6110
PRECTOT	-0.12303 0.7525	-0.14248 0.7146	-0.10967 0.7788	-0.09700 0.8039	0.04088 0.9168	0.51358 0.1573	-0.31427 0.4102	0.05406 0.8901	-0.11416 0.7699	-0.11302 0.7722	-0.03296 0.9329	-0.11160 0.7750

TABLE 48

Pearson Correlation Coefficients and Probabilities Between Slope Variables and Monthly Temperature

N = 9

	JANTMP	FEBTMP	MARTMP	APRTMP	MAYTMP	JUNTMP	JULTMP	AUGTMP	SEPTMP	OCTTMP	NOVTMP	DECTMP
V.AZIM	-0.40283 0.2824	-0.24671 0.5222	-0.24735 0.5211	-0.04663 0.9052	0.05239 0.8935	0.07424 0.8495	0.08196 0.8340	-0.05161 0.8951	-0.10401 0.7900	-0.05002 0.8983	-0.09548 0.8070	-0.24166 0.5310
V.SA	-0.41275 0.2696	-0.27507 0.4738	-0.18682 0.6303	0.17875 0.6454	0.21374 0.5808	0.27746 0.4698	0.26864 0.4846	0.18479 0.6341	0.14645 0.7069	0.14412 0.7114	-0.12194 0.7546	-0.39958 0.2867
V.EQL	-0.82666 0.0060	-0.85162 0.0036	-0.76928 0.0154	-0.55690 0.1193	-0.32009 0.4011	-0.35994 0.3414	-0.47720 0.1940	-0.42252 0.2572	-0.35063 0.3549	-0.43330 0.2440	-0.74175 0.0221	-0.83200 0.0054

TABLE 49

Pearson Correlation Coefficients and Probabilities Between Slope Variables and Monthly Precipitation

N = 9

	JANPREC	FEBPREC	MARPREC	APRPREC	MAYPREC	JUNPREC	JULPREC	AUGPREC	SEPPREC	OCTPREC	NOVPREC	DECPREC
V.AZIM	-0.14286 0.7139	0.14652 0.7068	-0.19773 0.6101	-0.21919 0.5710	-0.62599 0.0713	-0.34323 0.3658	-0.15255 0.6952	0.33284 0.3815	0.23539 0.5421	0.40300 0.2822	-0.01174 0.9761	0.03263 0.9336
V.SA	-0.01633 0.9667	-0.07694 0.8440	-0.19604 0.6132	-0.18739 0.6292	-0.27422 0.4752	-0.47935 0.1917	-0.12543 0.7478	0.62813 0.0701	0.47753 0.1936	0.59231 0.0929	0.05813 0.8819	-0.22073 0.5682
V.EQL	0.52949 0.1426	0.41662 0.2646	0.40304 0.2821	0.10955 0.7791	-0.14047 0.7185	0.16126 0.6785	0.24517 0.5249	0.70423 0.0342	0.68466 0.0419	0.31058 0.4160	0.48335 0.1875	0.28436 0.4583

TABLE 50

Pearson Correlation Coefficients and Probabilities Between Slope Variables and Monthly R4

N = 9

	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
V.AZIM	-0.07172 0.8545	-0.07007 0.8578	-0.06826 0.8615	-0.01516 0.9691	0.06364 0.8708	0.22646 0.5579	0.16653 0.6685	0.03508 0.9286	-0.03303 0.9328	-0.05174 0.8948	-0.06612 0.8658	-0.05834 0.8815
V.SA	-0.40170 0.2839	-0.39416 0.2939	-0.42138 0.2587	-0.41835 0.2625	-0.42815 0.2503	-0.29639 0.4387	-0.33987 0.3709	-0.42564 0.2534	-0.41180 0.2708	-0.39869 0.2878	-0.39353 0.2947	-0.38746 0.3029
V.EQL	-0.99325 0.0001	-0.99559 0.0001	-0.99782 0.0001	-0.99311 0.0001	-0.89901 0.0010	-0.61846 0.0758	-0.78622 0.0120	-0.97174 0.0001	-0.99879 0.0001	-0.99752 0.0001	-0.99441 0.0001	-0.99246 0.0001

TABLE 51

Pearson Correlation Coefficients and Probabilities Between Slope Variables and Monthly R3

N = 9

	JANR3	FEBR3	MARR3	APRR3	MAYR3	JUNR3	JULR3	AUGR3	SEPR3	OCTR3	NOVR3	DECR3
V.AZIM	-0.24190 0.5306	-0.21619 0.5764	-0.24732 0.5211	-0.25009 0.5163	-0.32829 0.3884	-0.56694 0.1114	-0.03434 0.9301	-0.34364 0.3652	-0.24833 0.5194	-0.24991 0.5166	-0.29983 0.4331	-0.25008 0.5164
V.SA	-0.23954 0.5348	-0.27056 0.4813	-0.26546 0.4900	-0.33089 0.3844	-0.27240 0.4782	-0.46382 0.2085	-0.31143 0.4146	-0.41131 0.2714	-0.26717 0.4871	-0.26876 0.4844	-0.31655 0.4066	-0.33265 0.3818
V.EQL	-0.56700 0.1114	-0.52661 0.1452	-0.52269 0.1488	-0.50809 0.1625	-0.55815 0.1183	0.34963 0.3564	-0.72424 0.0273	-0.44363 0.2317	-0.52617 0.1456	-0.52578 0.1460	-0.54851 0.1262	-0.57190 0.1076

TABLE 52

Pearson Correlation Coefficients and Probabilities Between Slope Variables and Other Climatic Variables

N = 9

	V.LAT	V.LONG	V.ALT	V.DIST	CONRAD	TVAR	TMPAVG	PRECTOT
V.AZIM	0.24500	0.11971	-0.44869	0.16241	0.57070	0.50586	-0.15310	-0.14873
	0.5252	0.7590	0.2257	0.6763	0.1085	0.1647	0.6941	0.7025
V.SA	0.26601	-0.29165	-0.43866	0.40089	0.72095	0.64163	-0.05522	0.01863
	0.4890	0.4464	0.2376	0.2849	0.0284	0.0625	0.8878	0.9621
V.EQL	0.52702	-0.42412	-0.22558	0.67655	0.60442	0.60713	-0.70088	0.51555
	0.1449	0.2552	0.5595	0.0454	0.0847	0.0829	0.0354	0.1554

TABLE 53

Pearson Correlation Coefficients and Probabilities for Slope Variables

N = 9

	V.AZIM	V.SA	V.EQL
V.AZIM	1.00000	0.43417	0.01643
	0.0000	0.2429	0.9665
V.SA	.	1.00000	0.37381
	.	0.0000	0.3217
V.EQL	.	.	1.00000
	.	.	0.0000

TABLE 54

Pearson Correlation Coefficients and Probabilities Between Monthly R3 and Monthly R4

N = 9

	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
JANR3	0.55126 0.1239	0.54304 0.1308	0.58258 0.0997	0.57660 0.1041	0.55469 0.1211	0.45331 0.2204	0.47906 0.1920	0.57277 0.1070	0.56150 0.1157	0.55815 0.1183	0.56449 0.1133	0.54887 0.1259
FEBR3	0.51393 0.1570	0.50500 0.1655	0.54203 0.1317	0.53601 0.1369	0.51492 0.1560	0.42280 0.2569	0.43030 0.2476	0.53245 0.1400	0.52129 0.1501	0.51945 0.1518	0.52644 0.1454	0.51118 0.1596
MARR3	0.50826 0.1624	0.49947 0.1710	0.53950 0.1338	0.53435 0.1383	0.51966 0.1516	0.43229 0.2452	0.44306 0.2323	0.53256 0.1399	0.51852 0.1527	0.51475 0.1562	0.52055 0.1508	0.50427 0.1663
APRR3	0.49550 0.1750	0.48362 0.1872	0.52836 0.1437	0.52410 0.1475	0.51622 0.1548	0.43420 0.2429	0.44297 0.2324	0.52610 0.1457	0.50725 0.1634	0.50203 0.1685	0.50703 0.1636	0.49028 0.1803
MAYR3	0.53499 0.1378	0.53393 0.1387	0.58021 0.1014	0.58529 0.0978	0.59720 0.0895	0.51690 0.1542	0.55912 0.1176	0.59257 0.0927	0.56060 0.1164	0.54590 0.1284	0.55111 0.1241	0.53574 0.1371
JUNR3	-0.33624 0.3763	-0.31773 0.4047	-0.30902 0.4184	-0.30966 0.4174	-0.22238 0.5652	-0.11419 0.7699	-0.26988 0.4825	-0.29956 0.4336	-0.32630 0.3915	-0.33766 0.3742	-0.33899 0.3722	-0.34636 0.3612
JULR3	0.71078 0.0318	0.71744 0.0296	0.72615 0.0267	0.73114 0.0252	0.68760 0.0407	0.52716 0.1447	0.58760 0.0961	0.72303 0.0277	0.72035 0.0286	0.71597 0.0301	0.72142 0.0282	0.71640 0.0299
AUGR3	0.42572 0.2533	0.42441 0.2549	0.46947 0.2023	0.47484 0.1965	0.50658 0.1640	0.46539 0.2068	0.43886 0.2373	0.48617 0.1845	0.44968 0.2246	0.43527 0.2416	0.43656 0.2401	0.41852 0.2622
SEPR3	0.51207 0.1587	0.50336 0.1672	0.54290 0.1309	0.53743 0.1356	0.52151 0.1499	0.43195 0.2456	0.44361 0.2317	0.53515 0.1376	0.52196 0.1495	0.51842 0.1528	0.52418 0.1474	0.50797 0.1627
OCTR3	0.51169 0.1591	0.50315 0.1674	0.54257 0.1312	0.53717 0.1359	0.52154 0.1499	0.43216 0.2454	0.44336 0.2320	0.53490 0.1378	0.52166 0.1497	0.51804 0.1531	0.52374 0.1478	0.50753 0.1631
NOVR3	0.52911 0.1430	0.52416 0.1475	0.56952 0.1094	0.57068 0.1086	0.57566 0.1048	0.49685 0.1736	0.51074 0.1600	0.57548 0.1049	0.54880 0.1260	0.53834 0.1349	0.54278 0.1310	0.52557 0.1462
DECR3	0.55681 0.1194	0.54543 0.1288	0.59175 0.0932	0.58903 0.0951	0.57906 0.1023	0.48271 0.1881	0.50892 0.1618	0.59144 0.0935	0.57125 0.1081	0.56441 0.1134	0.56919 0.1097	0.55237 0.1230

TABLE 55

Pearson Correlation Coefficients and Probabilities for Monthly R3

N = 9

	JANR3	FEBR3	MARR3	APRR3	MAYR3	JUNR3	JULR3	AUGR3	SEPR3	OCTR3	NOVR3	DECR3
JANR3	1.00000 0.0000	0.99116 0.0001	0.99468 0.0001	0.98386 0.0001	0.86241 0.0028	0.19783 0.6099	0.65890 0.0536	0.95474 0.0001	0.99426 0.0001	0.99398 0.0001	0.98853 0.0001	0.99233 0.0001
FEBR3	. .	1.00000 0.0000	0.99561 0.0001	0.98928 0.0001	0.82124 0.0066	0.26363 0.4931	0.65851 0.0538	0.96538 0.0001	0.99535 0.0001	0.99527 0.0001	0.97775 0.0001	0.98650 0.0001
MARR3	. .	. .	1.00000 0.0000	0.99517 0.0001	0.81846 0.0070	0.25913 0.5008	0.60931 0.0815	0.97042 0.0001	0.99995 0.0001	0.99992 0.0001	0.98062 0.0001	0.99239 0.0001
APRR3	. .	. .	. .	1.00000 0.0000	0.79711 0.0101	0.28829 0.4519	0.57860 0.1026	0.97704 0.0001	0.99519 0.0001	0.99523 0.0001	0.97337 0.0001	0.99313 0.0001
MAYR3	. .	. .	. .	. .	1.00000 0.0000	0.13194 0.7351	0.79406 0.0106	0.81082 0.0080	0.81476 0.0075	0.81377 0.0076	0.91071 0.0006	0.85237 0.0035
JUNR3	. .	. .	. .	. .	. .	1.00000 0.0000	-0.03384 0.9311	0.45184 0.2221	0.25856 0.5017	0.26137 0.4969	0.26603 0.4890	0.22171 0.5664
JULR3	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.57994 0.1016	0.60736 0.0828	0.60655 0.0833	0.68992 0.0397	0.63890 0.0640
AUGR3	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.97001 0.0001	0.97062 0.0001	0.96959 0.0001	0.96718 0.0001
SEPR3	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.99999 0.0001	0.97939 0.0001	0.99204 0.0001
OCTR3	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.97919 0.0001	0.99182 0.0001
NOVR3	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.98791 0.0001
DECR3	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000

TABLE 56

Pearson Correlation Coefficients and Probabilities for Monthly R4

N = 9

	JANR4	FEBR4	MARR4	APRR4	MAYR4	JUNR4	JULR4	AUGR4	SEPR4	OCTR4	NOVR4	DECR4
JANR4	1.00000 0.0000	0.99715 0.0001	0.99466 0.0001	0.97670 0.0001	0.84927 0.0038	0.52994 0.1422	0.71640 0.0299	0.94278 0.0001	0.99116 0.0001	0.99884 0.0001	0.99971 0.0001	0.99950 0.0001
FEBR4	. .	1.00000 0.0000	0.99547 0.0001	0.98273 0.0001	0.86881 0.0024	0.56272 0.1147	0.73866 0.0230	0.95217 0.0001	0.99419 0.0001	0.99808 0.0001	0.99675 0.0001	0.99650 0.0001
MARR4	. .	. .	1.00000 0.0000	0.99231 0.0001	0.89576 0.0011	0.60792 0.0824	0.77882 0.0134	0.96957 0.0001	0.99860 0.0001	0.99798 0.0001	0.99558 0.0001	0.99326 0.0001
APRR4	. .	. .	. .	1.00000 0.0000	0.94258 0.0001	0.69902 0.0361	0.84741 0.0039	0.99203 0.0001	0.99633 0.0001	0.98542 0.0001	0.97852 0.0001	0.97404 0.0001
MAYR4	. .	. .	. .	. .	1.00000 0.0000	0.89538 0.0011	0.96976 0.0001	0.97570 0.0001	0.91123 0.0006	0.87224 0.0022	0.85359 0.0034	0.84290 0.0043
JUNR4	. .	. .	. .	. .	. .	1.00000 0.0000	0.96021 0.0001	0.78102 0.0130	0.63649 0.0653	0.56847 0.1102	0.53830 0.1349	0.52158 0.1498
JULR4	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.90580 0.0008	0.80129 0.0094	0.74760 0.0206	0.72313 0.0277	0.70950 0.0323
AUGR4	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.97813 0.0001	0.95690 0.0001	0.94572 0.0001	0.93893 0.0002
SEPR4	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.99621 0.0001	0.99198 0.0001	0.98949 0.0001
OCTR4	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.99908 0.0001	0.99822 0.0001
NOVR4	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000	0.99946 0.0001
DECR4	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1.00000 0.0000

APPENDIX D

RAW DATA FOR NORTH KILLDEER MOUNTAIN QUADRANGLE SLOPES

TABLE 57

Azimuth and Slope Angle (Degrees) for 420 Pairs of Slopes Along Drainageways of North Killdeer Mountain Quadrangle

	SIDE A		SIDE B	
MEAS. #	AZIM	SA	AZIM	SA
1	NE	12.2	NW	14.6
2	E	17.6	W	13.4
3	NE	15.5	SW	12.3
4	NE	12.5	SW	11.2
5	NE	15.1	W	11.4
6	NE	18.1	SW	7.2
7	E	16.9	W	9.6
8	E	14.2	W	13.1
9	E	9.1	NE	11.0
10	SW	9.4	NE	13.5
11	SE	11.5	W	15.9
12	SE	10.8	W	12.9
13	SE	8.5	W	13.0
14	SE	12.0	W	8.5
15	NE	9.1	W	16.8
16	E	11.9	W	9.0
17	E	13.0	W	10.3
18	E	5.6	NW	10.3
19	NE	15.7	W	5.1
20	E	12.9	W	8.1
21	NE	8.1	SW	5.4
22	N	10.8	S	8.4
23	N	16.2	S	12.7
24	NE	17.2	S	14.2
25	E	16.5	SW	10.1
26	NE	12.1	S	17.2
27	NE	14.2	SW	10.8
28	NE	11.1	S	13.8
29	E	12.9	W	10.8
30	NE	20.4	SW	14.6
31	E	18.1	S	14.2
32	NE	8.0	SW	15.8
33	E	14.2	SW	9.6
34	NE	15.2	SW	6.8
35	N	19.8	SE	10.2
36	N	18.7	SW	7.7
37	NE	11.9	SW	17.6
38	NE	9.7	SE	10.8
39	N	16.6	S	16.6
40	NE	17.6	SW	19.9
41	NE	23.2	S	13.7
42	E	20.9	W	15.9
43	NE	22.7	SW	13.1
44	NE	9.2	S	16.5
45	N	13.7	SW	11.8
46	NE	15.6	W	15.6
47	E	25.0	W	19.2
48	E	9.6	W	9.6
49	NE	16.8	S	11.4
50	NE	13.1	W	25.0
51	NE	18.4	NW	18.4
52	NE	23.0	SW	17.6
53	E	9.2	NW	16.3
54	N	7.6	SW	24.0

TABLE 57--continued

MEAS. #	SIDE A AZIM	SIDE A SA	SIDE B AZIM	SIDE B SA
55	NE	26.9	SW	18.7
56	NE	15.6	SW	13.1
57	N	14.2	S	14.2
58	NE	14.3	SW	14.3
59	NE	18.3	SW	16.6
60	NE	7.2	SW	15.9
61	E	19.2	NE	13.1
62	E	12.3	NW	20.9
63	E	19.8	W	12.2
64	N	20.8	SW	15.9
65	E	22.1	NW	9.6
66	NE	17.6	W	20.8
67	SE	12.5	NW	10.1
68	E	14.2	W	17.6
69	NE	15.2	W	17.6
70	E	10.8	SW	13.7
71	SE	16.9	NW	12.3
72	NE	15.5	W	13.9
73	NE	19.8	N	19.8
74	E	20.4	W	20.4
75	NE	19.9	W	19.9
76	NE	23.3	W	19.8
77	E	26.2	NW	21.5
78	E	17.2	SW	26.3
79	E	19.2	W	25.0
80	NE	17.0	NW	14.7
81	NE	20.2	W	11.6
82	NE	14.2	W	14.2
83	N	13.4	S	20.8
84	N	17.0	S	22.8
85	N	14.2	S	14.2
86	N	12.5	SW	10.8
87	NW	9.4	S	13.3
88	N	15.1	SW	15.1
89	N	19.8	S	13.5
90	N	10.4	S	11.7
91	N	17.6	S	17.6
92	NE	12.7	SW	14.3
93	NW	13.0	S	14.7
94	N	14.0	S	20.5
95	NE	15.1	SW	15.1
96	NW	17.6	SW	15.0
97	N	19.2	SW	16.6
98	E	17.6	W	15.2
99	NE	23.5	SW	11.5
100	N	13.3	S	15.4
101	N	15.4	S	9.4
102	NE	15.6	W	15.6
103	N	21.9	S	13.6
104	N	17.6	SW	20.3
105	N	20.8	SW	20.8
106	NW	14.2	S	14.2
107	NW	13.6	SW	19.0
108	NE	13.0	SW	13.0
109	N	10.1	SW	10.1
110	NE	12.9	SW	9.3

TABLE 57--continued

MEAS. #	SIDE A AZIM	SA	SIDE B AZIM	SA
111	NE	14.2	W	14.2
112	NE	26.0	W	20.1
113	NE	18.4	W	14.9
114	E	26.9	W	22.1
115	E	21.6	SW	12.8
116	NE	22.1	NW	14.3
117	N	19.2	SW	15.6
118	N	9.6	SW	11.5
119	N	17.6	SW	11.2
120	N	16.5	S	10.1
121	NE	15.9	SW	5.4
122	N	26.9	S	13.0
123	N	20.8	S	20.8
124	N	15.9	S	20.9
125	W	15.6	SE	19.2
126	W	18.2	S	13.3
127	SW	11.5	E	18.7
128	NE	16.9	W	20.9
129	NW	19.2	S	15.6
130	N	19.8	SW	12.2
131	NE	19.6	SW	16.5
132	N	9.0	W	13.4
133	S	14.3	N	18.7
134	SE	13.6	N	8.6
135	SE	15.9	NW	9.3
136	NE	16.5	W	16.5
137	E	9.6	N	20.9
138	E	26.9	N	18.7
139	NE	21.5	SW	18.1
140	E	21.6	NW	14.8
141	N	19.2	S	25.0
142	NE	26.9	SW	22.1
143	N	20.8	W	20.8
144	SW	29.1	NE	15.5
145	S	37.2	NE	20.9
146	SE	14.7	NW	13.1
147	NE	13.3	SW	18.3
148	E	16.6	W	16.6
149	E	18.5	W	18.5
150	E	22.7	NW	13.1
151	E	18.2	NW	16.1
152	NE	16.2	W	18.7
153	NE	19.2	S	13.1
154	S	11.2	N	8.2
155	SE	11.7	NW	13.3
156	S	14.8	N	12.8
157	E	20.1	N	10.3
158	E	14.7	W	20.2
159	SE	15.7	NW	18.1
160	S	26.9	N	26.9
161	S	28.4	NE	15.1
162	S	27.9	NE	12.8
163	N	17.6	SW	20.8
164	NE	18.7	SW	22.1

TABLE 57--continued

MEAS. #	SIDE AZIM	A SA	SIDE AZIM	B SA
165	NE	14.2	SW	23.0
166	NE	17.1	NW	23.3
167	E	24.0	NW	19.6
168	NE	22.4	SW	18.3
169	SE	20.8	N	23.9
170	E	21.4	W	25.2
171	E	20.8	W	16.5
172	NE	20.8	W	18.1
173	NE	21.6	W	21.6
174	NE	32.4	NW	19.9
175	S	29.7	NW	24.6
176	E	18.7	W	18.7
177	SE	13.6	W	18.4
178	SE	16.8	NW	19.0
179	E	19.2	NW	21.7
180	SE	20.8	N	24.6
181	E	16.8	W	21.9
182	NE	19.8	W	19.8
183	S	20.2	N	17.0
184	S	17.1	N	19.8
185	N	19.9	S	19.9
186	N	15.5	SW	13.9
187	W	12.1	SE	23.2
188	NE	25.5	SW	15.2
189	N	14.2	W	14.2
190	N	22.9	W	22.9
191	N	20.9	SW	15.9
192	NE	20.8	W	18.1
193	NE	26.2	SW	21.5
194	NE	20.9	SW	16.9
195	NE	17.6	S	17.6
196	N	13.1	SW	6.6
197	E	16.9	NW	12.3
198	E	16.8	NW	16.8
199	NE	18.8	SW	11.9
200	E	18.4	W	10.8
201	NE	13.4	SW	14.5
202	NE	14.2	SW	10.8
203	NE	13.5	W	8.8
204	NE	13.9	SW	9.7
205	N	8.5	SW	10.4
206	NE	11.5	SW	5.8
207	NE	12.5	S	8.4
208	N	13.6	S	10.1
209	N	10.5	S	14.3
210	N	13.6	SE	8.6
211	NE	11.9	S	11.9
212	N	9.8	SW	10.5
213	E	8.4	W	9.5
214	E	9.7	SW	11.4
215	NE	7.9	NW	14.7
216	E	16.5	SW	9.5
217	NE	9.3	SW	10.8
218	N	8.9	SW	9.7
219	NE	13.5	W	23.3

TABLE 57--continued

MEAS. #	SIDE A AZIM	SIDE A SA	SIDE B AZIM	SIDE B SA
220	E	11.7	SW	14.2
221	NE	15.5	W	17.6
222	NE	18.0	SW	11.8
223	N	14.7	SW	10.8
224	NE	22.1	NW	9.6
225	NE	11.3	SW	15.6
226	N	16.9	SW	20.9
227	NE	25.7	W	21.9
228	E	26.2	NW	21.5
229	NE	34.1	W	16.2
230	N	17.1	W	15.1
231	NE	11.2	SW	24.0
232	E	11.3	W	13.1
233	E	6.7	W	13.9
234	SE	11.2	SW	7.8
235	SE	11.2	NW	14.2
236	NE	17.6	W	23.0
237	NE	12.5	SW	16.5
238	NE	14.2	SW	9.0
239	NE	6.2	W	12.3
240	NE	13.3	W	13.3
241	SE	10.8	NW	18.9
242	SE	7.8	NW	12.3
243	SE	16.3	N	6.9
244	E	15.9	W	15.9
245	E	11.9	W	14.2
246	NE	10.8	SW	12.9
247	NE	7.2	NW	14.2
248	NE	11.5	W	11.5
249	E	15.2	W	16.6
250	E	12.9	W	12.9
251	NE	7.2	W	18.3
252	E	9.4	NW	15.4
253	NE	26.9	NW	17.6
254	E	24.6	W	20.8
255	SE	19.2	N	15.6
256	SE	18.7	W	14.3
257	E	9.0	W	7.2
258	E	13.3	N	13.3
259	E	20.9	NW	20.9
260	SE	16.9	N	20.9
261	SE	20.9	W	12.9
262	SE	14.2	NW	14.2
263	N	16.5	W	7.2
264	E	18.1	NW	18.1
265	E	10.4	NW	10.4
266	E	15.0	NW	19.0
267	NE	18.3	W	15.4
268	SE	21.9	NW	13.6
269	S	13.1	NW	13.1
270	NW	15.9	SE	23.2
271	NW	19.2	S	19.2
272	N	21.4	W	12.0
273	NE	24.0	SW	19.6
274	N	15.6	S	15.6

TABLE 57--continued

MEAS. #	SIDE A		SIDE B	
	AZIM	SA	AZIM	SA
275	N	10.8	S	10.8
276	N	19.8	SW	15.1
277	NE	20.8	W	17.6
278	NW	14.2	S	25.2
279	N	15.1	S	28.4
280	N	22.4	S	22.4
281	W	23.0	S	23.0
282	N	14.9	S	10.8
283	NE	14.2	SW	11.2
284	N	18.3	SW	9.4
285	NE	15.5	SW	13.9
286	N	17.0	SW	17.0
287	NW	10.8	S	16.9
288	NW	16.2	SW	14.3
289	N	18.3	SW	13.3
290	N	14.2	SW	10.8
291	NW	10.8	SE	7.2
292	NW	8.8	SE	12.2
293	NW	15.1	S	11.1
294	N	17.0	SE	20.2
295	N	15.8	SE	32.4
296	N	16.5	S	19.6
297	N	19.6	S	19.6
298	NW	16.4	S	21.4
299	N	15.0	SE	19.0
300	N	12.5	W	16.5
301	E	14.3	NW	11.5
302	NE	10.8	NW	17.6
303	NE	17.6	W	17.6
304	SE	16.5	NW	16.5
305	SE	15.9	N	15.9
306	E	20.9	W	15.9
307	SE	24.0	N	24.0
308	SE	32.3	NW	23.0
309	SE	33.6	W	18.4
310	E	10.8	NW	7.2
311	S	20.9	N	20.9
312	SE	7.2	N	14.3
313	N	25.5	S	20.8
314	N	7.2	SW	7.2
315	NW	3.6	SW	2.1
316	N	14.2	S	9.6
317	NW	10.3	SW	14.2
318	W	11.4	S	21.9
319	SE	18.7	N	14.3
320	E	25.2	N	21.4
321	SE	28.4	NW	15.1
322	E	19.8	W	15.1
323	E	25.4	W	17.6
324	N	26.9	S	17.6
325	NE	15.4	SW	18.3
326	NE	14.7	SW	8.7
327	NE	12.3	SW	16.9
328	NW	12.9	S	9.3
329	NW	10.8	SW	16.9

TABLE 57--continued

	SIDE A		SIDE B	
MEAS. #	AZIM	SA	AZIM	SA
330	NE	17.6	S	10.3
331	E	19.2	SW	9.9
332	E	9.4	SW	9.4
333	N	16.2	S	14.3
334	N	14.2	S	12.5
335	NE	13.4	SW	7.7
336	N	14.3	S	10.8
337	NW	11.4	S	8.6
338	N	10.8	SW	12.3
339	N	14.3	SW	14.3
340	NW	8.6	S	13.6
341	NW	11.2	S	14.8
342	N	16.5	SW	14.2
343	NE	16.5	SW	16.5
344	NE	12.2	S	12.2
345	NE	16.3	SW	13.7
346	NW	6.7	S	13.3
347	NW	8.0	SE	14.2
348	N	10.2	SW	12.2
349	NW	10.4	SW	11.7
350	N	16.9	S	12.3
351	NW	17.0	SE	14.7
352	N	15.1	S	15.1
353	NE	10.8	SW	12.9
354	N	14.3	SW	14.3
355	NE	10.8	W	15.9
356	N	18.7	S	14.3
357	N	20.8	SW	14.3
358	NW	10.8	E	13.4
359	NW	17.6	S	13.4
360	NW	14.8	SW	12.8
361	N	17.6	SW	15.2
362	N	13.4	SW	9.8
363	E	14.8	SW	17.6
364	N	11.7	SE	22.4
365	W	11.8	E	20.1
366	W	7.2	S	10.8
367	NW	16.3	SE	13.7
368	NW	14.2	S	19.6
369	W	7.9	E	10.8
370	N	8.0	S	4.8
371	NW	17.0	S	14.7
372	NW	14.2	SE	16.9
373	W	19.8	SE	12.2
374	W	5.0	S	5.9
375	NW	6.0	S	7.2
376	N	17.0	S	14.7
377	W	12.5	SE	10.1
378	N	20.9	SW	12.9
379	N	11.8	S	16.3
380	NE	14.3	SW	10.5
381	N	12.7	S	10.5
382	NE	14.2	SW	7.6
383	NE	10.4	SW	8.5
384	NW	10.4	SW	11.7

TABLE 57--continued

	SIDE A		SIDE B	
MEAS. #	AZIM	SA	AZIM	SA
385	NW	14.2	SE	14.2
386	NW	9.6	SE	9.6
387	NE	13.8	SW	18.1
388	N	14.2	S	15.8
389	N	18.7	S	11.4
390	SW	12.7	SE	18.7
391	NW	14.2	E	17.6
392	N	15.9	S	12.9
393	N	10.8	S	14.3
394	NE	15.4	S	9.4
395	NW	13.4	SE	9.0
396	N	9.4	SE	11.7
397	N	9.0	S	12.0
398	W	6.0	E	12.0
399	N	14.3	S	20.8
400	N	12.5	SW	14.9
401	NE	11.3	W	13.1
402	N	8.2	W	10.0
403	N	7.2	SW	8.2
404	N	20.8	SW	8.7
405	N	15.9	SW	4.4
406	NE	10.8	W	10.8
407	W	5.4	SE	5.4
408	W	8.2	SE	14.3
409	W	6.0	S	10.8
410	NW	18.3	SE	18.3
411	NW	16.5	S	16.5
412	W	11.3	SE	15.6
413	NE	7.2	SE	10.8
414	N	18.1	SW	6.0
415	N	12.3	S	9.6
416	NE	10.4	W	13.3
417	E	16.3	W	11.8
418	NE	17.6	SW	17.6
419	N	16.9	SW	20.9
420	NE	16.2	SW	16.2

APPENDIX E

CHI-SQUARE ANALYSIS

TABLE 58

Chi-Square Analysis of Azimuth and Vegetation Data

1) E/W AZIMUTH AND THREE VEGETATION CATEGORIES

		E	W	Total
Woodland:	O	31	24	55
	E	27.5	27.5	
Shrubland:	O	20	23	43
	E	21.5	21.5	
Prairie:	O	30	34	64
	E	32.0	32.0	
Total:	O	81	81	162

$\chi^2 = 1.35$

Prob: $.75 > p > .50$

2) SE/NW AZIMUTH AND THREE VEGETATION CATEGORIES

		SE	NW	Total
Woodland:	O	21	27	48
	E	24.2	23.8	
Shrubland:	O	10	7	17
	E	8.6	8.4	
Prairie:	O	26	22	48
	E	24.2	23.8	
Total:	O	57	56	113

$\chi^2 = 1.60$

Prob: $.50 > p > .25$

TABLE 58--continued

3) N/S AZIMUTH AND THREE VEGETATION CATEGORIES

		N	S	Total
Woodland:	O	58	23	81
	E	40.3	40.7	
Shrubland:	O	28	33	61
	E	30.4	30.6	
Prairie:	O	20	51	71
	E	35.3	35.7	
Total:	O	106	107	213

$\chi^2 = 29.06$

Prob: $p < .005$

4) NE/SW AZIMUTH AND THREE VEGETATION CATEGORIES

		NE	SW	Total
Woodland:	O	62	39	101
	E	48.6	52.4	
Shrubland:	O	11	27	38
	E	18.3	19.7	
Prairie:	O	44	60	104
	E	50.1	53.9	
Total:	O	117	126	243

$\chi^2 = 14.13$

Prob: $p < .005$

TABLE 58--continued

5) NE/W AZIMUTH AND THREE VEGETATION CATEGORIES

		NE	W	Total
Woodland:	O	44	29	73
	E	36.0	37.0	
Shrubland:	O	6	12	18
	E	8.9	9.1	
Prairie:	O	26	37	63
	E	31.1	31.9	
Total:	O	76	78	154

$\chi^2 = 6.97$
Prob: $.05 > p > .025$

6) N/SW AZIMUTH AND THREE VEGETATION CATEGORIES

		N	SW	Total
Woodland:	O	45	20	65
	E	32.3	32.7	
Shrubland:	O	12	20	32
	E	15.9	16.1	
Prairie:	O	22	40	62
	E	30.8	31.2	
Total:	O	79	80	159

$\chi^2 = 16.80$
Prob: $p < .005$

TABLE 58--continued

7) NW/S AZIMUTH AND THREE VEGETATION CATEGORIES

		NW	S	Total
Woodland:	O	25	10	35
	E	18.3	16.7	
Shrubland:	O	11	13	24
	E	12.5	11.5	
Prairie:	O	11	20	31
	E	16.2	14.8	
Total:	O	47	43	90

$\chi^2 = 9.04$

Prob: $.025 > p > .01$

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